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18TH & 19TH December 2018
Colombo | Sri Lanka

Symposium Proceedings

NATIONAL BUILDING RESEARCH ORGANISATION
MINISTRY OF IRRIGATION AND WATER RESOURCES & DISASTER MANAGEMENT
INNOVATION FOR BUILD BACK BETTER

PROCEEDINGS OF 9TH ANNUAL NBRO SYMPOSIUM
INNAVATION FOR BUILD BACK BETTER

18TH & 19TH DECEMBER 2018
COLOMBO, SRI LANKA

Organized by
NATIONAL BUILDING RESEARCH ORGANISATION
MINISTRY OF IRRIGATION AND WATER RESOURCES & DISASTER MANAGEMENT
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“Innovation for Build Back Better”, NBRO, 2018, Colombo, Sri Lanka
FOREWORD

The 9th Annual NBRO Symposium on the theme “Innovation for Build Back Better”, is organized by the National Building Research Organisation (NBRO) as a tradition to disseminate the outcome of NBRO’s Research and Development (R&D) and other related studies, with a special focus to provide competitive advantage and innovation to Disaster Risk Reduction activities in Sri Lanka. NBRO’s R&D activities always seek knowledge to develop, design and enhance its products, services, technologies or processes.

The “Build Back Better” approach first gained global attention during the reconstruction of Banda Aceh, Indonesia following the 2004 Great Earthquake off the coast of Sumatra and the subsequent tsunami in the Indian Ocean. The Global Platform on Disaster Risk Reduction and the World Reconstruction Conference 1 and 2 have consolidated the experiences and given a high profile to the concept of build back better. The Sendai Framework for Disaster Risk Reduction 2015 – 2030 was adopted at the Third United Nations World Conference on Disaster Risk Reduction which notes that the recovery, rehabilitation and reconstruction phase is a critical opportunity for “Build Back Better”. As a country committed to adhere with Sendai Framework, Sri Lanka needs to adopt Building Back Better principles during its post disaster recovery process.

This publication seeks to provide pathways to incorporate disaster resilience into post-disaster recovery, rehabilitation and reconstruction process. Hence, this symposium proceedings consist research papers on following themes;

1. Emerging Technologies for Safer Built Environment
2. Preparedness for Effective Response
3. Innovations for Sustainable Building Materials
4. Engineering Approaches for Resilience
5. Environmental Adaptation for Sustainable Development
6. Recovery, Rehabilitation & Reconstruction

All the published papers were reviewed by panel of external reviewers having expertise in relevant subject areas. We believe this publication will inspire both international and local stakeholders to paint their visions to create a safer built environment.

I also express my heartfelt gratitude to United Nations Development Programme (UNDP), Norwegian Geotechnical Institute (NGI), and Asian Disaster Preparedness Center (ADPC) who have played active roles to make this symposium a success. Further, all the authors and members of the review panel should be congratulated for their contribution. I am also thankful to the members of the Symposium Organizing Committee and others who extended their support for staging this symposium.

Eng. (Dr.) Asiri Karunawardena
Director General
National Building Research Organisation
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**ENVIRONMENTAL ADAPTATION FOR SUSTAINABLE COMMUNITY**

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The need to protect people and property with a changing pattern of landslide hazard and risk caused by climate change and changes in demography, and the reality for societies in Europe to live with the risk associated with natural hazards, were the motives for the project SafeLand: “Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies.” SafeLand was a large, integrating research project under the European Commission’s 7th Framework Programme (FP7). The project started on 1 May 2009 and ended on 30 April 2012. It involved 27 partners from 12 European countries, and had international collaborators and advisers from China, India, USA, Japan and Hong Kong. SafeLand also involved 25 End-Users from 11 countries. SafeLand was coordinated by the International Centre for Geohazards (ICG) at the Norwegian Geotechnical Institute (NGI) in Norway. Further information on the SafeLand project can be found at www.safeland.no. This paper provides a brief overview of the research done in SafeLand, the key results and lessons learned, the vision for improved landslide risk management in the future.

Keywords: Landslide; risk management; global change; stakeholder involvement

1. Introduction

Climate change and the increase in population, infrastructure and valuable assets in areas susceptible to landslide activity are changing the landslide risk characteristic in many parts of the world. The dynamic risk pattern, the need to protect people and property, the reality for societies in Europe to live with the risk associated with landslides, and the need to manage this risk were the motives for the project SafeLand.

SafeLand – “Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies” was a large, integrating research project under the European Commission’s 7th Framework Programme (FP7). Further information on the SafeLand project can be found at its web site www.safeland.no.

2. Policy Context of SafeLand Project

The SafeLand project responds to a number of international policies. For Europe in particular, SafeLand supports the EU Thematic Strategy for Soil Protection (Commission of the European Communities, 2006a) and the associated Proposal for a...
Dr Farrokh Nadim is Technical Director at NGI, former Director of the Centre of Excellence, the International Centre for Geohazards (ICG), and adjunct professor at both the Norwegian University of Science and Technology (NTNU) and University of Oslo (UiO). Dr Nadim received his BSc in Structural Engineering from Sharif University of Technology in Iran, and his MSc and ScD in Civil Engineering from MIT, before joining the Norwegian Geotechnical Institute in 1982. His major fields of work are related to risk and reliability analysis, geohazards (landslides, earthquakes and tsunamis), geotechnical earthquake engineering, and offshore foundation engineering. He is the author or co-author of over 250 scientific publications, and a former Chair of Technical Committee 304 of ISSMGE: “Engineering practice of risk assessment and management”. He is the past president in Norwegian Society for Earthquake Engineering, a member of ISO Panel 5 for Development of Seismic Design Guidelines for Offshore Structures and ISO TC98 for Seismic Actions on Geotechnical Works, and one of the Lead Authors of IPCC’s Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX).

Dr Nadim has been work package leader and/or coordinator in a number of EU projects related to natural hazards in the 6th and 7th Framework Programmes (FP6 and FP7) as well as H2020. He was the scientific coordinator for the FP7 Project Safe Land "Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies". Dr Nadim was/is a Managing Editor of Georisk (2007-2013), and Editorial Board Member of Landslides (2004 – present) and Bulletin of Earthquake Engineering (2004 – 2010). He has delivered over ten keynote lectures and numerous invited lectures in international conferences covering a wide range of Atopics.
Project SafeLand: Living with Landslide Risk in Europe
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Abstract
The need to protect people and property with a changing pattern of landslide hazard and risk caused by climate change and changes in demography, and the reality for societies in Europe to live with the risk associated with natural hazards, were the motives for the project SafeLand: “Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies.” SafeLand was a large, integrating research project under the European Commission’s 7th Framework Programme (FP7). The project started on 1 May 2009 and ended on 30 April 2012. It involved 27 partners from 12 European countries, and had international collaborators and advisers from China, India, USA, Japan and Hong Kong. SafeLand also involved 25 End-Users from 11 countries. SafeLand was coordinated by the International Centre for Geohazards (ICG) at the Norwegian Geotechnical Institute (NGI) in Norway. Further information on the SafeLand project can be found at www.safeland.no. This paper provides a brief overview of the research done in SafeLand, the key results and lessons learned, the vision for improved landslide risk management in the future.

Keywords: Landslide; risk management; global change; stakeholder involvement

1. Introduction
Climate change and the increase in population, infrastructure and valuable assets in areas susceptible to landslide activity are changing the landslide risk characteristic in many parts of the world. The dynamic risk pattern, the need to protect people and property, the reality for societies in Europe to live with the risk associated with landslides, and the need to manage this risk were the motives for the project SafeLand. SafeLand – “Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies” was a large, integrating research project under the European Commission’s 7th Framework Programme (FP7). Further information on the SafeLand project can be found at its web site www.safeland.no.

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Soil Framework Directive (Commission of the European Communities, 2006b). The EU Thematic Strategy considers landslides as one of the main soil threats in Europe, and prompts for identification of areas at risk to landslides in EU Member States using common methodologies, as well as for risk reduction measures. On the other hand, according to the Commission’s Communication entitled “A community approach on the prevention of natural and man-made disasters” (Commission of the European Communities, 2009), a better understanding of disasters such as landslides is prerequisite for developing efficient prevention measures. This requires e.g. inventories of information on disasters and developing of guidelines on hazard and risk mapping. These are important objectives of the SafeLand project. The communication further states that outcomes of the Seventh Framework Programme for Research and Technological Development should be directly implemented in European prevention approaches.

At global level, SafeLand supports the UN International Strategy for Disaster Reduction (UNISDR). UNISDR aims at building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development, with the goal of reducing human, social, economic and environmental losses due to natural hazards and related technological and environmental disasters. These disaster reduction efforts are guided by “The Hyogo Framework for Action (HFA) 2005-2015: Building the resilience of Nations and Communities to Disasters”, to which 168 governments agreed in Hyogo, Kobe, Japan. The plan encourages local authorities to identify landslide risk and vulnerabilities, establish hazard maps and put in place effective monitoring systems. It also recommends implementing protective engineering works, urban planning strategies, environmental management and community preparedness. The landslide hazard and exposure mapping procedures developed in SafeLand have already been applied in UNISDR’s Global assessment reports on disaster risk reduction in 2011 and 2013 to assess the landslide risk in Indonesia and El Salvador, respectively.

Reducing loss of life and property from natural and human-induced disasters including also landslides is also one of the objectives of GEOSS, the Global Earth Observation System of Systems (2005-2015), currently constructed by the Group on Earth Observations (GEO).

The need for risk management strategies is further acknowledged by the Intergovernmental Panel on Climate Change (IPCC) who predicts an increase of the mean temperature as well as a change in rainfall patterns in the future, leading to potential increased instability of slopes especially in mountain and permafrost areas. In many global change scenarios, it is expected that more people will be exposed to landslide hazard. Therefore IPCC recently published a special report on “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation”.

In Europe, there is a general lack of legislative tools to reduce the risk posed by natural hazards, partly because of the risk complexity of the risk governance aspect. A notable exception to this judicial gap is the Floods Directive adopted by the European Commission in 2007. Member states have been asked to do flood risk assessment and develop maps to support flood risk management plans. This only constitutes a first step towards enhanced assessment and mapping methodologies for natural hazard risks, with a second stage planning effort foreseen in 2021.

SafeLand has developed the tools for landslide hazard and risk assessment and mapping at various scales. These tools will be available to end-users and their
consultants when such assessment becomes a requirement through a national law or an EC Directive.

3. Tools and Guidelines for Landslide Risk Management

One of the main aims of the SafeLand project was to produce practical tools and guidelines for stakeholders and end-users of various backgrounds. These products are a mixture of state-of-the-art practices and the results of new and innovative research. Some of the main products of SafeLand relevant for landslide risk stakeholders and end-users are:

Guidelines for landslide susceptibility, hazard and risk assessment and zoning.
Guidelines for use of early warning systems, remote sensing techniques, and monitoring.
Development of a prototype web-based “toolbox” of innovative and technically appropriate prevention and mitigation measures.
Research on stakeholder workshops and participatory processes to involve the population exposed to landslide risk in the decision-making process for choosing the most appropriate risk mitigation measure(s).

3.1. Guidelines for quantitative risk assessment

In Europe, there is a need for developing efficient and reliable tools on which support land use planning decisions, civil protection plans and mitigation measures to manage landslide risk. Either susceptibility maps showing the existing or potential unstable areas or hazard maps that further include the affected areas and the temporal probability of occurrence, or risk maps that additionally incorporate the severity of the consequences may be used to this end. Although the first two map types are the most common so far, latest global tendencies are shifting towards the consideration of credible risk scenarios in which location, nature and evaluation of damages can be fully analysed. Furthermore, zoning schemes tend to use quantified susceptibility, hazard and risk assessments, meaning that qualitative descriptive rankings (i.e. low to high) are replaced by the annual probability (or frequency) of a given event of a given magnitude/intensity and its consequences in numbers (financial, population of the affected exposed elements etc.).

The SafeLand project developed recommendations for landslide susceptibility, hazard and risk assessment and zoning, to be used for the quantitative assessment of the landslide hazard, vulnerability and risk, as well as for the verification and validation of the results (SafeLand Deliverable 2.4: Guidelines for landslide susceptibility, hazard and risk assessment and zoning). The recommended methodologies mainly focus on approaches for the quantitative assessment and zoning of landslide susceptibility, hazard and risk at different scales. Specific methodologies improving previously published guidelines have been developed. They mainly consist in new procedures for calculating quantitative vulnerability, based on fragility curves and for different landslide mechanisms. A selection of the best suited procedures for verification of the models and validation of the results are also presented. The proposed procedures are categorised according to the landslide type and the working scale (site specific, local, regional and national). Particularly important and innovative aspects have been the evaluation of the probability of occurrence of different landslide types with certain characteristics, the specific consideration of the elements at risk
(persons, buildings, infrastructures...) and their spatio-temporal probability in order to be directly incorporated in the quantitative risk assessment (QRA) analysis.

![Maps of Europe's exposed population to landslides](image)

Fig. 1. Estimate of changes in Europe's exposed population to landslides in 21st century.

For demonstration of the given guidelines, examples of the quantitative risk assessment QRA for different types of landslides, at different scales and for various exposed elements (buildings and people) have been included. For every case-study, the risk is expressed using a variety of risk descriptors. Different landslide types such as deep-seated landslides, debris slides, hyper-concentrated flow, and rockfalls are studied at scales varying from site-specific to regional. The innovative aspects which are discussed involve the use of remote sensing data and the incorporation of the vulnerability in quantitative terms. Especially the latter has been rarely considered so far by other methodologies.

Furthermore, the development of toolboxes (set of precompiled computer routines) that can be used by stakeholders, practitioners and other interested parties for the quantitative evaluation of the key components that are involved into the landslide zoning and risk calculation (hazard, vulnerability of the exposed elements...) have been developed. Three toolboxes were prepared based on deterministic or probabilistic approaches for the quantification of the risk parameters. The tools serve for (i) rockfall quantitative vulnerability of buildings (ii) rockfall quantitative risk assessment for protection galleries and (iii) rockfall quantitative risk assessment.

Standards for validation of both hazard and risk assessment models have been proposed for the quantification of the reliability of the assessment (accounting for data vagueness and uncertainties, “limited” knowledge on the physics of the processes and taking into account the issue of the “mapping unit”, independently of the scale), as well
as the quantification of the validity of the assessment (considering validation/evaluation of the maps, robustness and accuracy of the predicting systems and output types).

3.2. Guidelines for use of early warning systems and remote sensing techniques

A people-centred Early Warning System, EWS, comprises five key elements: (1) knowledge of the risks; (2) monitoring, analysis and forecasting of the hazards; (3) operational centre; (4) communication or dissemination of alerts and warnings; and (5) local capabilities to respond to the warnings received. In this context SafeLand addressed the technical and practical issues related to monitoring and early warning for landslides for different landslide types, scales and risk management steps, and identified the best technologies available in the context of both hazard assessment and design of early warning systems (SafeLand Deliverable 4.8: Guidelines for landslide monitoring and early warning systems in Europe – Design and required technology). The targets for this work were end-users and it aimed to facilitate the decision process for stakeholders by providing guidelines, based on a synoptic view of existing monitoring methodologies and early-warning strategies and their applicability for different landslide types, scales and risk management steps. The guideline includes several comprehensive checklists and toolboxes to support informed decisions. One of the main objectives in this work was to merge experience and expert judgment and therefore to create synergies on EC-level towards guidelines for early warning and to make these results available to end-users and local stakeholders.

A key element in modern EWS is the use of remote sensing techniques. Guidelines for use of remote sensing technologies have therefore been developed for end users and stakeholders (SafeLand Deliverable 4.4: Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides). These guidelines may be used for selecting the remote sensing technologies which are most suitable to detect/characterize/map/monitor the landslide process at hand. Combining the technological features of each remote sensing method, the possible geomorphological features of the landslides (e.g. typology, displacement velocities and observational scales) and risk management strategies, the guidelines can be used to initially constrain the choice of methods to a few techniques that seem most feasible for the landslide process at hand. Before final decisions on the methods to be used are taken, further information and expertise will typically be required which is available through the SafeLand web site.

3.3. Toolbox of risk mitigation measures

SafeLand researchers provided a compendium of tested and innovative structural and non-structural (including insurance) mitigation measures for different landslide types (SafeLand Deliverable 5.1: Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types). This compendium is the basis of a user-friendly web-based toolbox that can help experts and other users identify appropriate technologies for protecting people and property against landslides. The compendium and toolbox are based on a classification of measures depending on whether they reduce the hazard (for example, a retaining wall), reduce vulnerability (for example, strengthening structures) or reduce exposure (for
example, relocating homes). Each measure includes a “fact sheet” that describes the measure, gives guidance on its design, schematic details, practical examples and references. The fact sheets also include a subjective rating of the applicability of the specific mitigation measure in relation to the descriptors used for classifying landslides. The web-based toolbox includes the following features: data management, user forum, help function, report generation function and the ranking of the mitigation measures as they apply to a particular landslide context.

Please review mitigation method(s) by priority

<table>
<thead>
<tr>
<th>Rank</th>
<th>Category</th>
<th>Mitigation Measures</th>
<th>TwiFi</th>
<th>Most weighting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface protection</td>
<td>Vegetated cover</td>
<td>66</td>
<td>Material / Debris, Type of movement / Flows</td>
</tr>
<tr>
<td>2</td>
<td>Surface protection</td>
<td>Surface drainage</td>
<td>65</td>
<td>Depth of movement / Shallow (0.5 - 3 m), Depth of movement / Superficial (&lt; 0.5m)</td>
</tr>
<tr>
<td>3</td>
<td>Surface protection</td>
<td>Infilling of tension cracks</td>
<td>62</td>
<td>Rate of movement at time of works / Slow, Rate of movement at time of works / Fast</td>
</tr>
<tr>
<td>4</td>
<td>Reducing Consequences</td>
<td>EWS (Early Warning System)</td>
<td>36</td>
<td>Depth of movement / Superficial (&lt; 0.5m), Material / Rock</td>
</tr>
<tr>
<td>4</td>
<td>Reducing Consequences</td>
<td>Restrictive construction activity</td>
<td>36</td>
<td>Depth of movement / Superficial (&lt; 0.5m), Material / Rock</td>
</tr>
<tr>
<td>5</td>
<td>Structural reinforcement</td>
<td>Jet-grouted piles</td>
<td>31</td>
<td>Type of movement / Flows, Type of movement / Spreads</td>
</tr>
<tr>
<td>7</td>
<td>Structural reinforcement</td>
<td>Soil nailing</td>
<td>24</td>
<td>Type of movement / Flows, Type of movement / Fail</td>
</tr>
<tr>
<td>8</td>
<td>Structural reinforcement</td>
<td>Root reinforcement</td>
<td>21</td>
<td>Groundwater / Artesian, Groundwater / High</td>
</tr>
</tbody>
</table>

Fig. 2 Example output toolbox, ranked mitigation measures.

3.4. Stakeholder involvement and decision making process

Increasingly public interventions to reduce the risk of landslides and other hazards are moving from “expert” decisions to include the public and other stakeholders in the decision process. Indeed, EU legislation, most notably the Water Framework Directive, is requiring public officials to consult stakeholders in the allocation of public funds for risk mitigation. The SafeLand project developed and tested a public communication and participatory process for mitigating the risks of landslide in the highly at-risk community of Nocera Inferiore in southern Italy (SafeLand Deliverable 5.7: Design and testing: a risk communication strategy and a deliberative process for choosing a set of mitigation and prevention measures). The pilot study demonstrated the potential and challenges of public participation in decisions characterized by high personal stakes and intricate technical, economic and social considerations. It should prove useful in informing similar processes, as
stakeholders in Europe increasingly demand a voice in choosing landslide mitigation measures.

The research for the design and testing of a participatory process was structured in four parts: 1) a case study analysis with a literature review and semi-structured interviews, 2) a public questionnaire, 3) six meetings with selected residents, and 4) communication activities, including a website, videos, an online discussion group, press releases and contacts with local media. In the end, the selected resident group agreed on fundamental priorities, i.e. the improvement of the warning system, the implementation of an integrated system of monitoring and active (usually non-structural) risk mitigation measures. Much more debate was devoted to the relocation of residents from the most endangered areas and/or the need to build passive structural works, especially on private properties. The results show that it is feasible to organize an expert-informed participatory process that respects and builds on conflicting citizen perspectives and interests, and demonstrates spheres of policy consensus as well as policy dissent.

4. Recommendations and vision

The research done in SafeLand clearly demonstrates that risk and vulnerability assessment for landslides, or any other natural hazard a society is facing, requires expertise from different disciplines. Risk and vulnerability assessment activities thus require looking beyond the borderlines of single disciplines or single sectors. Inter-disciplinary research is not an easy task. Policy and decision makers could decide to favour or provide incentives for inter-disciplinary, for example by allocating funds through research programs and calls specifically asking for inter-disciplinary research.

A proactive approach to landslide risk mitigation is far more effective than a reactive approach. However, decision makers and authorities do not always have the necessary information to invest in natural hazard risk reduction measures and such investments must compete with many other societal needs. Improved communication between decision makers and scientists and experts is essential in setting the priorities for a society. This requires an effort both from the decision makers and from the scientific community.

References

[7] (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)
[8] SafeLand Deliverable 4.4: Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides.

[9] (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)


[12] SafeLand Deliverable 5.1: Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types.

[13] (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)


[15] (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)
SafeLand Deliverable 4.4: Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides. (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)

SafeLand Deliverable 4.8: Guidelines for landslide monitoring and early warning systems in Europe – Design and required technology. (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)

SafeLand Deliverable 5.1: Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measures for different landslide types. (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)

SafeLand Deliverable 5.7: Design and testing: a risk communication strategy and a deliberative process for choosing a set of mitigation and prevention measures. (can be downloaded from https://www.ngi.no/eng/Projects/SafeLand/#Reports-and-publications)

EMERGING TECHNOLOGIES FOR SAFER BUILT ENVIRONMENT
Application of UAV Photogrammetry Survey Along with SFM-MVS Image Processing Technology in Rock Fall Monitoring in the Context of Sri Lanka

S Jayaprakash¹, D Munasinghe², D Jayathilake³
¹Scientist, National Building Research Organisation, Sri Lanka
²Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Rockfalls are creating a significant threat to road users and it is required to monitor rock movements continuously to identify rockfall events. UAV photogrammetry along with structure-from-motion in combination with multi-view-stereo (SFM – MVS) technology-based 3D model is a precise technology in the monitoring of rock surfaces. Time series UAV photogrammetry surveys are a low-cost monitoring technique in this context.

Point cloud-based displacement measurement is one of methods under the SFM-MVS technology based on 3D models for displacement analysis. In this method, SFM is applied to estimate and calibrate the geo location, orientation and camera parameters. MVS is applied to construct the dense point clouds for both master and slave imageries. Finally, point clouds of both models are compared in Cloud Compare platform by utilizing C2C and M3C2 plugins, which estimates the deviation of the dense points from the master and slave point clouds.

Rockfall site, located at 18th bend of Kandy – Mahiyanganya Rd, is selected as the study area. Experimentally, master imageries captured with manually placed measured boxes and then, slave images were captured after three-dimensional adjustment of the boxes. Displacements were calculated for X, Y and Z directions. Results were visualized through displacement maps with scalar bar and numerical statistics, which indicated spatial adjustment taken place in the slave models with 95% accuracy.

This procedure was applied to another set of master and slave models which covered the area without the manual placement of the objects. But the precession map and displacement statistics revealed no spatial variation at rock surface area. So, it can be concluded that no displacement occurred in the study area within the time span of the UAV photogrammetric survey.

Keywords: Rock fall; Point clouds; UAV photogrammetry; SFM-MVS.
1. Introduction

Rapid physical infrastructure development in the rock fall hazardous area is causing a high risk to the exposed elements in the area. Specially road side vertical rocky cliffs are posing threats to both road users and other elements located within the vulnerable zone. In order to prevent and as a precaution for such disaster incident, it is required to do continuous monitoring over such area.

The traditional approach towards monitoring such hazardous and inaccessible rocky surfaces makes it time consuming and costly. Advancement in the UAV based photogrammetry technology has enabled the way to investigate hazardous rocky areas by capturing required georeferenced topographic and geometric properties. The information acquired by drone surveys facilitates the planning process of mitigation measures. Thus, many of the case studies involved in this subject use UAV survey combined with the computer based digital image processing techniques as a contemporary technology to observe the temporal changes (by capturing time lapse imageries) in the geo structure of the rock surfaces at minimal cost (Santo, M, Di Crescenzo, Ramondini, & A, 2013).

Among the various image processing techniques, surface from motion combination with multi-view-stereo (SFM- MVS) approach has been adopted based on the literature reviews on the researches related to this context. Current applications cover monitoring Coastal Environments (Francesco, Marco, Mario, & Francesco, 2013). Use of UAV for photogrammetric surveys in rockfall instability (Santo, M, Di Crescenzo, Ramondini, & A, 2013), Implementing an efficient beach erosion monitoring system for coastal management (Kristina, Igor, Suzana, Mike R., & Branko, 2018), monitoring cliff erosion at an operational scale (Pauline, Marion, Philippe, Jérôme, & Stéphane, 2018), and Mapping landslide displacements using SFM and image correlation (Arko, Steven M., & Darren, 2013). Above mentioned researches used this approach to register the unstructured image acquisition via image-to-image registration procedures to produce reality model (in the format of point clouds, mesh and TIN) of target area.

Once the reality model is prepared for different time period based on SFM- MVS approach, it is required to detect the spatial changes over the time span of the drone survey. Detecting the spatial changes over rock surfaces (complex geometrical objects) need the comparison of two or more 3D model (Dimitri, Nicolas, & Jérôme, 2013), Dimitri, Nicolas et al (2013) reviewed existing displacement measurement methods based on the 3d models and their uncertainty. There are 3 types of comparison methods available. Such as DEM to DEM; pixel-based displacement algorithms, which suites to rock area with relatively flat surfaces, cloud-to-mesh comparison (C2M) displacement algorithms, that can apply for moderately vertical rock surfaces and the third method is direct cloud-to-cloud comparison with closest point technique (C2C) which consists of advanced algorithms to characterize the complex geometry of vertical rock surfaces. Figure 1 shows comparison and structure of above mentioned methods.

Most of the applications dealing with comparison of complex geometrical features adopted C2C and M3C2 (Multiscale Model to Model Cloud Comparison) as measurement tools for displacement variability of topographic change. Among that Theodore B. et al (2013) compared both C2M and M3C2 and concluded, C2M outputs represent higher magnitude of topographic change over the short time period of the survey but lower in the long time.
Fig. 1. Structure of the comparison methods (source: Dimitri, Nicolas, & Jéréme, 2013)

Thus, this research investigates the application of this modern technology in the context of monitoring rock fall sites in Sri Lanka, to determine whether point clouds models derived from SFM-MVS approach based on UAV images and the dense cloud-based displacement measurement tools have potential over the manual methods.

2. Research Design and Methods

2.1 Study area

One of the vertical rock cliffs is located at 18th bend of Kandy – Mahiyanganya Road was selected as study area as it is identified as rockfall prone area. Height of the rock surface ranges from 680m to 740m and the length is about 100m. For the experiment purpose portion of the area has been selected for accuracy assessment to validate the results.

Fig. 2. Location of the study

2.2 Methodology

<table>
<thead>
<tr>
<th>UAV Based photogrammetry survey</th>
<th>Applying SFM image processing techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Phantom 4 pro UAV</em></td>
<td><em>Agisoft Photoscan</em></td>
</tr>
<tr>
<td>A. Marking Ground Control Points</td>
<td>A. Photo alignment</td>
</tr>
<tr>
<td>B. Set up the flying properties</td>
<td>B. Point Quality control and enhancement</td>
</tr>
<tr>
<td>C. Placing the sample boxes</td>
<td>C. Georeferencing</td>
</tr>
<tr>
<td>D. Collecting aerial images</td>
<td>D. Bundle adjustment for slave models</td>
</tr>
</tbody>
</table>

Applying cloud to cloud based comparison for displacement measures

<table>
<thead>
<tr>
<th>Cloud Compare</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Displacement map</td>
</tr>
<tr>
<td>B. distant statistics</td>
</tr>
</tbody>
</table>

Applying MVS image processing techniques

<table>
<thead>
<tr>
<th>Agisoft Photoscan</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Sparse point generation</td>
</tr>
<tr>
<td>B. Dense cloud matching</td>
</tr>
</tbody>
</table>

Fig. 3. Work flow of the research
2.2.1 UAV based photogrammetry survey

There are several types of UAV drones available for professional photogrammetry survey depending on the context, scale and resolution. For this case phantom 4 pro was employed. It has a gimbal-stabilized FC6310 (8.8mm) camera containing the Sony EXMOR 1/2.3 sensor with a relatively wide field of view (FOV) of 94°. The JPEG images are compressed and 2.53 x 2.53 μm pixels in size (5464 x 3070), geotagged using the quadcopter’s navigational GPS and contain pointing information (http://www.dji.com/phantom-4-pro).

The survey was monitored by the DJI Go professional app (https://www.dji.com/goapp). Following figure 4 and table 1 shows the drone path and other physical properties which was set during the survey.

**Table 1. Properties of drone survey**

<table>
<thead>
<tr>
<th></th>
<th>Number of images</th>
<th>Camera stations</th>
<th>Flying altitude</th>
<th>Tie points</th>
<th>Ground resolution</th>
<th>Coverage area</th>
<th>Projections</th>
<th>Reprojection error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of images</td>
<td>136</td>
<td>136</td>
<td>36.8 m</td>
<td>114,490</td>
<td>8.59 mm/pix</td>
<td>0.0129 km²</td>
<td>391,859</td>
<td>0.567 pix</td>
</tr>
</tbody>
</table>

**Fig. 4. Camera locations with image overlap and error estimates**

In order to georeferenced the slave models according to master model. 18 GCP were marked before survey. For this purpose, structures which are visible, permeant and evenly distributed were selected and marked by recognizable symbols. To check the capacity and the reliability of the displacement measurement tools, 4 pre-measured boxes (with different dimensions) were manually placed in the corners of the rock cliffs. First master images were captured with those boxes, then boxes were adjusted...
for certain distance (mostly 10-30 cm) and slave images were captured. Figure 5 shows the sample images of GCP points and placed boxes with actual measurements.

Fig. 5. Location of GCP and placed boxes

<table>
<thead>
<tr>
<th>BOX</th>
<th>Width (cm)</th>
<th>Length (cm)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>42.5</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
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<td>24</td>
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<td>3</td>
<td>30</td>
<td>45</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>31</td>
<td>23.5</td>
</tr>
</tbody>
</table>

2.2.2 SFM-MVS image processing techniques

Since the raw images obtained from the phantom 4 drone has higher resolution based on the adjusted properties during the survey; flying distance (36m), camera angle, image overlaps 75%, etc., those images have the capacity to produce high resolution Ortho mosaics and point clouds. mainly this post processing accuracy determined by the Structure from Motion (SFM) photogrammetry processing procedures, which was applied for the processing of those images (Marion Jaud, Sophie Passot, Réjanne Le Bivic, & Christophe Delacourt, 2016). SFM approach estimates three-dimensional structured model from two-dimensional unstructured image arrangements that are based on the feature recognition algorithms. It recognizes common features in images and calculate camera positions, postures and scene geometry automatically (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012)

SFM techniques were adopted within Agisoft Photoscan. First quality of the drone images was analyzed, images with the with quality lower than 0.6 (0-1, low to high) have been removed. WGS 84 was set as reference coordinate to reflect the GPS values for the camera positions. Master images were aligned with higher accuracy and quality of tie points were refined based on the RMS tie point image residual values. MVS algorithms calculate depth maps for every image and establish survey geometry and camera models to generate 3D points.

To align the slave models based on master. GCPs which were positioned in the field were placed in to the dense cloud prepared for the master model through Making GCP image observations. Then those markers were exported to use as reference GCP for slave models. These referencing procedures have been done through the bundle adjustment in the slave models. Exported dense clouds of the rock fall site consist
around 4 Mn points. Figure 6 shows the work flow applied in the processing of slave point clouds.

**Fig. 6. Steps involved in the slave model processing**

2.2.3 Change detection using cloud to cloud-based comparison methods

First to validate the geometry of the point clouds, boxes placed in the dense cloud was measured and compared with actual measurement (refer table 2). Following figure 7 shows the derived measures of box2 from point cloud.

**Fig. 7. Derived measures of point clouds (box 2’s dimension)**

Compared to original measurements, point cloud measurements represent 98% accuracy in length (Y axis), 96% in width (x axis) and 98% in Height (z direction), which indicate that the model represents the real geometry values. Measured distance between the adjusted box2 was 20 cm in Y direction. Following figure 8 shows referenced cloud, 9 shows compared cloud and 10 shows the overlay of both clouds and visualize the shift in the box 2.

**Fig. 8. Reference cloud**  **Fig. 9. compared cloud**  **Fig. 10. overlaid clouds**

First deviation of the compared cloud to its reference cloud was measured using C2C tool, as it estimates nearest point in the reference cloud and computes their (Euclidean) distance. So, if the master cloud is highly dense then the distance to the adjacent neighbour practically as accurate as the true distance to the real-world surface represented (Daniel, 2015). Certain parameters were set in cloud to cloud measurement. First octree level (level of iteration) was set as 5-7. Since the box’s height
is 24 cm, maximum distance was set as 0.3m (30cm) to accelerate the process. Following figure 11 shows the changes in the Z direction. Fig 12 indicate, 0.06% of the total points in the reference cloud has moved up to 24 cm.

Fig. 11. Distance variation in Z axis

Compared to the original height of the box, derived distance variation in the Z direction of the compared cloud indicate accurate measurement (0.248m) (red points). blue colour indicates the negative value (-0.249m) since the box has moved 0.248m towards Z axis. green indicates the almost no change in the point clouds and range (0-001). However, vegetation cover has effect on the results, apart from moved box, some patches in the area represented by yellow colour as (mostly within the range of 10 – 15mm) shown in the following figure 13.

Fig. 13. Effect of the vegetation

These small changes were identified due to rapid changing nature of the trees to the wind. so, when interpreting the results, it is important to consider the vegetation cover in the rock surface. And also, it would better to remove the dense vegetation area through point cloud classification process before the compression.
M3C2 was used to identify the local distance between master and slave clouds along the normal surface direction which trace X, Y, Z variations in surface orientation. Further it estimates confidence interval based on point cloud roughness and registration error (Dimitri, Nicolas, & Jérôme, 2013). Number of parameters have set based on the point clouds properties as described in the following figure 14.

![Diagram of M3C2 method](image)

**Fig. 14. Parameters of the M3C2 method** *(source: Dimitri, Nicolas, & Jérôme, 2013)*

Under the scale parameters, the maximum depth has been set to 0.3m since the box adjustment was within 30 cm, radius (D) to define the normal vector for reference cloud (i) set as 6 cm to detect the small changes, diameter for the spherical neighbourhood (d) defined as 10 cm and displacement was calculated for X, Y, Z orientations separately. Figure 15 and 16 shows the distance uncertainty of points, and 95% of the points are within 4 mm to 3cm which shows good measurement and registration properties. Higher uncertainty of points up to 10 cm (5%) was observed in the vegetation patches.

![Distance uncertainty of point clouds](image)

**Fig. 15. Distance uncertainty of the point clouds**

![Uncertainty graph](image)

**Fig. 16. Uncertainty graph**

This procedure was applied to another set of master (captured on 12/5/2018) and slave models (13/11/2018) which covered the area without the manual placement of the objects. The figure 16 shows part of the overlaid clouds of the rock surface. Figure 17 shows the absolute distance variation derived from M3C2 plugin. Except the vegetation patches variation of rock surfaces ranges within near zero values (0 – 1mm). This indicate that no spatial variation occurred in the study area within the time span of the UAV photogrammetric survey.
3. Conclusion

Rockfall monitoring is highly required for conduct any engineering activities (e.g. cutting slopes for road development). In this study UAV Photogrammetry Survey along with SFM-MVS image processing technology was used to analyse the rock movements. Time series UAV images used with 75-80% overlaps. The method was tested by using 4 boxes and details examined for only one box. Through this method, 4 mm – 3cm level of displacements could be identified with 95% accuracy. Further this analysis helps to calculate the geometrical measurements of rock movements and also this method can be used as pre-identification of rockfall movements and the detail investigation can be proceed based on these results.

These methods are effective to do a rapid assessment on the rock surfaces at a low cost and minimum time as they include including computer-based automation process. However, some factors must be seriously considered to visualize the actual scenario.

Since the results are entirely depending on the quality of the inputs, accuracy of the displacement and change measurements are dependent on three main factors. First is the density of the point clouds, higher densify point clouds give accurate measurement as it represents the whole structure. Second factor is the temporal resolution, mainly the M3C2 tool indicating significant changes taken place over the time. So, if we want to know the actual scenario of the rockfall movements it is important to capture the images more frequently. Third is registration of the point clouds, it is a must requirement to georeference the master and slave models in one platform. Even small deviation in the location may lead to false detections.

Acknowledgement

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References


Applications of Differential Thermal Analyser in Scientific Research

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²Director, Geotechnical Engineering & Testing Division, National Building Research Organization, Sri Lanka

Abstract

Determination of micro level parameters of different materials has become an important factor when considering the new technology. Such detailed analyses are highly required in many fields such as in material industry, building industry and proper disaster management systems. In this regard, adopting more effective techniques using effective instruments in research work is vital. Differential Thermal Analyser (DTA) is one of the techniques used in almost all scientific fields around the world. It facilitates to identify the changes in properties of materials and study it as a function of temperature.

DTA assist to measure all reactions and processes which are related to the change in energy during heating or cooling of a sample. It can measure endothermic reactions due to dehydration, dehydroxylation, structural decomposition and transformation, magnetic changes, sintering and melting, or evaporation and sublimation, as well as exothermic due to oxidation or crystallization of amorphous materials. With all its capabilities, it can be used in material science in the process of innovating cost-effective materials and accurately identify materials specially in situations such as clay where the structural similarities of different forms which are difficult to distinguish using other experimental methods.

In such situations, DTA facilitates to obtain the fingerprint of clay mineralogy with exact identification of the clay type. With the help of the DTA apparatus available in NBRO, the changes can be identified in properties of materials is studied as a function of temperature or identify materials with high accuracy up 1500°C.

Keywords: DTA; materials; clay; minerals; landslide

1. Introduction

Sri Lanka is moving into a new era towards the development adopting resilient development strategies. Improving recovery capacity after a natural disaster is highly prioritized in this process. To achieve this vast concept, inventing new cost-effective construction materials, reconstruction methods and identifying disastrous situations in advance are vital. In this regard, numerous researches work in material sciences already are being carried out by several facilities. The purpose of this study is to
address the range of usages of Differential Thermal Analyzer (DTA) in innovation practices and to identify possible contributing factors for most frequent disaster; landslides in Sri Lanka.

Thermal analysis is a branch of material science where changes in properties of materials are studied as a function of temperature. Thermal analysis comprises a group of physical and chemical methods. DTA is one of the techniques to carry out thermal analysis for vast number of materials. Hence, it is a technique which is used in almost all fields of scientific investigation. DTA is a technique for recording the difference in temperature using a set of thermocouples between a substance and reference material against either time or temperature as the two specimens are subjected to identical temperatures regimes in an environment heated or cooled at a controlled rate (Plante, 2009). A DTA curve can be used as a fingerprint for material identification, especially in situation such as clay where the structural similarities of different forms renders diffraction experimental difficult to interpret (Bhadeshia, 2017).

2. Applications of DTA

DTA allows for detecting exothermic and endothermic reactions as a function of temperature. DTA available at NBRO facilitates to detect these changes up to a temperature level of 1500°C. It can measure endothermic reactions caused due to dehydration, dehydroxylation, structural decomposition and transformation, magnetic changes, sintering and melting, or evaporation and sublimation, to determine the phase diagrams, heat change measurements and decomposition in various atmospheres, as well as exothermic due to oxidation or crystallization of amorphous materials.

It is used in many fields such as cement chemistry, mineralogical research, environmental studies, in Food industries, pharmaceuticals and to study archaeological materials (Kingery, 1974; Regmi, Yoshida, Dhital, & Devkota, 2013; Smykatz-Kloss, Heil, Kaeding, & Roller, 1991; V.S.Ramachandran, 1969; Villanueva, Girela, & Castellanos, 1976) Although differential thermal analysis have been made for many materials, the major applications have been concerned with clay and carbonate minerals (Rowland, 1952).

In this study results of two clay samples analysed using the DTA instrument available at the NBRO, is illustrated. According to Cooray (1984), Sri Lanka is comparatively rich in clays of various kinds such as kaolinite, montmorillonite and gibbsite. Clay minerals are hydrous aluminium silicates plus other metallic ions, and also can form as either primary or secondary minerals (Lancellota, 2007). Many studies indicates a clear relationship between behaviour of the landslide slip surface and clay minerals (Bhandary et al., 1997; Istiyanti & Goto, 2017; Jeong et al., 2015; Regmi et al., 2013; Vacondis, Konstantopoulos et al., 2007). According to Vacondis et al., (2007), presence of clay minerals such as Montmorillonite, with high swelling properties and low frictional resistance can become a contributing factor to a slope failure. Along a slip surface, frictional resistance decreases as clay content increases. A small amount of swelling of expansive clays can cause relatively great increase in the plastic properties in the material. As Sri Lankan soil formation is predominant with the tropical climatic conditions of rapid weathering. Study about clay mineralogy is important to understand the role played by the clay minerals on activation of
landsides. Clay minerals have an affinity with water and also have a negative behaviour which can be a key role in landslides (Meade, 1964)

3. **Identification of Clay Minerals Using DTA**

DTA available at NBRO have the ability to reach temperature up to 1150°C and use $\alpha$AL2O3 as reference material. The geometry of a differential curve of clay is usually made up of three distinct parts. The first is a low-temperature endothermic loop which is registered when atmosphere water departs from the material. A second or midrange endothermic loop accompanies the loss of bound water or the dissociation of hydroxyls from lattice. The third is a high temperature combination of loop accompanying the final breakdown of the lattice and formation of one or more new minerals (Rowland, 1952)

In this study, identification of Na- Montmorillonite and Kaolinite (Fig.1) is present. Description of samples used is given in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Physical properties</th>
<th>Sample received from</th>
<th>Mass of the specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>kaolinite</td>
<td>Off white Powdered formation</td>
<td>University of Moratuwa</td>
<td>19.80 mg</td>
</tr>
<tr>
<td>Na-Montmorillonite</td>
<td>Pale Brown Powdered formation</td>
<td>Bentonite which used for the Field Investigations</td>
<td>20.00 mg</td>
</tr>
</tbody>
</table>

**Fig. 1. Prepared specimen Kaolinite (on right), Reference sample (on left)**

Specimen and the reference sample ($\alpha$AL2O3) were retained in platinum crucibles and have been undergone up to 1100°C and were held for 10mins. The atmosphere used was Nitrogen and the rate of flow is 50ml/min.

Differential thermal analytical curve of Na- Montmorillonite indicates three endothermic reactions at 96.45°C, 507.59°C and 980.05°C (Fig. 2). Differential thermal analytical curve for Kaolinite indicates two endothermic reactions at 72.25°C and at 539.58°C followed by an exothermic reaction at 1005.38°C (Fig 3).
Fig. 2. Differential thermal analytical curve of Na-Montmorillonite

Fig. 3. Differential thermal analytical curve of Kaolinite

Kaolinite and Na-Montmorillonite were analysed using DTA and out comes were recorded following Table 2.

<table>
<thead>
<tr>
<th>Clay Mineral</th>
<th>Observations from the DTA curve</th>
<th>Interpretation</th>
<th>Endothermic/Exothermic reaction and its temperature (°C)</th>
<th>Published values (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na-Montmorillonite</td>
<td>Strong broad endothermic peak</td>
<td>Dehydration</td>
<td>96.49</td>
<td>100-200</td>
</tr>
<tr>
<td></td>
<td>Weak broad endothermic peak</td>
<td>Low temperature dehydroxylation</td>
<td>507.59</td>
<td>500-700</td>
</tr>
<tr>
<td></td>
<td>Weak broad endothermic peak</td>
<td>Structural decomposition and crystallization</td>
<td>980.05</td>
<td>850-1000</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Weak broad endothermic peak</td>
<td>Removal of the natural moisture</td>
<td>72.25</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Strong broad endothermic peak</td>
<td>Dehydroxylation</td>
<td>539.58</td>
<td>530-590</td>
</tr>
<tr>
<td></td>
<td>Weak narrow exothermic peak</td>
<td>Transformation in to crystalline phases</td>
<td>100.36</td>
<td>900-1000</td>
</tr>
</tbody>
</table>

*Reference: (Viczián, 2013)
4. Discussion

Thermal Analyser results for the Kaolinite sample have recorded the followings. In general, the sample comprises its own natural moisture content and this removal of the moisture content resulted the weak broad endothermic peak at 72.25 °C. At the temperature of 539.58 °C, strong broad endothermic peak of Dehydroxylation of Kaolinite in to amorphous meta kaolinite has formed.

\[
\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \rightarrow \text{Al}_2\text{O}_3\cdot2\text{SiO}_2 \text{ (amorphous meta kaolinite)} + \text{H}_2\text{O}
\]

At the temperature of 1005.36 °C, exothermic transformation of amorphous meta kaolinite in to crystalline phases has occurred.

\[
\text{Al}_2\text{O}_3\cdot2\text{SiO}_2 \rightarrow 2\text{Al}_2\text{O}_3\cdot3\text{SiO}_2 \text{ (primary mullite or pseudomullite)} + \text{amorphous SiO}_2 + \gamma \text{ Al}_2\text{O}_3
\]

Thermal Analyser results for the Na-Montmorillonite sample have recorded the followings.

At the temperature of 96.46 °C, endothermic dehydration has been experiential by the strong broad endothermic peak. Endothermic Dehydroxylation of Na-Montmorillonite observed at the temperature of 507.59 °C which shown in the graph by weak broad endothermic peak. Endothermic-exothermic peak system of structural decomposition and crystallization of cordierite, mullite, Mg-spinel, quartz, cristobalite has been formed at the temperature of 980.05 °C. This curve is shown by the weak broad exothermic peak.

5. Conclusion

DTA is a possible medium to identify clay minerals which can be contribute for landslides in Sri Lanka. Likewise, DTA also can be used for many other scientific investigations in the field of material science, mineralogy, geology and cement chemistry.

Acknowledgement

We convey our extended gratitude to the Director General of National Building Research Organisation and all the staff for the encouragement given to us.

References


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Post Processing Analysis of Ground Penetrating Radar Signals for Detecting Subsurface
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Abstract

Identification of underground features or structures is a challenging task. Ground Penetrating Radar (GPR) is a technique that uses different ultra-wide bandwidth signals to determine underground features. Raw data file was generated through the GPR instrument and predeveloped with a MATLAB based programme to visualize the data. Expert judgement-based image interpretation techniques were used in the analysis of results from the GPR survey for which experienced scientists were required to obtain better outputs.

Post Processing analysis on GPR signals is a timely requirement to scientifically prove that, the expert judgement was correct or not. The Continuous Wavelet Analysis on the Fourier theorem had been used to do the analysis of this GPR Raw data file and generated the post processing results.

A pilot study was done at an archeological site in Anuradhapura Inner Citadel area and Continuous Wavelet Transform (CWT) graphs were developed. The reference data table was developed at the known location of the site and Post Processing Analysis was done based on the reference table. According to the results, more descriptive results could be identified than the visual interpretation. This paper discussed the method of the Post Processing Analysis done for the selected site at Anuradhapura Inner Citadel area.

*Keywords:* Continuous Wavelet Transform (CWT), Ground Penetrating Radar (GPR).

1. Introduction

Results of a Ground Penetrating Radar (GPR) survey considerably depend on the Post Processing Analysis (visual interpretation techniques and methods) which are adopted to convert the readings of the sensor (radargram data). In order to interpret the actual scenario of the complex archeological context beneath, it is important to carry out an analysis of amplitude slice maps and iso-surface renderings along with processed profiles of the reflection and individual traces to differentiate the categories of materials (Lawrence, 2015).
Studies which have utilized the GPR to investigate archeological sites, took into consideration number of factors which influence in the interpretation of results. First, based on the survey, the following factors have to be considered.

- Separation distance between the transmitter and receiver
- Frequency and wavelet pulse width.
- Dielectric properties of the subsurface.

(Maria Paula, 2013) Illustrated GPR profile of two cases based on the operating frequency as shown below.

Figure 1. GPR profile of Objects underneath sandy soil scanned with a 1.5 GHz frequency, b. Tow road tunnels and two cable with a 50 MHz frequency

The Radargram profile is displayed as a function of the depth and the penetration time of the waves. Figure 1 (a) shows the time and depth scales which are smaller than the profile with the lower frequency in Figure 1 (b). So, it can be identified that the area surveyed with a higher frequency represents higher pulse resolution.

Geoffrey (2008) had done the archaeological study of historic burial grounds in Alabama. The following Figure 2 shows identified features in the radargram. Blue lines indicate near horizontal indicators, it might from the bedrock. Yellow arrows specify hyperbolic reflections due to discrete reflectors. Those indicated correlate with an area containing depressions and possible grave markers, and likely to result from burials. Red arrows indicate fewer shadow reflections as by the yellow arrow. The distorted depth indicates that burials are between 0.5 m and 1.5. Shallower distinct point reflections are likely to be reflected by tree roots (Geoffrey, 2008).

Figure 2. Identified features in the radargram
Visual interpretation methods are significantly varying with the scientific background and the available geophysical information. Alternatively, Fourier theorem with Continuous Wavelet Transform analysis can be used for the postprocessing.

2. Signal Processing through Wavelet Function

2.1. The Fourier theorem

The Fourier theorem was developed by Fourier in 1822 (Resnick & Haliday, 1960) and it has been the foundation for many signal analysis techniques such as Fourier Transform, the Short-Time Fourier Transforms (STFTs) and, more recently, the Wavelet Analysis. The theory explains the formation of the signals as a combination of sine waves of varying frequency, amplitude and phase that may or may not vary with time. The Fourier transform is a mathematical technique based on which theorem breaks a signal up into its constituent sinusoidal components (Miner, 1998).

2.2. Wavelet analysis

Wavelet analysis is the subsequent logical step for analyzing time-varying physical signals, where window techniques such as Short Time Fourier Transform (STFT) is used with variable windows. Wavelet transforms are often described as useful for signal analysis and synthesis compared to traditional Fourier transform and short-term Fourier transform techniques. Wavelet analysis has two stages: signal decomposition (wavelet transformation) and reconstruction (inverse wavelet transformation). The main advantage of using waves is that locally changing information is explicitly recorded as variable length and a finite filter is used for signal analysis (Miner, 1998). The decomposition coefficients obtained from the wavelet analysis provide a basis for tracking signal characteristics over time and frequency. These coefficients, approaches, and details can be manipulated as needed, and the original signal characteristics can be changed in the application being considered. The wavelet transform reconstruction algorithm iteratively combines the coefficient groups in order to capture the original signal or the version of the original signal by some modification of the decomposed coefficients archived based on the actual requirements (Miner, 1998).

Applications based on wavelet transforms, especially those based on signal and image processing for noise reduction, compression and object recognition, have been adopted to better diagnose of fingerprint compression, speech recognition, and anything from cardiac problems to birth impairments. In addition, wavelet methods have been used in such fields as approximation theory, numerical analysis, computer science, electrical engineering and physics (P Johansson, Juselius, & Sundholm, 2005).

Ingrid Daubechies constructed wavelet bases with compact support, implying that the wavelets are non-zero on an interval of finite length (as opposed to the infinite interval length of the FT sine and cosine bases functions). Compactely supported wavelet families accomplish signal decomposition and reconstruction with only Finite Impulse Response filter (FIR). This development made the discrete-time wavelet transform a reality (Miner, 1998).
The Figure 3 graphically illustrates the wavelet transform steps on an arbitrary signal using the Daubechies 4 (db4) wavelet type (Miner, 1998).

A variation of the FT is the windowed FT, time dependent FT, or short-term Fourier transform (STFT) developed by Denis Gabor (Cohen & Ryan, 1995). STFT views (and analyzes) the input signal in a section with a movable window function. This technique provides analysis of signals with time varying information. However, the resolution of the analysis is limited by the selection of the window size. This section describes the STFT technique and shows an example of using STFT in music synthesis (Miner, 1998).

The STFT method uses FT as the localization time slot of the signal set in the window function to calculate the frame of Fourier coefficient. After the window has changed or "skipped (hopped)" over a period of time, another window shaped FT is executed. Discrete STFT is mathematically shown in Equation (1). (Oppenheim & Schafer, 1989), (Serra & Smith, 1990):

\[
X(l, \omega) = \sum_{n=-\infty}^{\infty} x[n + lH]w[n]e^{-j\omega n} \quad l = 0, 1, 2 \quad \text{Equation (1)}
\]

where \(x[n]\) is a discrete input signal, \(l\) is a particular frame, \(H\) is the hop size, \(w[n]\) is the window function, \(\omega\) is the radian frequency and \(X(l, \omega)\) are the resulting set of FT coefficients for the frame.

In Equation (1), the discrete analysis window function \(w[n]\) determines the portion of the input signal that is processed in a particular frame \(l\). \(H\) is a constant representing the magnitude (hop size) or quantity that moves the signal. STFT computes the FT spectrum on the window-size portion of the input signal \(x[n]\) in each frame \(l\). The signal is advanced by the hop-size \(H\), thereby "shifting" it past the window function. Therefore, in each frame \(l\), another part of the signal is seen through the window and analyzed with FT (Miner, 1998).
Selection of the analysis window determines the flexibility of the spectrum and the recognition of different sinusoidal components. The most widely used windows are Rectangular, Hamming, Hanning, Kaiser, Blackman, Blackman-Harris. Harris, (1978) explains the features of these windows and their advantages and disadvantages. The properties of the analysis window remain fixed during STFT analysis (Miner, 1998).

3. Continuous Wavelet Transform

Based on the math work explanation, the CWT used for the time frequency analysis, and filtering of time defined frequency components. CWT can be utilized to relates the radar signal to shifted and compressed or stretched versions of a wavelet, so it produces joint time and frequency visualization of the input. The following equation (2) describe the functionality of the CWT of 1-D signal \( f(x) \in L^2(R) \):

\[
w(s, b) = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} f(x) \psi^\ast \left( \frac{x-b}{s} \right) \, dx = \frac{1}{\sqrt{s}} (f * \overline{\psi})
\]

Equation (2)

Where, \( s, b \in R^+ \) are scale and shift parameters, respectively; \( L^2(R) \) is the Hilbert space of 1-D wave functions having finite energy; \( \psi^\ast (x) \) is the complex conjugate function of \( \psi (x) \), an analyzing function inside the basic, \( f * \psi^\ast \) expresses complication integral of \( f'(x) \) and \( \psi^\ast (x) \).

The coefficients derived from the CWT, relates function of scale or frequency and time. By comparing the radar pulse to the wavelet at various scales and positions, a function of two variables can be derived.

4. Result and Discussion

The CWT function was developed by using MATLAB software to analysis the frequency domain and time domain of the GPR RAW data. This function produced a CWT graph which could be expressed in Figure 4.

In the graph, X axis represented the time domain, Y axis represented the frequency and colour code represented the signal magnitude. This Fieldfox GPR can transmit different frequency signals within consecutive time periods. These frequencies can pass different depths according to the size of GPR antenna. Therefore, the time domain represented the depth of the investigation area. There were set of RAW data rows generated while moving the GPR instrument. Each row represented a new set of information of different frequencies.

The reference wavelet signal was developed at the known location which was previously identified through a manual survey or other methods. The reference graph was shown at the first graph of the series. The rest of the graphs represented the new location of a new movement.

The initial generated graph of the GPR survey is shown in Figure 5. In here, there were cleared layer can be identified at 3.0 and 3.5m depth. Between 0.5 to 2 m level, there were different signal patterns could be visible but cannot be defined what they were. A similar location had been analyzed through the wavelet function (approximately 14 m) and it could be shown in Figure 6.
The CWT figures had been plotted and rearranged according to the trace number. After, similar detected materials were connected through the line to observe the pattern of the material layer. This CWT analysis could help to identify 3 different layers of rock surfaces which were located at 0.8, 2.1 and 3.78m depth. Also, minor rock particles could be identified at different levels.
5. Conclusion and Recommendation

Post processing of GPR signals is required for the detailed assessment of a ground situation. The initial data representation graph couldn’t identify the minor variations. Most of the time, visual interpretation of the GPR graph might lead to wrong and uncomfortable answers.

The reference graph was developed at a well-known location which exactly had material to detect. Continuous Wavelet Transform (CWT) was used to detect similar signals in the continuous signal range from the GPR RAW data files. MATLAB based CWT analysis data module had been developed for analysing the GPR results.

This CWT was detected similar kind of signals in different scales and it represented the highest probability of reference type material existed in the identified zone.

It is recommended to test the model by using different test models and materials at the laboratory and on the site.

Acknowledgment

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References

Application of Logistic Regression Models to Map the Landslide Susceptibility Using GIS

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Abstract

Losses of lives, property damages and infrastructure damages due to landslides are experienced every year in Sri Lanka with a considerable increment creating enormous socio-economic and environmental issues. Landslides frequently disturb the life and affect property and infrastructure in the Central Highlands of Sri Lanka that cover nearly 20,000 km² (30% area of the country) of the total land area of the country, where 38% of the total population lives. In order to reduce the effects of this phenomenon, it is necessary to scientifically assess the area susceptible to landslide. To achieve this, landslide susceptibility map was produced for the Upper Ritigaha Oya and Welihel Oya subwatershed in Kegalle District, where many landslides were recorded in the last few decades.

In this study, a GIS-based logistic regression method was applied to determine the landslide susceptibility. The parameters included slope angle, aspect of slope, lithology, land use, landform, soil thickness, soil type, basin order, streams order and the distance from roads. Statistical relationships for landslide susceptibility were developed using past landslide and landslide causative factors.

The results classified into four classes of landslide susceptibility and the moderate susceptible area is scattered in more than half of the study area (66.5% of the total area), 11% of the study area is classified as a high susceptible zone. The extremely high susceptible zone covers 10% of the total area and it is only 12.5% of the total area classified as the low susceptible zone. The quality of the susceptibility map was validated, and the values for the validation data were 84.5%.

Keywords: landslide; landslide susceptibility mapping; logistic regression

1. Introduction

Landslide is a part of the geodynamic process that naturally shapes up the geomorphology of the earth. Among the natural hazards, landslides are attracting increasing attention in the world due to its accelerating effect on human lives and economy causing substantial damage to development projects, farmlands, forest growth, and infrastructures such as educational facilities, domestic and industrial
supply systems, roads, railway lines, and communication systems and therefore the economic development of many countries are threatened by them. The total extent of loss of forest cover, wildlife and damage to the ecosystem by landslides cannot be estimated and will probably remain unknown.

Therefore, prior identification of susceptible hill slopes is vital to recognize the distribution of hazard potential associated with those mountains for planning future development activities and to implement the landslide risk management strategies in these regions. Landslide hazard or susceptibility zonation/mapping is a primary tool to understand the basic characteristics of the slopes that are prone to failure. While landslide hazard zonation is defined as the mapping of areas with an equal probability of occurrence of landslides in a given area within a specific period of time, Landslide Susceptibility Zonation (LSZ) is termed as a prediction of the Spatial distribution of landslide, which is a function of landslide-related terrain factors.

Geographic Information system (GIS) can be identified as a special kind of information system that is used to handle geographically referenced data or geospatial data. That often facilitates to explore the hidden spatial relationships of the real world objects. GIS as a growing application of quantitative techniques in many areas of the earth sciences that facilitates to modeling and simulation while overcoming many of the difficulties normally associated with the handling of data in the study of geomorphic hazards and it supports to make disaster-related decisions (Burrough, 1986; Aronoff, 1989; Marble, 1990). The study of landslide hazard also applied these basic tools frequently and intensively. In this study, it tested to incorporate the landslide related terrain factors with past landslides to identify the spatial distribution of landslide potentials [1].

In order to systematically account for the parameter uncertainty, Logistic Regression (LR) was applied in this study as widely used tactical methods in the assessment of landslide susceptibility, [2,3,4,5&6]. Logistic regression establishes a linear function of causative factors for interpreting the landslide distribution from a set of training data. The linear function is allowed to calculate the landslide susceptibility index (LSI) for each cell. The LSIs are then used to establish a probability of failure and the formulae are given as follows,

$$P_r = \frac{e^u}{1+e^u} \quad (1)$$

Where "P_r" is the output of the model which is the probability of a landslide occurrence, and "u" is the independent variable which is a linear combination of the contributing factors (for example, the slope, geology, land cover, etc.). and the formula for logit “u” is given as follows,

$$u = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \quad (2)$$

β1, β2, β3, etc. are corresponding coefficients to each of the respective contributing factors which indicate their contribution to landslide susceptibility.

Development of a spatial database for future landslide analysis, development a landslide susceptibility map using logistic regression model and hence provide an improved decision support tool for hazard managers and planners were main objectives of the study.
1.1 Study area

The area is located in Yatiyantota Divisional Secretariat in the Kegalle District, Sabaragamuwa Province of Sri Lanka which is located in between the Low Country and the Hill Country of Sri Lanka (fig. 1). The area is covered by the geographical coordinates of longitude 80.249903° to 80.480678° and latitude 7.021783° to 7.137139°. The elevation varies between 500m-3500m above mean sea level. The study area covers 176 km² and 10,178 buildings were located within the area. The area receives an annual rainfall of over 2500 mm. Geomorphology in the area is complex, consisting of hills and ridges, broad valleys, gouges and plateaus. The landform demonstrates generally a dissected nature with corrugated hill slopes, complex, corrugated and dissected mountain slope, and terraced slope. Most of the soils found in the area developed in situ in residual material. The dominant soil group found in the area is the Red Yellow Podzolic soils. Dominant land use type of the area is rubber and mixed tree crops. The rocks that found in these areas mainly contain with garnet-sillimanite gneiss, granulatic gneisses, quartzites, marbles, calc-gneisses, and a variety of charnockitic gneisses. The majority of these rocks have metasedimentry origin [7&8].

This area has experienced several slope failures in the past few years and according to the National Building Research Organization (NBRO) registers, 59 incidents have been recorded and some of them had caused damage to the built environment in the area with significant direct and indirect consequences.

2. Methodology

As shown in fig. 2, the first step of the study was data collection. Then a landslide inventory is established. In parallel with this, the causative factors of the landslides are processed. In this study, slope angle, aspect of slope, lithology, land use, landform, soil thickness, soil type, basin order, distance from roads and streams order were selected as the causative factors. These factors are then statistically tested, and the most effective factors are selected for susceptibility analysis (fig. 3).
Fig. 2. Chart showing the working methodology

This was followed by assessing the landslide susceptibility considering the relationship between landslides and causative factors, and the subsequent validation of results. A key feature of this method is that the probability of landslide occurrence will be comparable with observed landslides. After recombining the coefficients, as seen in Eq. (2), the possibility of occurrence of landslides was finally computed and susceptibility map was produced. Landslide susceptibility in the resulted map was categorized into four classes utilizing natural breaks classification as, low susceptibility, moderate susceptibility, high susceptibility and extremely high susceptibility. Then validation of the results done and the validation procedure was based on a comparison between the results provided by the LR and an external dataset (not used in the training stage).
3. Results and Discussion

The selected catchment in Kegalle District consists of 59 number of landslides and the area of landslides in that catchment range from 300 m² to 40×10⁴ m², which cover 0.57% of the total study area.

According to the resulted map (Fig. 4), moderate susceptible area is scattered in more than one-third of the study area (66.5% of total area), 11% of the study area was classified as high susceptible zone. Extremely high susceptible zone covers 10% of total area and it is only 12.5% of the total area included as a low susceptible zone. The percentage of the different susceptible zones of the study area is given in Table 1.
Table - 1 Table showing area percentage of each susceptibility class of selected study area

<table>
<thead>
<tr>
<th>Susceptibility Class</th>
<th>Area (km²)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>22</td>
<td>12.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>117</td>
<td>66.5</td>
</tr>
<tr>
<td>High</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Extremely High</td>
<td>17</td>
<td>10</td>
</tr>
</tbody>
</table>

Results revealed that the likelihood of failure occurrence is particularly low in the gentle slope (0° - 11°) where the Southeastern region of the study area and scattered patches. This part of the basin is characterized by residual soil with 1m - 3m range of thickness and underneath Garnet biotite gneiss (BtGn) layer. Tea and rubber are the distinguish land use type in that area.

The highest percentage of the study area belongs to the moderate susceptible category are scattered all over the area. Moderate susceptible areas generally take place in low steep up to the moderate steep area (0° - 31°). Those areas are mainly covered by rubber and tea covers. The dominant soil type is residual soil with 1 m to 2 m thickness and the underneath lithology types of the area are Charnokitic gneiss and Quartzite.

The high and extremely high susceptible areas are concentrated in steep slope areas of the study area. The slope gradient of the area varies from 31° to 80°. These areas are laid upon Biotite gneiss material. The extensive presence of land uses of the area are mixed tree crops, degraded forest, scrubland, tea, and rubber. High thickness (ranging from 1 m to 8 m) residual soil and the scattered patches of the colluvium soil can be observed in the area.

Validation results show that the highest percentage of the observed landslide points of the external data set were located within the extremely high susceptibility zone that is 47.5%. 37% of the landslide points occur in the areas lays with high susceptibility classes. 10.5% of the landslide points were concentrated in the area with moderate susceptibility zones. The percentage value of low susceptibility class in the selected catchment is 5% and it is significantly low compared to other classes.

4. Conclusions

According to the findings of the study, it can be concluded that the logistic regression analysis clearly interpret the existing between the occurrence of landslides and causative factors.

Five factors including slope, the order of basin, lithology, soil type and distance to first order stream were highly influenced factors on slope failure occurrences than other factors.

In particular, factors such as “distance from fifth order streams” and “distance to roads” show zero weight and, it is due to the negligible influence on landslide occurrences.

Validation results of landslide susceptibility analysis illustrated that most of the observed landslide points were located in high and very high susceptibility areas and it pointed out that the map correlates well with existing field conditions. The model seems to be reliable to the selected areas.
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References


Landslide Flow Path Modelling: A Case Study on Aranayaka Landslide

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Abstract

Recent population growth and developments taking place close to landslide-prone hilly areas increase their vulnerability and climate change impacts further raise the potential of landslide hazard. Therefore, to prevent the loss of lives and damage to property, proper observation and analysis of unstable slope behavior is crucial.

Landslide flow path forecasting is important for determining a landslide flow route and it is an essential element in hazard mapping. In this work, the major landslide incident in Sri Lanka at Aranayaka area in Kegalle district is taken as a case study to model the flow path. Spreading area assessment was based on two flow directional algorithms namely deterministic eight-node (D8) and Multiple Direction Flow (MDF) Algorithm. Results obtained by the model were compared with the actual Aranayaka landslide data set and the landslide hazard map of the area.

Landslide flow paths generated from the implemented tool using D8 algorithm shows more than 65% agreement and MDF shows more than 69% agreement with the actual flow paths and other related statistics such as maximum width of the slide, runout distance, and slip surface area.

Keywords: Flow path modelling; D8 Algorithm; Multiple Direction Flow Algorithm

1. Introduction

A landslide is a wide range of ground movements which happens when a slope changes from a stable to an unstable condition. Landslides occur due to geological and morphological causes or human activities. There are many different categories of landslides, namely rockslides, earth flows, debris slides, debris flows and rock falls.

Rainfall is the main triggering factor of most landslides in Sri Lanka. At times of heavy rainfall, water penetrates through the top soil on the ground into the deep soil layers beneath, consequently filling in empty pores in the soil. When the water in pores reaches to saturation, it brings to bear a pressure internally called pore water pressure and most of the time this causes a landslide.

Landslide flow path prediction is very important for determining the flow route and the depositional area, as it is an essential element for producing landslide hazard maps, issuing early warnings, facilitating evacuation and implementing landslide
mitigation. It is a key component in risk assessment and design of remedial measures against rapid landslides.

Therefore, the development of an indicative susceptible map of the flow path and run out spreading is important in the identification of hazardous zones and in decision making to minimize the socio-economic impacts during a landslide disaster.

2. Designing and Implementation

Development of the model is done using MATLAB R2017. Following methodology is carried out,

**Fig.1: Design methodology**

2.1 Data pre-processing

Contour data formatted as shapefile was obtained from the Survey Department of Sri Lanka and converted to ASCII format which is a convenient format to MATLAB. The conversion is done by using inbuilt functions of ArcGIS software.

2.2 Generating DEM using ASCII data

A 10m resolution couture data was used to obtain DEM of Aranayaka Landslide area. DEM file is created as a grid object which contains a numerical matrix and information on georeferencing. Grid object is associated with datasets such as flow accumulation grids, gradient grids etc. Created DEM has a projected coordinate system and that elevation and horizontal coordinates are in meter units.

2.3 Modeling stream networks of the DEM

Based on the flow direction of a digital elevation model an instance of stream object is created which encapsulates the information on geometry and connectivity of a
stream network. A flow routing algorithm determines the way in which the outflow from a given cell will be distributed to one or more neighboring downslope cells.

2.4 Generating flow path when the initiation point is given

The debris flow run out algorithms, control the direction of the flow from one cell to its eight neighbors. To serve the purpose, Single Directional Flow (SDF) and Multiple Directional Flow (MDF) algorithms were used.

The D8 SDF algorithm is one of the basic and well-known algorithms which directs flow from each grid cell to one of eight nearest neighbors based on the gradient of the slope. To calculate the primary flow, the direction of the slope (Si) to each neighbor has to be calculated and set the direction for which Si is the greatest.

\[
S_{ij} = \frac{Z_i - Z_j}{d_{ij}} \quad \text{(Equation 1)}
\]

The MDF algorithm partitions and transfers discharge in each cell in multiple directions to all downward neighbor cells and thus allows for divergence and convergence of flow. It directs water to every adjacent downslope cell on a slope weighted basis. The slope gradients, slope lengths, and two weights are used to direct the flow from the center cell to each downslope cell in a 3 x 3 moving window. Each cell receives a fraction of the discharge from each upslope cell, and therefore, the upslope contributing area of the receiving cell is typically composed of partial contributions from many different cells. In this study, both D8 and MDF algorithms were developed and tested.

2.5 Calculating landslide statistics

Finally, statistics of the landslide such as landslide area, runout distance, landslide crown, maximum width, and length of the main body were generated. To calculate the above statistics main user input is the initiation points of the landslide. Statistics were produced using flow paths generated from different flow routing algorithms. These statistics can be verified with actual Aranayaka landslide data taken from NBRO.

To calculate statistics multiple points were selected from the D8, and the MDF generated the main body of the landslide. As shown in Figures 1 and 2, B and C are the initiation points and A is selected as the toe of the main body. The Euclidian distance between points of the flow paths B-A and C-A were calculated and from that total main body area (area covered by A, B, C points), crown width (Euclidian distance between B-C), and maximum width are derived. All these landslide statistics were computed for both SDF and MDF flow paths.
Fig. 2: Selected points from the main body of the landslide (MDF)

Fig. 3: Selected points from the main body of the landslide (SDF)
3. Evaluation

The developed model was evaluated using the pre- and post-landslide data available. In Aranayaka post-landslide data such as drone images after the disaster and actual flow path and other related statistics such as length of the landslide, and flow volume are taken as the baseline for the evaluation criteria. Therefore, the accuracy of the generated information from this research can be tested with available post data for compatibility and for deviations.

![Diagram of evaluation methodology]

**Fig.4: Evaluation methodology**

After creating all the available streams of the landslide area, the flow path is predicted with the given landslide initiation point. Afterward, the actual boundary created with ARC GIS can be placed on top of the generated model to check for the closeness.

3.1 Identifying actual flow path using drone images

Unmanned Aerial Vehicle (UAV) is a useful technology to capture aerial images with Global Positioning System (GPS). Using drones for mapping is a fast, low cost, safe and accurate method. The image processing techniques can be used to combine the images and develop orthophoto from many individual photographs.

3.2 Plotting the actual flow path in the location of landslide using GIS

The goal is to verify the flow path of the Aranayaka Landslide generated by the model. For this purpose, landslide flow path generated by drone images are plotted in the Aranayaka map by georeferencing. ArcGIS is used for the mapping. To map the landslide flow path, contour data of the studied area was taken from Sri Lanka Survey Department (SLSD) which is the national institution for surveys & mapping.

For evaluation of the carried-out work, Aranayaka landslide data were taken from National Building Research Organisation (NBRO) which is designated as the national focal point for landslide risk management in Sri Lanka. Using the data obtained from NBRO, actual boundary of the Aranayaka landslide area was generated on top of the contour map. The produced boundary was used to evaluate the model generated from MATLAB.
3.3 Place the flow path on top of the generated model

Actual landslide flow path mapped from ARC GIS in the previous step was placed on top of the generated model by geo-referencing. For geo-referencing in MATLAB M_Map v1.4 toolbox was used.

4. Results

Based on the result of different simulations, it was observed that both SDF and MDF flow paths fit inside the actual landslide boundary when the initiation points are given and flow directions were also in the acceptable direction of the actual landslide.
Actual landslide statistics were obtained from NBRO as per their detailed analysis and investigations were carried at the actual landslide site area. These actual statistics and statistics generated from SDF and MDF are shown in the below table.

**Table 1: Comparison of results**

<table>
<thead>
<tr>
<th>Area of Landslide (km²)</th>
<th>Main Body</th>
<th>Actual</th>
<th>SDF</th>
<th>MDF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.56</td>
<td>0.366</td>
<td>0.386</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Landslide crown (C-D) (m)</th>
<th>345.45</th>
<th>329.8</th>
<th>325.57</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Maximum width (E-F) (m)</th>
<th>600.07</th>
<th>486.6</th>
<th>619.9</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Length of the main body (Km)</th>
<th>1.26</th>
<th>792.5</th>
<th>1.18</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Flow length (Km)</th>
<th>2.268</th>
<th>1.75*</th>
<th>1.75*</th>
</tr>
</thead>
</table>

Among the generated statistics, the maximum width, length of the main body and flow length are indicators important to identify the landslide spread. After identifying the landslide spread, people living within a predicted perimeter can be warned to evacuate as the area is identified as high risk and landslide-prone. Also, safe evacuation paths can be determined by examining the predicted flow path of the landslide so the lives of people will not be endangered during the evacuation process.

MDF algorithm produced the length of the main body of Aranayaka Landslide as 1.18 km which is very close to the actual length of the main body of 1.26 km, also, the MDF-calculated maximum width of the landslide deviates only by 3.3% from the actual Aranayaka data. However, both D8 and MDF algorithms generate a flow path length of 1.75 km which is a 22.8% deviation from the actual flow length.

### 5. Conclusion and Future Works

The landslide flow paths and statistics predicted by the implemented tool show good agreement with the actual landslide data collected for the selected case study. However, MDF produced more fitting flow paths and relevant statistics for the selected landslide.

Variation of the generated flow paths and other statistics would have resulted due to unavailability of some site-specific data such as soil condition, soil type, spreading velocity, volume of the slip surface, gravity and other forces.

Even not knowing any of the site-specific data, this tool can be used to predict results with more than 65% accuracy with contour data of the landslide-prone area as the only input. When comparing the implemented tool with the other flow path-based tools such as FLOW-R, RAMMS, and DAN3D, all of these tools require site specific data.

This study has been mainly based on Aranayaka landslide area. With additional work, this model can be expanded to fit into most of the Sri Lankan landslides in...
context and predict landslide statistics with higher accuracy by inputting site-specific data. Other than the used SDF and MDF algorithms, there are many more flow routing algorithms available, which also can be integrated and implemented with this model to obtain results with higher accuracy.

References


Introducing Cost Effective Technology Using Real Time Data Processing to Forecast Landslides

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Abstract

Landslides have always been one of the major disasters affecting Sri Lanka. These landslides are triggered by heavy rain and in addition to that haphazard human activities often contribute to their occurrence. It is not possible to stop the natural causes. However, affected people can be alerted before a landslide occurs with real time data. Continuous monitoring and early warning as early as possible before beginning of such disaster may lead to avoidance of the loss of human lives and damages to properties. This study focuses on identifying physical characteristics of the hazard areas and reading variations in such characteristics before a landslide occurrence. Rainfall monitoring systems and extensometer systems designed by the author as low-cost apparatus are introduced by this paper.

Keywords: Landslide monitoring; Arduino; automated rain gauge; extensometer;

1. Introduction

Most landslides can be predicted before it happens by real time updating of hazard zonation characteristics. Therefore, to alert people living near a landslide, scientists use many techniques such as measuring rainfall intensity and ground water level, movements in wire extensometers and tilt sensors with accelerometers.

Accuracy of the prediction of a landslide occurrence can be improved by using multiple sensors combined together. However, applications of such techniques may have some limitations due to weather condition and economic problems.

When the rainfall increases, the ground water level will also increase. The rainfall can be measured by a rain gauge and the ground water level can be measured using dip meters, soil moisture sensors and other types of sensors. The method for checking the ground water level using a pressure sensor located at the bottom of a bore hole after properly insulating it, is shown by Fig.1. The resistivity is also an important physical property that could be used using simple electronics for monitoring ground water level. The resistivity change in a soil sample is shown in Fig.2. Wire extensometers, and accelerometers / tilt meters can also be used in some locations for more accurate detection of ground movement in a hazard area.
2. Methodology

The rain gauge and the extensometer described in here are based on an electronic device called ‘Arduino’. It is a microcontroller board with ATmega328 (Arduino Uno Fig.3). The Uno has 14 pins of digital output, including 6 PWM signal pins and 6 Analogy input pins. It is equipped with 16 MHz crystal oscillator, USB connector, ICSP header and a reset button. The Arduino can be powered by 5V power supply even through a USB cable. In standalone operations, it can be used with a battery up to 12V with a solar power charger. 12V is the maximum operating voltage it can work. For Arduino, the programming languages are C-language and open source.

Specification (Arduino Uno R3: Microcontroller ATmega 328, operation with 5V power, input voltage (recommended) 7-12V, Input Voltage (limits) 6-20V Digital I / O Pins 14 (6 provide PWM output) Analog Input Pin 6, DC Current per I / O Pin 40mA, When 3.3V Pin 50 mA DC, Flash Memory 32 KB (ATmega328) that is used by bootloader 0.5 KB, 2 KB SRAM (ATmega 328), 1KB EEPROM (ATmega328) and 16 MHz Clock Speed. (Resources; www.arduino.cc)
Fig.3. Arduino Module (Source: www.arduino.cc)

2.1 Real Time rainfall gauge

It is basically a self-emptying tipping bucket (Fig.4 & Fig.5). Rainwater is collected into the bucket. Once sufficient rainwater has been collected, the bucket will tip over, and the water will drain out from the base, and the opposite bucket will come up into position. When using a tipping bucket, it must be essential to refer the datasheet of the product for accurate rainfall monitoring, because different types of tipping buckets contain different water capacities.

Typically, these gauges are fitted with an RJ11 plug even though they only use two wires: one red and one green. Inside the ridge between the two buckets, there is a small cylindrical magnet that points towards the back wall. Inside the back wall there is a reed switch. When one of the buckets tips, the magnet passes the reed switch, causing it to close momentarily. RJ11 can be connected to Arduino and it will count the reed switch pulses and after multiplying by the capacity of the tipping bucket, rainfall can be calculated. The Arduino module can be set for auto resetting the bucket count after a certain time period. The counted data can be transferred through ‘GPRS’ or ‘GSM’ or wireless ‘Zigbee’ module (Fig.6) to a web server for monitoring by NBRO District Offices and the Head Office. The operation of the Zigbee module has been clearly described in a paper published by Malithi De Silva in a past NBRO Symposium.
The linear extensometer is a very expensive device and it can be replaced with a simple unit. Basically, a simple unit will contain a precision potentiometer connected to Arduino. In this application, there is a low-cost Arduino that can replace the UNO, which is referred to as Arduino Nano. Arduino Nano (Fig.7) is similar to the Arduino Uno, and has ATmega328p microcontroller, with 14 digital pins including with 6 PWM pins. These 14 pins can be operated as inputs or out puts using as pin Mode ( ),digitalWrite ( ),and digitalRead ( ). Also, there are 7 Analog pins available. Operating voltage is the same as the Uno. And maximum voltage is 12V. It has ICSP slot similar to Arduino Uno (Resources; www.arduino.cc).

In the proposed simple extensometer system, the potentiometer shown by Fig.8 is connected to the badge reel in Fig.9 by a cable placed in the hazard area. One end of the cable should be connected to a fixed concrete structure or something permanent in the hazard area. The other end is connected to the linear potentiometer cable (Fig.10). The cable connected to the potentiometer cable must be covered with a steel tube for preventing contact with any other physical thing.
The potentiometer is then connected to the Arduino Nano and it must be calibrated in centimetres per Ohm (cm/ohm) or Kilo Ohm and provided with hardware button for calibrating the potentiometer to a default value. The readings are set to transfer at specific time intervals. These data will not directly go to NBRO District Offices or Head Office and instead, they will be first transmitted to a central point at the site and then will be transferred using the method mentioned previously. When transferring data through WiFi, it can be used with a high gain outdoor AP. Then it can be connected with multiple devices to create a network among the points easily (Fig.11).

Some real extensometer values presented by Lakmali et al at the 8th Annual Symposium and measured by the three extensometers installed at Nawalapitiya (namely the points E1, E2 and E3) are given in the Table1 where hourly displacement readings had been taken since 10thOctober 2014. These reading were recorded by an
electronic data logger. The extensometer readings are shown in Table 1. Since the temperature variation is not significant, temperature correction was not done. E1 is located at the main scarp facing downslope and it shows a maximum displacement of 1.1 mm. E2 is located at the poorly developed minor scarp facing downslope and shows negative displacement throughout the time. Readings obtained from this extensometer were not reliable since both ends of the extensometer were installed on the moving land. This can be the reason for the negative displacement values. E3 is located at the left flank facing the landslide axis. E3 shows positive values throughout the time with a maximum displacement of 0.6 mm. These readings did not show any fluctuation with the time.

Table 1. Extensometer Readings (Source: 9th NBRO Annual Symposium)

<table>
<thead>
<tr>
<th>Extensometer</th>
<th>Installed date</th>
<th>Maximum Displacement (mm)</th>
<th>Displacement rate (mm/month)</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>10/30/2014</td>
<td>1.1</td>
<td>0.5</td>
<td>1010°</td>
</tr>
<tr>
<td>E2</td>
<td>10/30/2014</td>
<td>-0.7</td>
<td>0</td>
<td>1010°</td>
</tr>
<tr>
<td>E3</td>
<td>10/30/2014</td>
<td>0.6</td>
<td>0</td>
<td>280°</td>
</tr>
</tbody>
</table>

3. Conclusion

The experiments were conducted based on rainfall and extensometer monitoring and require further testing and recalibrating due to human and instrumental errors. The distance measuring instrument (extensometer) based on Arduino is still in the concept level. It is expected that in future, the developed instruments can be used as a replacement to conventional extensometers. All the described equipment must be retested under actual environmental conditions as well. Using Arduino is cost-effective and it can be operated under stand-alone situation using a battery backup together with a solar panel and a charger.

Acknowledgement

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References

[5] LOW COST STRING-POT DISPLACEMENT TRANSDUCER by adjuvomotion
PREPAREDNESS FOR EFFECTIVE RESPONSE
Determination of Rainfall Thresholds for Landslides in Sri Lanka

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²Senior Scientist, National Building Research organization, Sri Lanka  
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Abstract

Rainfall is the main triggering factor of landslides in Sri Lanka. During monsoon season, landslides in populated areas cause mammoth damage to lives and property. More than 19,500 km² (almost 30% land area of the country) within thirteen administrative districts in Sri Lanka are considered to be prone to landslides. Landslide early warning could be considered as one of the major non-structural risk reduction measure. However, it is challenging and misleading to predict rainfall thresholds at local scale without comprehensive study. Therefore, it is vital to determine valid thresholds at local level with the historical data. In this study about 200 landslide events with associated daily rainfall data were extracted from 325 landslides occurred in the period from 1999 to 2018. The antecedent periods measured for the events in this study were 1 to 15, 18 and 20 days. The 1-Day, 2-Day, 3-Day, 5-Day, 10-Day, 15-Day and 20-Day antecedent rainfall threshold values were derived for the whole country and localized rainfall threshold values for Badulla, Galle, Hambantota, Kalutara, Kegalle, Matale, Matara and Ratnapura districts were determined separately. When entire country is considered, the present results exhibit a significant deviation from the previously defined rainfall thresholds for the initiation of landslides. Initiation of landslides in some districts are attributed with the effect of continuous cumulative rainfall of more than 10 days and in the other districts continues cumulative rainfall of 3 days or shorter time period with high intensity rainfalls.

Keywords: Landslides; triggering; rainfall thresholds;

1. Introduction

Landslide is one of the major disaster that cause extensive damage to property and loss of lives across Sri Lanka. Every year, especially during monsoon and inter-monsoon seasons, intense and cumulative rainfall is the main triggering event for the occurrence of landslides. More than 19,500 km² (almost 30% land area of the country) within thirteen administrative districts in Sri Lanka are considered to be prone to landslides and almost 38 % of the total population of the country is living in these
districts. According to the available records, major landslides occurred during past three to four decades have caused to death of more than 1,500 human lives making over 200,000 homeless. For instance, more than 100 deaths in 2014 mainly in Badulla district, more than 150 deaths in 2016 in Kegalle district and more than 230 deaths in Rathnapura, Kalutara, Galle and Matara districts in 2017 were recorded recently.

National Building Research Organization (NBRO) is the focal point for landslide studies and related concurrent researches in Sri Lanka. Currently, NBRO have defined three landslide triggering rainfall thresholds (75 mm/day, 100 mm/day, 150 mm/day) for the entire country. Importance of developing localized rainfall thresholds has long been recognized by NBRO. However, due to lack of comprehensive landslide database and sufficient rainfall data associated with the events, subsequent inefficiencies in the field are inevitable. The effect of precipitation for the landslide initiation will differ locally. Therefore, when issuing early warnings for any landslide occurrence, it is problematic and misleading to predict for local areas using a regional or country wise rainfall threshold. So, the necessity of locally defined rainfall thresholds has been treated as an urgent requirement. In order to develop such rainfall thresholds a comprehensive landslide database must be prepared.

In Nepal Himalaya region, the rainfall thresholds for landslides have been defined using Intensity-Duration threshold curve (Dahal et al., 2008). Empirical models are more suitable for the development of rainfall thresholds at regional scale. Previous researchers used Bayasion approach to estimate the probability of landslide occurrence (Berti et al., 2012).

This study is focused on the generation of local rainfall threshold values for each district in Sri Lanka by observing the empirical relationship between historical landslides and associated rainfall data. For the purpose of establishing an empirical relationship, 200 landslide events occurred from 1999 to 2018 with daily rainfall data were considered.

2. Study Area

This study mainly targeted the Central and South-Western provinces of the country with high frequency of landslides encountered during monsoon seasons. It encompasses Districts like Matale, Mahanuwara, Nuwara Eliya, Badulla, Kegalle, Ratnapura, Kalutara, Galle, Matara and Hambantota. This area is within $6^\circ\ 46'\ 20''$ $N$ to $7^\circ\ 25'\ 21''$ $N$ and $80^\circ\ 35'\ 23''$ $E$ to $80^\circ\ 39'\ 53''$ $E$. The entire study area is underlain by high grade metamorphic rocks.
3. Methodology

For the study, initially a comprehensive landslide database with required data for the proposed analysis were prepared. The compiled database consists of about 2,000 landslide events, out of which 200 landslides with required data for the analysis. The data was extracted from existing data sheets and reports. The remained events were not considered due to following reasons:

- Reported landsides with unknown dates of occurrence or unknown location
- Cutting failures and rock falls
- Potential landslides

For the completion of the landslide database, daily rainfall data associated with landslide events was extracted from both Meteorological Department rain gauges and NBRO rain gauges. To select the rainfall stations corresponding to a particular landslide, spatial distributions of landslide locations and rain gauge stations were analyzed in a Geographic Information System (GIS). The most effective three rain gauges for each landslide were selected by considering the morphology of the area and the distance between rain gauges and the particular landslide.
Then, the most effective rain gauges were listed with associated rainfall data. If there were no any rainfall data in a particular rain gauge on the date of occurrence, secondly most-effective rain gauge was selected for such locations. Rain gauges were selected in a way that particular landslide is not far away from few kilometers and it is assumed that the rainfall values sufficiently represent the conditions at the respective landslide location.

First, outliers were identified and removed from the data set using statistical method. Then, antecedent rainfall requirement for the initiation of landslides were established using previous daily rainfall data for each event. Here, the seven antecedent time periods (1, 2, 3, 5, 10, 15 and 20 days) have been selected for the events. The most representative rainfall for each antecedent time period was determined using method of statistical mean. Then, mean value of each antecedent time period which is less than the mean of the sample (entire) data set was calculated. Finally, mean value of each antecedent time period of the data set in between the above two means were determined.

The graphs of antecedent cumulative rainfall against number of dates were plotted for each landslide for a period of twenty days for each district. Then, the graph of mean of cumulative rainfall of each antecedent dates were plotted (Fig. 2.). The most effective rainfall period for the initiation of landslide in each districts were determined from these graphs. Then, graphs with similar trends were grouped (Fig. 4).
Fig. 2: Cumulative rainfall against number of antecedent dates (a. Graphs for all landslides, b. Graph showing mean cumulative rainfall of each antecedent date.)

4. Results and Discussion

1-Day, 2-Day, 3-Day, 5-Day 10-Day, 15-Day and 20-Day cumulative rainfall for the initiation of landslide were calculated for the entire country (Table 1) and for each district (Table 2). Then, three initial threshold levels of cumulative rainfall for the above dates were determined using the mean values as shown in Table 1 and 2.

Table 1. Determined initial threshold levels for the entire country

<table>
<thead>
<tr>
<th>Initial threshold level</th>
<th>1-day (mm)</th>
<th>2-day (mm)</th>
<th>3-day (mm)</th>
<th>5-day (mm)</th>
<th>10-day (mm)</th>
<th>15-day (mm)</th>
<th>20-day (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>62</td>
<td>98</td>
<td>146</td>
<td>244</td>
<td>317</td>
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<td>2</td>
<td>58</td>
<td>110</td>
<td>165</td>
<td>211</td>
<td>326</td>
<td>413</td>
<td>478</td>
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<tr>
<td>3</td>
<td>111</td>
<td>202</td>
<td>271</td>
<td>318</td>
<td>407</td>
<td>492</td>
<td>565</td>
</tr>
</tbody>
</table>

Fig. 3: Cumulative rainfall against number of antecedent dates (a. Graphs for all landslides in study area; b. Graph showing mean cumulative rainfall of each antecedent date.)
As shown in the Fig. 3, 3-day cumulative rainfall can be considered as the most effective threshold values for the initiation of landslides in the context of the entire country.

Table 2. Determined initial threshold levels for each district

<table>
<thead>
<tr>
<th>District</th>
<th>Initial threshold level</th>
<th>1-day (mm)</th>
<th>2-day (mm)</th>
<th>3-day (mm)</th>
<th>5-day (mm)</th>
<th>10-day (mm)</th>
<th>15-day (mm)</th>
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<td>Badulla</td>
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<td>46</td>
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<tr>
<td></td>
<td>3 32</td>
<td>62</td>
<td>73</td>
<td>123</td>
<td>198</td>
<td>269</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>Kagalle</td>
<td>1 8</td>
<td>36</td>
<td>80</td>
<td>108</td>
<td>209</td>
<td>242</td>
<td>407</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 21</td>
<td>77</td>
<td>137</td>
<td>170</td>
<td>294</td>
<td>337</td>
<td>534</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 35</td>
<td>123</td>
<td>179</td>
<td>227</td>
<td>378</td>
<td>486</td>
<td>606</td>
<td></td>
</tr>
<tr>
<td>Ratnapura</td>
<td>1 32</td>
<td>116</td>
<td>156</td>
<td>236</td>
<td>297</td>
<td>377</td>
<td>470</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 83</td>
<td>237</td>
<td>298</td>
<td>378</td>
<td>419</td>
<td>512</td>
<td>534</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 103</td>
<td>278</td>
<td>339</td>
<td>383</td>
<td>450</td>
<td>543</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Matara</td>
<td>1 150</td>
<td>314</td>
<td>329</td>
<td>336</td>
<td>344</td>
<td>380</td>
<td>428</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 257</td>
<td>392</td>
<td>392</td>
<td>396</td>
<td>402</td>
<td>444</td>
<td>502</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 328</td>
<td>431</td>
<td>450</td>
<td>455</td>
<td>464</td>
<td>517</td>
<td>582</td>
<td></td>
</tr>
</tbody>
</table>

According to Table 2 and Fig. 4, it is evident that there is a significant difference of rainfall trend of initiation of landslides between central districts (Badulla, Kandy, Kegalle and Matale) and south western districts (Galle, Hambantota, Kalutara, Matara, Ratnapura).

Fig. 4. Mean of the cumulative rainfall against number of antecedent dates grouped according to
All landslides in Ratnapura, Kalutara, Galle, Matara and Hambantota Districts which is grouped as south-western districts shows that landslides in this area were generally occurred with high daily rainfalls. And, those curves reached the threshold value within 72-hour period rainfalls; according to the graphs (Fig. 3) most effective rain period to initiate a landslide in these areas is 3 days.

When consider the Center Highlands there is no significant change in gradient until 20 day cumulative rainfall. Therefore it is hard to find critical period of antecedent rainfall. Because of that it is necessary to do further studies to determine the rainfall threshold values for this area.

Table 3. Rainfall threshold values for all study area

<table>
<thead>
<tr>
<th>Alert value</th>
<th>Threshold value within 72 hours (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alert 1</td>
<td>100</td>
</tr>
<tr>
<td>Alert 2</td>
<td>155</td>
</tr>
<tr>
<td>Alert 3</td>
<td>270</td>
</tr>
</tbody>
</table>

Rainfall thresholds for South-Western districts (Galle, Hambantota, Kalutara, Matara, Ratnapura) were finalized using above results. Warnings will be issued considering cumulative three days rainfall.

Table 4. Rainfall threshold values for south-western districts

<table>
<thead>
<tr>
<th>District</th>
<th>Threshold value within 72 hours (mm)</th>
<th>Alert 1</th>
<th>Alert 2</th>
<th>Alert 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galle</td>
<td>155</td>
<td>250</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td>Hambantota</td>
<td>180</td>
<td>335</td>
<td>395</td>
<td></td>
</tr>
<tr>
<td>Kalutara</td>
<td>150</td>
<td>270</td>
<td>380</td>
<td></td>
</tr>
<tr>
<td>Matara</td>
<td>330</td>
<td>390</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>Ratnapura</td>
<td>155</td>
<td>300</td>
<td>340</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusion

This study was carried out to investigate the relationship between occurred date/time of landslides and antecedent rainfall characteristics. All the landslides in these areas had occurred after a rainy period. It means that all studied landslides had occurred as an effect of rainfall. The lower thresholds for initiation of a landslide in the area of study can be established critically. Landslides in some districts logically are connected with a shorter time period of rainfall, some are not. To determine the effective antecedent rainfall threshold values, 1-day, 2-day, 3-day, 5-day, 10-day, 15-day and 20-day cumulative rainfall were considered. With the increase in rainfall, the pore water pressure will increase. This pressure tends to make the slope destabilized. This study shows that the effect of rainfall vary with each district. In central highland districts the crucial soil moisture to trigger a landslide is related to more than 15-20 days antecedent rainfall (lower intensities over long time period) and in South-
Western districts the crucial soil moisture to trigger a landslide is related to less than 3-5 days antecedent rainfall (high intensities over long time period). Studies proved that not only the daily rainfall affects for the initiation of a landslide but also, the antecedent rainfalls are a necessity. As a result of these different features in different scale, more research is needed to investigate the relation between rainfall and other physical characteristics to trigger a landslide event.

Acknowledgement

The authors wish to thank Director General and other staff members of NBRO for their kind support and encouragement. Last but not least, authors like to thank Director General, Department of Meteorology for authorizing to obtain rainfall data.

References


Rock Slope Stability Analysis of the Proposed Cut Slope in Central Expressway Project, Sri Lanka

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²Senior Scientist, National Building Research Organisation, Sri Lanka
³Director, Landslide Research and Risk Management Division, National Building Research Organisation, Sri Lanka

Abstract

This study incorporates the stability analysis of proposed road cut slope within 69+900 to 69+990 chainage which is located near Pothuhera junction in central expressway project. Cause of this location is cutting angle should be maintain as 800 because of the old temple that is located in upper slope. Therefore, this study was carried out to identify the possible failures due to excavation. Stereograph analyses were done to find mode of failures. Planar, wedge and topple failures were possible in rock slopes. Then continuous slope mass rating (CSMR) technique has been used for slope stability analysis at these locations. CSMR is modification of original slope mass rating (SMR) proposed by Romana which is based on well-established rock mass rating (RMR) technique. Kinematic analysis was also carried out to evaluate these sites for types of failure and its potential failure directions.

Data was collected in two locations within this area. According to the structural data that was collected in each location two prominent joint set could be observed with foliation. Bore hole data and unconfined compressive strength (UCS) test were used to determine rock quality designation (RQD) values and strength of the rock respectively. Also, normal blasting conditions were used to this analysis.

According to the stereographic analysis two topple and two wedge failures were identified in one location and one wedge failure was identified in other location. The results of CSMR analysis is indicate that there are one unstable wedge failure and others are partially stable. So that, mitigation methods such as removing unstable rock parts, rock bolting and rock anchoring methods can be recommended accordingly in the future. Also, smooth blasting method can be used to prevent decries of existing stability. As well as this analyze is further recommended after the excavation.

Keywords: Central Expressway, SMR; CSMR; RMR; Rock Slope Stability
1. Introduction

As a developing country, Sri Lanka has been experiencing massive developments of transportation sector during the past decades. Hence newly constructing highway network in Sri Lanka plays a vital role in keeping smooth and speedy connectivity with remote urban centres and local areas of the country. Proposed central expressway which is one of such developments connects Colombo and Kandy. The middle and latter part of the highway run through Central Highlands and hence keeping the level of the highway has to critically be considered. High grounds such as hillocks and passages of mountains and mountain ranges have to be flattened. In this process some cut slopes which need sound mitigation to avoid earth instabilities have been created.

It has been identified that cutting failures occur due to construction activities are one of the most frequent hazards in Sri Lanka. Such failures may lead to disturb the continuity of transportation and huge loss of properties and lives. The cut slopes are the results of levelling of passage of central expressway and most of the cut slopes are concentrated in between Mirigama and Kurunegala segment. Unplanned excavation may cause rock falls and vibrations due to blasting may cause widening of joints and fractures.

Most of the slope cuts of central expressway are compulsory and steep angles have to be maintained due to the restriction of adjacent land extend. Hence some of the cut slopes are prone to fail. Preliminary studies revelled that the cut slope at chainage 69+910 needs to be evaluated in detail for its stability while proposing mitigatory measures to reduce potential hazards.

![Figure 1: Location map of the study area](image)

Several approaches of slope stability analysis such as limit equilibrium, analytical and kinematic, physical and numerical models are being used [1, 6]. One of the most widely used and adequate method is slope mass rating (SMR) technique [7, 8]. SMR is based on the rock mass rating (RMR) technique introduced by Bieniawski [3, 2]. RMR technique is based on detailed field study which involves collection of data at site and
laboratory analysis. The field data such as slope angle, strength of rock exposed on slope face, condition of discontinuities, spacing of discontinuities, orientation of discontinuities and ground water condition are used in RMR technique for the analysis. SMR includes RMR along with some adjustment factors based on in relation of joint orientation with slope and method of slope excavations. The adjustment factors in SMR technique, proposed by Romana [9], are discrete and more decision based. The Continuous SMR (CSMR) proposed by Tomas provides continuous determination and very less decision based [10]. The CSMR assigns unique value to each adjustment factor of slope those results into more accurate value of SMR [10].

The study area is located at 69+910 chainage with a stretch of 80 m up to 69+990 chainage of central expressway (Fig. 1). The study site is located within Nakalagamuwa and Dambokka exchange in Kurunegala District.

2. Methodology

CSMR has been used to identify the expected instability due to proposed excavation and design [3, 11]. CSMR technique is a modification of SMR of Romana [3, 4]

$$\text{CSMR} = \text{RMR} - (F_1, F_2, F_3) + F_4$$

Where,

$$F_1 = \frac{16}{25} - \frac{3}{500} \tan^{-1}\left(\frac{1}{10} (|A| - 17)\right)$$
$$|A| = \sqrt{\alpha \cdot 0.8}$$ for planer failure,
$$|\alpha l \cdot 0.8|$$ for wedge failure,
$$|\alpha j - 0.8|$$ for toppling failure,

and $\alpha j, 0.8$ and $\alpha l$ are dip direction of joint, slope and plunge direction of line intersection of two joint planes.

$$F_2 = \frac{9}{16} + \frac{1}{195} \tan^{-1}\left(\frac{17}{100} B - 5\right)$$

Where; $B$ equals to dip ($\beta j$) of joint for planer failure and toppling to dip on plunge of line of intersection for wedge failure.

$$F_3 = -30 + \frac{1}{3} \tan^{-1}(C)$$ (For wedge failure)

$$F_3 = -13 - \frac{1}{7} \tan^{-1}(C - 120)$$ (For toppling)

Where, $C$ is an angular difference of dips of joint and slope ($\beta j - \beta s$) for a planer failure. $C$ is difference of dip of plunge of line and dip of slope ($\beta l - \beta s$) for a wedge. For topping, $C$ is defined as sum of dip of a joint and a slope ($\beta j + \beta s$).

(F4) has been fixed empirically as follows: Natural slopes: $F_4 = +15$, Presplitting: $F_4 = +10$, Smooth blasting: $F_4 = +8$, Normal blasting: $F_4 = 0$, Deficient blasting: $F_4 = -8$, and Mechanical excavation: $F_4 = 0$.

Structural properties of rock and conditions of joints were taken from field investigation. Structural properties of the rocks were collected in two locations where bedrock is exposed. Friction angle value of the bed rock was considered as $30^\circ$ and RQD and UCS values were taken from the borehole and Unconfined Compressive Strength Test on Intact Rock Core Specimens.

Recommendations were obtained by using Grimstad and Barton’s estimated support categories based on the tunnelling quality index $Q$ [5].
3. Results and discussion

Location 1 (L1)

There are three discontinuity planes including the foliation plane and two sets of joints. (Table 1) can be identified. Regolith thickness is less than 1 m and it is mainly soil. Surface exposed bed rock and scattered in-situ boulders are observed with in the surrounding area (Fig. 2).

<table>
<thead>
<tr>
<th>Table 1: Orientation of foliation and joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliation/Joint</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>J1</td>
</tr>
<tr>
<td>J2</td>
</tr>
</tbody>
</table>

Figure 2: Views of Location 1

Details of joint spacing, joint condition and ground water conditions were taken from above mentioned discontinuity planes. These details are summarized in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Condition of foliation and joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliation/Joint</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>J1</td>
</tr>
<tr>
<td>J2</td>
</tr>
</tbody>
</table>
Stereographic Analysis

Three set of discontinuities which were observed in location 1 are plotted in stereo-net.

<table>
<thead>
<tr>
<th>Description</th>
<th>Dip/ Slope</th>
<th>Dip Direction/ Slope direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope along LHS</td>
<td>80°</td>
<td>335°</td>
</tr>
<tr>
<td>Slope along RHS</td>
<td>80°</td>
<td>155°</td>
</tr>
<tr>
<td>F</td>
<td>53°</td>
<td>265°</td>
</tr>
<tr>
<td>J1</td>
<td>90°</td>
<td>171°</td>
</tr>
<tr>
<td>J2</td>
<td>77°</td>
<td>044°</td>
</tr>
</tbody>
</table>

Figure 3: Plot of joint and slope at L1. The pink coloured area indicates the critical zone of failure. The symbols used in figure are as SP1, SP2: Slope; F: Foliation; J1, J2: Orientation of joint, W1, W2: Wedge formed by intersection of joints; T1, T2: Topplin

Considering the cut slope along Left Hand Side (LHS) of the road, the analysis made through stereo-net plot shows that, the most unfavourable condition is the result of intersection formed by the discontinuities J1/F and J2/F. Hence, it is a case of probable wedge failures. Otherwise the analyses of stereo-net indicate that the J1 is found close to the cut slope direction. Hence, it is considered as toppling condition.

According to the analyses of stereo-net only one possible failure is observed at the cut slope along the Right-Hand Side (RHS) because of orientation of J1 is closed the orientation of cut slope. Hence, it is considered as toppling condition.

Location 2 (L2)

In that location, three discontinuity planes with two joint sets and the foliation plane (Table 3) can be identified. Surface exposed bed rock is observed with in the surrounding area (Fig. 4)
Figure 4: Views of location 2

Table 3: Orientation of foliation and joint

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Dip</th>
<th>Dip Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>71°</td>
<td>260°</td>
</tr>
<tr>
<td>J1</td>
<td>79°</td>
<td>000°</td>
</tr>
<tr>
<td>J2</td>
<td>28°</td>
<td>087°</td>
</tr>
</tbody>
</table>

Details of joint spacing, joint condition and ground water conditions were taken from above mentioned discontinuity planes. These details are summarized in Table 4.

Table 4: Condition of foliation and joint

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Joint Spacing</th>
<th>Joint Condition</th>
<th>GW condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>6cm, 17cm, 21cm</td>
<td>Slightly rough surface, Slightly weathered rock, Separation &lt; 1mm, No considerable filling</td>
<td>Completely dry</td>
</tr>
<tr>
<td>J1</td>
<td>10cm, 40cm, 60cm</td>
<td>Slightly rough surface, slightly weathered rock, 1mm &lt; Separation &lt; 5mm, Filling in some place</td>
<td>Completely dry</td>
</tr>
<tr>
<td>J2</td>
<td>50cm, 60cm</td>
<td>Slightly rough surface, Slightly weathered Rock, 1m &lt; Separation &lt; 5mm, No considerable filling</td>
<td>Completely dry</td>
</tr>
</tbody>
</table>
Stereographic Analysis

Three set of discontinuities which were observed in location 2 are plotted in stereo-net.

<table>
<thead>
<tr>
<th>Description</th>
<th>Dip/ Slope</th>
<th>Dip Direction/ Slope direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope along LHS</td>
<td>80°</td>
<td>335°</td>
</tr>
<tr>
<td>Slope along RHS</td>
<td>80°</td>
<td>155°</td>
</tr>
</tbody>
</table>

| F | 71° | 260° |
| J1 | 79° | 000° |
| J2 | 29° | 087° |

Figure 5: Plot of joint and slope at L2. The pink coloured area indicates the critical zone of failure. The symbols used in figure are as SP1, SP2: Slope; F: Foliation; J1, J2: Orientation of joint, W1: Wedge formed by intersection of joints; T1,T2: Toppling.

Considering the cut slope along LHS of the road, the analysis done with stereo-net plot shows that, the most unfavourable condition is the result of intersection formed by the discontinuities J1/F. Hence, it is a case of probable wedge failures. Otherwise according to the analyses of stereo-net, there is no any possible failure in both cut slopes.

SMR Analysis

RMR values were calculated for both locations (Table 5) and possible failures are obtained as follows (Table 6).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>L1</th>
<th>L2</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCS Rating</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>RQD Rating</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Joint Spacing Rating</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Joint condition Rating</td>
<td>2+1+3+6+5=17</td>
<td>4+1+3+6+5=19</td>
</tr>
<tr>
<td>Ground water Rating</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>RMR</td>
<td>62</td>
<td>64</td>
</tr>
</tbody>
</table>
Table 6: Result of slope mass rating

<table>
<thead>
<tr>
<th>Location</th>
<th>RM R</th>
<th>Slope orientation</th>
<th>Feature</th>
<th>Dip direction</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>SM R</th>
<th>Class/ Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 62</td>
<td>80/335</td>
<td>W1 53 261 0.1 6 0.9 5 59.2 0 52.9 9</td>
<td>iii/Partially stable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>W2 35 323 0.4 8 0.7 9 59.5 8 0 39.4</td>
<td>Iv/unstable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T1 90 171 0.1 2 1 25.6 9 0 58.9 1</td>
<td>iii/Partially stable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>80/355</td>
<td>W1 67 297 0.2 5 0.9 8 58.5 3 0 49.6 6</td>
<td>iii/Partially stable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Conclusion

The cut slope at the location 1 creates three partially stable failures, of which, two are toppling, one is wedge and the other is unstable wedge failure. That of at the location 2 creates a partially stable wedge failure. It can be inferred that method of excavation highly affects to the grade of stability of the above all failures according to the F4.

Another wedge failure will be occurred at the location 2, if friction angle of the rock mass is reduced by two or more degrees (if, $\phi<28^\circ$).

The present prediction is mainly based on the discontinuities presently exposed at the site. But more discontinuities can be appeared during and after the excavation and depending on their orientations more failures can be expected.

Remedial measures should be taken for W1, W2 and T1 identified at the L1 and W1 identified at L2, since cut slope is designed with restricted spaces due to a temple nearby.

5. Recommendations

As per the study, installation of fully grouted or shotcreeted rock bolts with a diameter of 20mm, 3-5 m long systematic bolts with a space of 1-2.5 m and wire mesh and 50-150 mm shotcrete are proposed as mitigatory measures to prevent wedge and toppling failures.

This investigation should be carried out again once again, after the excavation is completed for confirming possible failures and stabilities. Mitigation methods should be finalized based on result of final analysis.
References


A Quantitative Methodology for Decision Making on Landslide Risk Reduction Options

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2 Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Disaster risk reduction (DRR) is a systematic approach which involves identifying, assessing and reducing the risks of disaster. Landslide is one of the major disaster events in Sri Lanka, which has increased its frequency of occurrence in the last 2-3 decades. It has been identified that about 30% of Sri Lanka’s land area are prone to landslides. With this trend of increasing landslide occurrences, most part of the above settlement areas has become high risk. Within this context, application of disaster risk reduction activities like mitigation, adoption, recovery and development is important to reduce the future disaster risk. However, studies shows that decision on selecting a DRR option has made without systematic approach.

Thus, this study focused on developing a methodology for assessing the landslide at-risk locations and making decision on risk reduction options. The methodology was supported by comprehensive literature review and field assessment. This paper presents the approach used for the development of methodology and the final output. Findings of this study can be used for assessing any landslide at-risk location and make DRR decisions.

Keywords: Disaster Risk Reduction (DRR); Landslides, Quantitative Methodology

1. Introduction

Disaster Risk is a result due to a combination of hazard, vulnerability and the capacity of element at-risk. Disaster risk reduction is a systematic approach to identifying, assessing and reducing the risks of disaster (UNISDR, 2018). National Building Research Organisation (NBRO) as the main national institute for the landslide disaster studies, regularly landslide risk identification is conducted through the mapping of landslide hazard areas and site specific landslide investigations (SPI). However, the assessments of the above identified locations have become a challenge due to not having systematic scientific approach. Therefore, it is questionable that the decisions taken to reduce risk at identified locations is the best option or not. Landslide mitigation, living with landslide with soft mitigations (adoption) and resettlement of risk elements are the currently practicing basic risk reduction options. Selecting of these option is a challenging task due to its complexity nature.

With this background, this paper presents a methodology for assessing the landslide risk location with field verification in highly landslide prone district of Badulla.
2. Methodology

A comprehensive literature review was conducted to understand the landslide disaster risk reduction options and to define the criteria for developing an assessment methodology. Expert interviews and brainstorming sessions were conducted to develop the initial framework. Four criteria were defined and separate assessment tools were developed to assess risk of a house and landslide susceptibility. Finally, the developed methodology was tested in Badulla district where the landslide hazard and risk mapping have been completed and SPIs are available. The field testing were carried out in 10 randomly selected landslide locations. First 07 locations had been previously identified through site specific investigations and the next 03 landslide location was identified through the landslide hazard zonation mapping process.

3. Literature Review

Disaster Risk Reduction (DRR) is a systematic approach to identifying, assessing and reducing risks (Twigg, 2015). It was further described that DRR is a concept and practice of reducing disaster risks through systematic efforts to analyses and manage the causal factors of disasters, including, reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment and improved preparedness for adverse events. There are several approaches to reduce the identified disaster risk. According to the Twigg (2004), mitigation and preparedness are the main approaches available for disaster risk reduction. However, NBRO has identified main three risk reduction options in their landslide risk reduction framework such as living with landslides (disaster adaptation), landslide mitigation and resettlement. Whatever the options are used in risk reduction, it is essential to identify and assess the disaster risk before deciding on a risk reduction approach. As stated by the UNISDR (year?), risk can be calculated by the following equation;

\[
\text{Risk} = \frac{\text{Hazard} \times \text{Vulnerability}}{\text{Capacity}}
\]

According to the above risk formula and disaster risk reduction framework proposed by the ISDR (2004), hazard analysis and the vulnerability analysis should be performed to define the risk. In this study selected hazard is the landslide. As Jayathilaka (2015) stated NBRO has developed landslide hazard mapping methodology for Sri Lanka covering the all landslide prone districts. According to the ISDR (2004), Vulnerability is determined by the social, physical, economic and environmental factors. Therefore, vulnerability assessment should cover all the above aspects. As presented in equation (1), capacity is the final factor to be assessed to calculate the risk. As ISDR (2004) mentioned, capacity is the combination of all the strengths and resources available within a community, society or organization that can reduce the level of risk, or the effects of a disaster.

With the above literature, following criteria were defined to identify the risk of a location by referring to the risk formula.
Table 1. Criteria and its reference to Risk Formula

<table>
<thead>
<tr>
<th>#</th>
<th>Defined Criteria</th>
<th>Reference to Risk Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landslide Susceptibility</td>
<td>Hazard</td>
</tr>
<tr>
<td>2</td>
<td>Damage Assessment</td>
<td>Vulnerability</td>
</tr>
<tr>
<td>3</td>
<td>Social Vulnerability</td>
<td>Vulnerability</td>
</tr>
<tr>
<td>4</td>
<td>Structural Stability</td>
<td>Capacity</td>
</tr>
</tbody>
</table>

4. Analysis

The above defined criteria were weighted using the mathematical model of AHP (Analytic Hierarchy Process) and expert consultation process. Finally, the following weights have been assigned. For the assessment of each criteria and separate tool were developed through an expert interview as shown in the table 2.

Table 2. Criteria weightage and Assessment Tools

<table>
<thead>
<tr>
<th>#</th>
<th>Defined Criteria</th>
<th>Weights</th>
<th>Assessment Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landslide Susceptibility</td>
<td>60</td>
<td>Landslide susceptibility analysis tool</td>
</tr>
<tr>
<td>2</td>
<td>Damage Assessment</td>
<td>10</td>
<td>Building Structural Assessment Tool</td>
</tr>
<tr>
<td>3</td>
<td>Social Vulnerability</td>
<td>5</td>
<td>Social Vulnerability Assessment Tool</td>
</tr>
<tr>
<td>4</td>
<td>Structural Stability</td>
<td>25</td>
<td>Damage Assessment tool</td>
</tr>
</tbody>
</table>

4.1 Landslide Susceptibility Analysis Tool (LSAT)

The landslide susceptibility assessment tool developed by the NBRO was used as a tool for the analysis of landslide susceptibility under this methodology. The tool uses six criteria to assess a location susceptible to a landslide. These criteria are Bedrock Geology and Structural Features, Type of Natural Soil Cover & Thickness, Slope Range & Category, Hydrology & Drainage, Land use & Management, and Land form. Apart from above criteria, the tool make further observation on Landslide history and Potential instability features of the location. Finally, the tool come up with a final score according to the following table 3;

Table 3. Landslide Susceptibility Criteria and Hazard Range

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Hazard Range</th>
<th>Hazard Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total score &lt;40</td>
<td>1</td>
<td>Landslide Not Likely to occur (LR)</td>
</tr>
<tr>
<td>40 &lt; Total score &lt; 55</td>
<td>2</td>
<td>Modest level of landslide hazard exists (MR)</td>
</tr>
<tr>
<td>55 &lt; Total score &lt; 70</td>
<td>3</td>
<td>Landslides are to be expected (HR)</td>
</tr>
<tr>
<td>Total score &gt;70</td>
<td>4</td>
<td>Landslides most likely to occur (HR)</td>
</tr>
</tbody>
</table>

4.2 Building Structural Assessment Tool (BSAT)

A tool comprising of key components required for a building to be structurally stable was developed to assess structural stability of a building. The hazard resilient house construction manual which was developed by NBRO was used to develop this tool. The tools provides structural stability rating and a final score for the assessment as shown in the Table 4.

Table 4. Building Structural Assessment Criteria

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Score &lt; 30%</td>
<td>structurally stable and safe</td>
</tr>
<tr>
<td>30% &lt; Total score &lt; 40%</td>
<td>structurally Stable</td>
</tr>
</tbody>
</table>
4.3 Social Vulnerability Assessment Tool (SVAT)

The social vulnerability assessment tool developed by the (Katic, 2017) in UNDP for Disaster Risk Reduction and climate change programming, was selected to assess the social vulnerability of families. The tool uses five variables to determine the social vulnerability of a family or a community. The variables are age variable, gender variable, education variable, income variable and disable variable. All these vulnerability variables were mathematically calculated and finally Comparable Social Vulnerability Profile (CSVP) was developed for each family.

Table 5. CSVP Assessment Table

<table>
<thead>
<tr>
<th>CSV Profile</th>
<th>A(v)</th>
<th>G(v)</th>
<th>E(v)</th>
<th>I(v)</th>
<th>D(v)</th>
<th>Result</th>
<th>CSVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family 1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Family 2</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-1</td>
<td>4</td>
</tr>
<tr>
<td>Family 3</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-2</td>
<td>3</td>
</tr>
<tr>
<td>Family 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-3</td>
<td>2</td>
</tr>
<tr>
<td>Family 5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-4</td>
<td>1</td>
</tr>
<tr>
<td>Family 6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-5</td>
<td>0</td>
</tr>
</tbody>
</table>

According to the above CSVP table, a family having higher vulnerability categories such as 4 or 5, is therefore recognized as more vulnerable (as opposed to the family with 1 or 2 higher vulnerability categories in its favor is recognized as less vulnerable).

4.4 Damage Assessment Tool (DAT)

Damage assessment tool was developed to assess any unbearable condition of a house located in a landslide risk area. The tools assess the damage of the main components of a house such as foundation, walls and roof. Finally, the tools come up with a score which represents the current damage level of a house.

Table 6. Damage Assessment Criteria

<table>
<thead>
<tr>
<th>Structure</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most bearing components are intact, the specific unbearable component is destroyed slightly, repairing can go on and use</td>
<td>Total Score &lt; 30%</td>
</tr>
<tr>
<td>The specific bearing component presents and can see the crack, the Unbearable component has obvious cracks, do not need or repair and can continue using a little</td>
<td>30 % &lt; Total score &lt; 40%</td>
</tr>
<tr>
<td>Most bearing components appear in the slight crack, there are obvious cracks partly, the specific unbearable component is destroyed seriously, need general repair</td>
<td>40% &lt; Total score &lt; 50%</td>
</tr>
<tr>
<td>Most bearing components are destroyed seriously, or there is part that collapses, need overhauling, the specific house repairs the difficulty</td>
<td>50% &lt; Total score &lt; 60%</td>
</tr>
</tbody>
</table>
Finally, the results of above four tools is combined to set up the final methodology for identify the overall risk of the location and decide on risk reduction option to be adopted. The final score will be calculated using teach value of assessment tools and criteria weights (See Table 7).

Table 7. Final Weightages of the Assessment Tools

<table>
<thead>
<tr>
<th>#</th>
<th>Criteria</th>
<th>Score Level</th>
<th>Weights</th>
<th>Weighted Score Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landslide susceptibility of the location</td>
<td>xx</td>
<td>0.6</td>
<td>xx</td>
</tr>
<tr>
<td>2</td>
<td>Structural stability of the considered houses</td>
<td>xx</td>
<td>0.25</td>
<td>xx</td>
</tr>
<tr>
<td>3</td>
<td>Percentage damage of the considered house</td>
<td>xx</td>
<td>0.1</td>
<td>xx</td>
</tr>
<tr>
<td>4</td>
<td>Social vulnerability of the families living in the considered houses</td>
<td>xx</td>
<td>0.05</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td><strong>Final Score Level</strong></td>
<td></td>
<td></td>
<td><strong>xx</strong></td>
</tr>
</tbody>
</table>

The landslide risk reduction options such as resettlement, mitigation and adoption will mainly be decided on results of landslide susceptibility assessment tool. The options will be selected as mentioned in Table 8;

Table 8. Risk Reduction Option Selection Condition Table

<table>
<thead>
<tr>
<th>Condition 01</th>
</tr>
</thead>
<tbody>
<tr>
<td>If, Landslide susceptibility score is 55&gt; with medium or high potential instability features are present – resettlement option will be selected</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditions 02</th>
</tr>
</thead>
</table>
| If, Landslide susceptibility score is 55< and no or low potential instability features are present  
And “Hydrology & drainage” and “Land use and management” contribute higher portion to the final score compared to the other criteria – the risk reduction option will be mitigation or adoption base on the further investigation. |

Final risk value of assessments will be used to prioritize families selected for risk reduction option.

5. Results and Discussion

As mentioned in the research methodology section, 10 field assessments were conducted to verify the practical application of the methodology.

Landslide Susceptibility scores of the field assessments are presented in Table 9 and 10.
### Table 9. Landslide Susceptibility Final Score

<table>
<thead>
<tr>
<th>No</th>
<th>Factor</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Bedrock Geology &amp; Structural Features</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>02</td>
<td>Type of Natural Soil Cover &amp; Thickness</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>03</td>
<td>Slope Range &amp; Category</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>04</td>
<td>Hydrology &amp; Drainage</td>
<td>17</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>05</td>
<td>Land use &amp; Management</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>06</td>
<td>Land form</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>Sub Total Score</strong></td>
<td><strong>62</strong></td>
<td><strong>60</strong></td>
<td><strong>60</strong></td>
<td><strong>72</strong></td>
<td><strong>72</strong></td>
</tr>
<tr>
<td>07</td>
<td>Instability features</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td><strong>Total Score</strong></td>
<td><strong>186</strong></td>
<td><strong>90</strong></td>
<td><strong>90</strong></td>
<td><strong>144</strong></td>
<td><strong>144</strong></td>
</tr>
</tbody>
</table>

### Table 10. Landslide Susceptibility Criteria Score

<table>
<thead>
<tr>
<th>No</th>
<th>Factor</th>
<th>Case 6</th>
<th>Case 7</th>
<th>Case 8</th>
<th>Case 9</th>
<th>Case 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Bedrock Geology &amp; Structural Features</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>02</td>
<td>Type of Natural Soil Cover &amp; Thickness</td>
<td>8</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>03</td>
<td>Slope Range &amp; Category</td>
<td>25</td>
<td>16</td>
<td>25</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>04</td>
<td>Hydrology &amp; Drainage</td>
<td>16</td>
<td>16</td>
<td>14</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>05</td>
<td>Land use &amp; Management</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>06</td>
<td>Land form</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>Sub Total Score</strong></td>
<td><strong>72</strong></td>
<td><strong>58</strong></td>
<td><strong>68</strong></td>
<td><strong>57</strong></td>
<td><strong>70</strong></td>
</tr>
<tr>
<td>07</td>
<td>Instability features</td>
<td>2</td>
<td>1.5</td>
<td>2</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>Total Score</strong></td>
<td><strong>144</strong></td>
<td><strong>87</strong></td>
<td><strong>136</strong></td>
<td><strong>85.5</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>

### Table 11. Scoring of potential instability features.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Availability</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Landslide Scars</td>
<td>None</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Recent Landslides</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground Subsidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension cracks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground heaving</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rocks or movement of boulders, small isolated failures or collapses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaning/tilting of trees telephone/electricity poles, retaining walls or fences</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken water lines and other underground utilities, Offset fence lines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilting or cracking of concrete floors/walls and foundations. Soil moving away from foundations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Springs, seeps, or saturated ground in areas that have not typically been wet before. Sudden oozing of new springs and sudden dry out of existing springs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sudden decrease in water levels in creek (small stream)/tanks or any other water bodies

If one of the above are present with level of low, multiplication factor is 1.5. If few of the above are present with low, multiplication factor is 1.5 to 2.
If any of the above is present with a level of Medium or above, multiplication factor is 2.
If two or more of the above are present with a level of Medium or above, multiplication factor is 3.

Overall score of the assessment is presented in Table 12.

<table>
<thead>
<tr>
<th>Table 12. Final Score of the All Assessment Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>LSAT</td>
</tr>
<tr>
<td>BSAT</td>
</tr>
<tr>
<td>SVAT</td>
</tr>
<tr>
<td>DAT</td>
</tr>
<tr>
<td>Final Score</td>
</tr>
</tbody>
</table>

5.1 Example 01 – Location identified through the SPI (Case 01)

According to the above assessment table overall final score of the assessment of Case 1 is 135 (after calculation with the given weights). Landslide susceptibility sub score is 62, and due to present of potential instability features are high, instability score is 3. Then the final score of the landslide susceptibility assessment is 186. In susceptibility hazard range the score is in 4th category, which means “Landslides most likely to occur”. With this situation, although the variable factors such as “Hydrology & Drainage” and “Land use & Management” contributed higher portion to final score, improvement to the variable will not be effect to the final score or in other work improvement of above two factors won’t reduce the landslide susceptibility of the location.
When considering the results of other assessment tools, the house is completely structurally unstable, several cracks have appeared in the most bearing components of the house, and social vulnerability of the family is in the medium high category. With this analysis, condition 01 will be applied. Risk reduction option is to resettle the house.

5.2 Example 02 Location identified through the SPI (Case 07)

The landslide susceptibility score of the Case 7 is more than 87. However, present of instability features are low. Again “Hydrology & Drainage” and “Land use & Management” criteria has contributed higher portion to the final score. Therefore, with the above conditions, there is a possibility to reduce the landslide susceptibility through mitigating options. According to the physical observations also mitigation of site will protect the high risk and thereby condition 02 will be applied. The risk reduction option will be mitigation.
5.3 Example 03 Location identified through the Landslide Hazard Maps (Case 08)

The case 08 house is located in a medium hazard zone category of the landslide hazard zonation map. The landslide susceptibility score of the house is 136 and it is due to the availability of high and medium instability features. The house is structurally stable and no major damages on the bearing components. Social vulnerability of the family is also in the low category. However, since landslide susceptibility score is 50> and medium or high potential instability features are present (Condition 01 will be applied), the risk reduction option will be resettlement.

5.4 Example 04 Location identified through the Landslide Hazard Maps (Case 10)

The location is marked as high hazard zone in the landslide hazard map. Landslide susceptibility score is 70. However, no landslide potential features or instability features are present. Slope range category, land use management, and hydrology & drainage factors contributed higher portion to the landslide susceptibility assessment. The house is structurally stable and no recorded damage or social vulnerability. According to the analysis, the condition 02 will be applied to the case. Hence, the risk reduction option will be mitigation or adaptation.

6. Conclusions

Adaption, mitigation and resettlement are the main identified disaster risk reduction option. Risk reduction option should be selected through a systematic approach. This study developed an approach to select most appropriate risk reduction option for a house with a landslide risk. The methodology comprises four technical assessments such as landslide susceptibility, structural stability, damage to the house and social vulnerability of the family who lives in the house. Finally, the risk reduction option was selected based on the results of above assessments and developed conditions.

The developed methodology was tested in the field and required adjustments were made accordingly. Few case studies were successfully done to validate the conceptual model.

References

An Assessment on Residential Units Expose to Landslide Hazard in Nuwara Eliya District, Sri Lanka

LJ Prasanna¹
¹Scientist, National Building Research Organisation, Sri Lanka

Abstract

Landslides are one of the major natural disasters that occur in Sri Lanka resulting in loss of lives and severe damages to livelihood and property. Heavy loss of life as well as the unprecedented damage to property and infrastructure caused by the landslides in 1980s prompted the Government of Sri Lanka to initiate appropriate measures for the reduction of the impact of landslides. Landslide Hazard Mapping Project (LHMP) was launched to forecast potential landslide prone areas in order to protect people and their properties and to initiate evacuation of people in short-term and long-term basis.

The main objective of this mapping exercise is to identify areas vulnerable to landslide hazard. As the next step of the LHMP, spatial distribution of buildings expose to landslide hazard are being identified through 1:10,000 scale landslide hazard zonation maps developed for the Grama Niladari Divisions in Sri Lanka. Data collection on buildings expose to landslide hazard was carried out on residential units, commercial/institutions, religious places and schools. The empirical evidence revealed pertinent issues; construction of houses without professional support (69.27%); construction of houses with load bearing walls (81.5%); construction of houses without obtained approval from relevant authorities (84.43%); construction of houses without obtaining landslide risk assessment report (98%); construction of houses on steep slope (>31°) terrain (44.3%); change of land morphology for construction of houses (51.5%); and having no drainage system to discharge rain water (30.5%). This paper presents set of implications to address these prevailing challenges found from the assessment in residential units expose to landslide hazard in Nuwara Eliya District.

Keywords: Landslide; residential units; challenges

1. Introduction

Occurrence of devastating landslides has become more frequent in Sri Lanka attracting more and more attention due to its increasing effect on human and economic loss. Many of the natural hill slopes that are considered as safe in the past are now recording landslides due to human interventions (Disaster Management Centre, 2012). Of the 65,000 Sq.km of land extent of Sri Lanka, nearly 20,000 Sq km
encompassing 10 districts are prone to landslides. It is about 30% of Sri Lanka's land area and spread into districts; Badulla, Nuwara Eliya, Kegalle, Ratnapura, Kandy, Matale, Kaluthara, Mathara, Galle and Hambantota. Highest impacts to the landslides have been reported in Badulla, Nuwara Eliya, Kandy and Rathnapura Districts. Nuwara Eliya district is one of the most landslide prone district in Sri Lanka. All the Divisional Secretariat Divisions in Nuwara Eliya District is vulnerable for landslide hazard (Bandara, 2005).

National Building Research Organisation (NBRO) is the national focal point for landslide risk management. NBRO is carrying out landslide hazard mapping project covering 10 landslide prone districts in Sri Lanka to identify areas susceptible to landslide hazard. As the next step, Landslide Risk Profile Development Project is implemented with the objective of develop a spatial database of the communities expose to landslide hazard. Spatial distribution of buildings expose to landslide hazard are identified using 1: 10,000 scale landslide hazards maps prepared for the Grama Niladari Divisions. Data collection was conducted on housing units, commercial/institutions, religious places and schools, which are located within very high and high landslide hazard prone areas of the Nuwara Eliya District. Purpose of this survey is to collect information on characteristics of the inhabitants, characteristics and use of the buildings etc. Within this context, the scope of this paper is to explore the challenges that contribute to protect against landslide hazard and reducing landslide disaster risks in residential units expose to landslide hazard in Nuwara Eliya District.

2. Assessment of Buildings at Risk

Risk assessment is an essential component in disaster risk management. The purpose of a risk assessment is to define the nature of the risk, answer questions about characteristics of potential hazards (such as frequency, severity), and identify vulnerabilities of communities and potential exposure to given hazard events. Risk assessment includes the process of risk analysis and risk evaluation. Risk analysis generally contains; analyze the risk, identify and measure the frequency, magnitude, and type of hazard and the vulnerability and exposure of the elements at risk (Asian Disaster Preparedness Center; 2006). Buildings are one of the main groups of elements at risk for hazardous event. It comprises the inhabitants and the properties accommodate in the buildings. Behaviour of a building under a hazard event, determines whether the inhabitants in the building might be injured or killed by the occurrence of hazardous phenomena. Defining the characteristics of the building is important in order to assess the potential losses and degree of damage of buildings that are exposed to a certain type of hazard.

Elements at risk are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. The interaction of elements at risk and hazard defines the exposure and the vulnerability of the elements-at-risk. Although elements at risk information may be derived from existing data sources such as census data, there is always a need to collect additional information to characterize the elements at risk for estimating the vulnerability. For collecting information on building types, construction materials, land ownership, and the checking of urban land use, normally stratified samples are taken, as it is often too time consuming to do a complete house-by-house survey (Westen. et.al, 2011). The procedure adopted to obtain the elements at risk varies for local and regional scale.
analysis. Identifying the elements at risk of landslide and vulnerability assessment need the exact spatial distribution of buildings in the study area, as well as the socio-economic information like the number of stories, possession of properties, economic values etc. All of the data considered as elements at risk are basically extracted from cadastral data and participatory GIS procedures (Gaprindashvili et al., 2014). Building information can be obtained in several ways. Ideally, it is available as building footprint maps, also be derived from databases. If such data are not available, building footprint maps can be generated using screen digitisation from high-resolution images, or through automated building mapping using high-resolution multispectral satellite images and LiDAR (Corominas, 2013). Literature review was carried out on methods employed in earlier studies to assess the characteristics of the buildings and socio-economic status of the inhabitants reside in buildings expose to hazards. From the above literatures methods employed to acquire socio-economic information of both the buildings and inhabitants accommodate in risk buildings are; 1) stratified samples 2) house-by-house survey 3) participatory GIS procedures 4) building footprint maps. After reviewing those methods, this study applied house-by-house questionnaire survey method for data collection because of (1) limitations in GIS-based approaches in relation to availability, quality, and scale of the digital data (2) non-availability of spatial reference in available census data (3) advantage of using house-by-house questionnaire survey for accurate data collection directly from the occupants.

3. Study Area and Method of Study

This study was carried out in Nuwara Eliya District, Sri Lanka. Nuwara Eliya District is located at an altitude of about 2000 meters above sea level of the Central highlands in the Central Province. Due to its highland location, Nuwara Eliya has a subtropical highland climate having no pronounced dry season with a mean annual temperature of 16 °C (61 °F). Nuwara Eliya town, the capital of Nuwara Eliya district is located 150 Kilometers away from Colombo. Landslide hazard maps available for 223 GN divisions in 3 Divisional Secretariat Divisions of Nuwara Eliya, Hanguranketha, and Walapane. Study was carried out in 16,235 housing units locate in 223 GN divisions of 3 DS Divisions in the District.

This study adopted house-by-house questionnaire survey as a method of data collection. Although house-by-house survey method is very time consuming and expensive, house-by-house survey was carried out in order to ensure the accuracy of data collection. Questionnaire survey is good instrument when all desired information of the researchers is received in the form of data. This study utilized primary data collected through questionnaire survey among the buildings that are located in landslide hazard zones; (1) landslides are most likely to occur, (2) landslides are to be expected, (3) landslides have been occurred in past, and (4) subsidence & rock fall based on landslide hazard map. The survey questionnaire consisted of both open and closed questions. Open-ended questions provided space which allowed the researcher to fill in the response exactly as was given by the respondent. Closed-ended questions had pre-selected responses to the questions (Darkwa, 2006). The questionnaire is divided into seven main sections: (i) general information (ii) demographic profile of the households (iii) land use and of characteristics of housing units (iv) construction guidelines followed to build the house (v) disaster impacts (vi) disaster preparedness (vii) disaster risk reduction measures. Prior to field work, a pilot survey was conducted in the study area to identify the possible problems that may arise from the
questions during the field survey. After the pilot survey, the questionnaire was then modified and rearranged by incorporating the experience gathered. The questionnaire survey has been conducted by the Grama Niladari (GN), of the respective GN Division. A guide book was designed and distributed among the survey enumerators and GNs were provided with a special training for conducting the survey.

The collected quantitative data were checked and then entered into the spread sheet in the Statistical Package for Social Science (SPSS), the same statistical software has been used to present descriptive statistics including percentage, mean, and frequency from the collected data.

Sri Lanka’s Census of Population and Housing-2012 revealed, total of 178,440 housing units locate among 5 Divisional Secretariat Divisions of Nuwara Eliya District (Department of Census and Statistics, 2012). Approximate 16,235 housing units locate in very high and high landslide hazard prone areas of 3 Divisional Secretariat Divisions contributed to the survey. The minimum number of housing units surveyed is 1418 housing unit from Nuwara Eliya Divisional Secretariat Division. While maximum number of housing units surveyed is 9504 from Walapane Divisional Secretariat Division (Source: Survey data).

Fig. 1. Map of Sri Lanka showing Nuwara Eliya District (Source: taooftea.com)

4. Findings and Discussion

4.1 Year of construction and professional support to build the house

According to the housing units surveyed, 111 housing units have been constructed between 1626 and 1900, and 8,776 housing units have been constructed between 1901 and 1999. Same time, 3,713 housing units have been constructed between 2000 and 2010. Meantime, 1,911 housing units have been constructed between 2011 and 2017.

Professional support is vital in identification of appropriate designs and incorporating disaster resilient features in housing construction. Of those housing units surveyed, majority (69.27%) of the housing units are not built with the support obtained from professionals such as engineers and architects. Only 12.6% has employed professional services in building the house.

4.2 Designer of the house

A well designed and built house is a house that supports the lifestyle of the dweller and a well-constructed house protects the lives of the occupants. Use of hazard resilient engineering design and construction practices are essential when constructing houses in disaster prone areas. The result implies, majority (44.7%) of the houses have been designed by the house owners themselves. While 17.3% of houses have been designed by masons. Only 11.4% of houses have been designed by Architect/Draftsman.
4.3 Approval for construction

Prior to construction, it is essential that the house plan should be submitted to the local authority, whom shall confirm to the planning and building regulations and grant approval. However, only 15.57% of houses have been constructed with the approval obtained from local authority/NBRO/other agencies. While, over three-fourths (84.43%) of houses have been constructed without obtaining approval from relevant authorities.

Issuance of landslide clearance for construction in landslide prone areas could be identified as a good practice in building a disaster resilient built environment. In 2011, the Ministry of Disaster Management in Sri Lanka issued circular with regard to National Building Research Organisation’s clearance for building construction in landslide prone areas. As per the circular, obtaining clearance for construction in ten landslide prone district, viz., Badulla, Galle, Hambantota, Kalutara, Kandy, Kegalle, Matale, Matara, Nuwara Eliya and Ratnapura is a mandatory requirement. However, it was found out of 1895 houses constructed between 2011 and 2017, only 37 houses have obtained approval from National Building Research Organization (NBRO).

4.4 Type of wall

Generally, buildings are constructed either with a load-bearing wall or columns structure wall. In landslide prone areas it is recommended that the house should be constructed as a reinforced concrete frame structure with masonry walls between columns. However, 81.5% of housing units have been constructed with load bearing walls. While only 18.4% of housing units have been constructed as columns structure walls. This shows, that a majority of the housing units have little resistance to being destroyed/damaged by the impact of landslide hazard.

4.5 Type of the terrain and change of land morphology

Type of terrain and slope angle are the two important factors governing the suitability of land for housing. For the purpose of assessment of landslide potential, the type of terrain is classified as; steep slope, rolling terrain, gentle slope and flat. Of these categories of type of terrain, about 44.3% of the houses are located on steep slope (>31°) terrain, 32.1% of housing units locate within the gentle slope (5°-11°) terrain, while 19.3% of the houses are located on rolling terrain. At the same time, minor share (4.23%) of houses are located on flat terrain.

Of those housing units surveyed, inhabitants in 51.5% of the houses stated that the land morphology was changed for construction of the house. While, land morphology of the 39.2% of the houses were not changed for construction and 9.20% of the respondents in the housing units don’t know whether the land morphology was changed for the construction of house.

4.6 Presence of warning signs of landslides in the vicinity of the house

The location that is been selected for the house construction is recognized to be free from any landslide risks or free of any signs or features that are indicative of landslide threats or slope instability. According to the survey, landslide signs can be
observed in 34.3% of housing units. Cracks on buildings appear in 9.8% of housing units and record of early subsidence/landslide/rock falls can be observed in 0.7% of housing units. At the same time, in 13.6% of housing units, more than one tell-tale landslide signs can be observed in the vicinity of the house.

4.7 Actions taken to discharge water

Most of the landslides in Sri Lanka have occurred when heavy storms and prolonged rainfall have been experienced. There will be a reduction in the strength of soil as a result of surface erosion of the soil on a slope due to heavy storms and prolonged rainfall. Therefore, it is extremely important to manage both surface and subsurface drainage of a slope. It must be ensured that natural drainage, stability and environment of the land and surrounding area are not adversely affected during and after construction. Of those housing units surveyed, 30.5% of housing units have no drainage system available. While only 23.8% of housing units have systematic drainage system and 45.7% of housing units have a drainage system, but not sufficient.

5. Conclusion

Findings of the risk assessment in residential units located in landslide prone areas of Nuwara Eliya District reveals number of challenges contribute to protect against landslide hazard and reducing landslide disaster risks. The main challenges that have emerged are discussed in this paper while highlighting the ways of overcoming the identified challenges. The main challenges emerged and suggestions to overcome the challenges are;

Table 1. Suggestions to overcome issues to make resilient built environment against landslide hazard

<table>
<thead>
<tr>
<th>No</th>
<th>Challenges</th>
<th>Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Nearly half share of houses are located on steep slope (&gt;31°) terrain.</td>
<td>Formulate and practice risk-based land use plans with adequate coordination between sector-specific agencies engaged with land management.</td>
</tr>
<tr>
<td>02</td>
<td>Majority of housing units a drainage system, but not sufficient.</td>
<td>Execute a well-planned surface water drainage plans with the application of community knowledge and site specific technical investigations.</td>
</tr>
<tr>
<td>03</td>
<td>Majority of the houses not obtain clearance for construction in landslide prone areas.</td>
<td>Build local citizen awareness on obtaining approvals for erection of buildings and the need of incorporating disaster resilience in planning, designing and construction.</td>
</tr>
<tr>
<td>04</td>
<td>Over three-fourths of houses constructed without obtained approval from relevant authorities.</td>
<td>Formulate procedures to monitor all the existing developments at specified intervals to ensure construction is in accordance with approved plans.</td>
</tr>
<tr>
<td>05</td>
<td>Nearly half share of the houses is constructed after changing land morphology.</td>
<td>Organise educational and training programmes for practitioners and laymen on construction compliance with</td>
</tr>
<tr>
<td>06</td>
<td>Only minor share of housing units built with the support of professionals.</td>
<td>Share know-how through public campaigns and demonstrations on hazard resilient engineering design and construction practices when building houses.</td>
</tr>
<tr>
<td>07</td>
<td>Over one fourth of housing units have presence of warning signs of landslides.</td>
<td>Enhance capacity of the residents to decide what needs to be done in order to prevent and protect themselves from landslides.</td>
</tr>
</tbody>
</table>

References

Sensitizing Children for Risks and Hazards in and around the Home

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Abstract

The mortality rate of children in Sri Lanka regarding unintentional injuries is high and the total number, including non-lethal injuries, is a shady figure. To reduce these numbers and work against this socio-economic problem of child mortality, children themselves need to be addressed in an age appropriate method to raise awareness. Model for such a manual can be the educational materials developed and published by the World Health Organisation (WHO) in cooperation with the United Nations International Children’s Emergency Fund (UNICEF) and one by the European Union (EU). Nevertheless, these materials need alterations regarding the missing topics such as the dealing with social media and the adaption to Sri Lankan living conditions. To guarantee an improvement, the explaining of risks and how to prevent them as well as the introduction into self-protection needs to be an elementary part of school education.

Keywords: Children; Injury; Risks; Prevention; Awareness; Safety

1. Introduction

National Building Research Organisation (NBRO) has developed a Home Safety Manual to inform and educate the public about risks and hazards that can be found inside and around the home. Accidents happen in everyday life and the manual is a guide for adults to establish a safer environment for all members of the household. But accidents and unintentional injuries can happen to anyone and therefore it is important to educate children and build awareness on risks and hazards, and on self-protection, too.

Table 1 is an extract of the statistic “Number of deaths according to cause by age and sex – 2013” published by the Department Of Census And Statistics – Sri Lanka. The original statistic shows the total reported number of deaths in Sri Lanka, according to causes like infectious diseases, mental disorders, external causes of morbidity and mortality and many others, the differentiation of the sex and the different age groups ranging from newborns to 85 years of age and above. This paper specializes on sensitizing children for risks and hazards in and around the home, and focuses therefore only on unintentional injuries that led to death which are listed under ‘external causes of morbidity and mortality’ and regards the age groups from newborn
up to age 19. For the purpose of generalizing the topic regardless of the sex, the male and female deaths were added together. All deaths calculated as displayed in Table 1 (Total <19), there were 462 children, from birth up to the age of 19, that died of external causes. These external causes, which are declared in this paper as unintentional injuries are: transport accidents, falls, accidental drowning and submersion, exposure to smoke, fire and flames and accidental poisoning by noxious substances. If it is put into account that children younger than age 4 cannot themselves prevent injuries and that children or young adults of age 15-19 have a different perception closer related to those of adults, the target group for a child-friendly safety manual are children age 5 to 14. Are the number of deaths of children age 5-9 and 10-14 combined, the total number of children that died is 135. This total of 135 made it one fatal, unintentional injury more often than every third day in 2013. (Department of Census and Statistics, 2014)

Table 1  Extract of ‘Number of deaths according to cause by age and sex 2013 - External causes of morbidity and mortality’ on unintentional injuries (Department of Census and Statistics, 2014)

<table>
<thead>
<tr>
<th>Unintentional Injuries</th>
<th>&lt; 1 year</th>
<th>Age 1-4</th>
<th>Age 5-9</th>
<th>Age 10-14</th>
<th>Age 15-19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport accidents</td>
<td>8</td>
<td>24</td>
<td>20</td>
<td>26</td>
<td>105</td>
</tr>
<tr>
<td>Falls</td>
<td>2</td>
<td>14</td>
<td>14</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Accidental drowning and submersion</td>
<td>4</td>
<td>36</td>
<td>29</td>
<td>33</td>
<td>108</td>
</tr>
<tr>
<td>Exposure to smoke, fire, and flames</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Accidental poisoning by and exposure to noxious substances</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total for each age group</td>
<td>15</td>
<td>82</td>
<td>69</td>
<td>66</td>
<td>230</td>
</tr>
<tr>
<td>Total age 5-14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>135</td>
</tr>
<tr>
<td>Total &lt;19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>462</td>
</tr>
</tbody>
</table>

Putting into account that this statistic only reports the injuries that led to death, it is to be estimated that the number of non-lethal, but bodily-harmful injuries is much greater. It is hard to predict a specific number, because minor injuries can be treated at home and are therefore uncountable compared to those reported in hospitals. This concept can be displayed by the child-injury pyramid (Figure 1), showing that death is not the only outcome and nor the most common. (Margie Peden et al., 2008, p. 5) To reduce injuries and especially deaths due to unintentional injuries, children need to be educated more and sensitized for risks and hazards in and around the home. The highest cause of accident in all age groups is accidental drowning and submersion, indicating that there is an urgent need for education.
2. Objectives

- To reduce deaths of children, caused by unintentional injuries.
- To reduce bodily harm to children.
- To raise children’s awareness on risks and hazards at and around the home.
- To educate children on self-protection.
- Create information material that can be implemented into school education.

3. Literature Review

Projects like this have been conducted and leaflets have been designed around the globe. The WHO and UNICEF published a child-friendly report in 2008, targeting children from age 7 - 11. The document, called ‘Have Fun, Be Safe!’ uses a playful approach to teach children about different injuries and preventive measures by including games, puzzles and colorful illustrations. (UNICEF and WHO, 2006)

A similar project funded by the EU is called ‘Raising young people’s awareness on preparedness and self-protection’ (YAPS). This educational material was published in 2017 aiming to decrease unintentional injuries of children age 7 – 12. The topics presented are different natural hazards but also household risks and a safe way to school. Participants are the German Federal Office of Civil Protection and Disaster Assistance (BBK), the Austrian Red Cross (ARC), the Romanian General Inspectorate for Emergency Situations (IGSU), and the Babes-Bolyai University of Cluj (BBU), Romania. The education methods are online games, storybooks, worksheets as well as guidance material for teachers and trainers. (German Federal Office of Civil Protection and Disaster Assistance et al., 2017)

4. Discussion

Materials of both projects can be used for educational purpose but problems can arise since they are not geared to the living conditions of children living in Sri Lanka and the language might also be a barrier. The publication by the WHO and UNICEF is designed for children all around the globe and is therefore worded in general terms. Considering all special cases and getting into detail about certain living conditions,
goes beyond the constraints of their informational material. Whereas the WHO material is too general, the YAPS project gets into detail, but focuses on children living in Eastern and Central European countries and might not be representative to the standards in Sri Lanka.

These projects focus on bodily-harm but neglect the psychological aspects which are not to be underestimated due to the modern internet age with social media platforms and peer pressure. Children have access to the internet at a young age and they are vulnerable target groups. From an early age they need to be advised on how to interact with others over social media platforms, how to react in certain situations and how to deal with sensible, personal information.

However, there are also variations in living situations in Sri Lanka itself, regarding urban and rural areas but also differences between the various provinces. For example, is the Western Province more socio-economically developed than other provinces in the country. Therefore it is necessary to carry out various random studies in all provinces of Sri Lanka, not only in urban but also in rural areas in order to generalize the findings and conclusions. If the results of the studies show great discrepancies between the provinces or urban and rural areas, it might even be necessary not only to develop one manual for all children, but to create different versions to meet all needs.

Structure and layout can be arranged to the creator’s preference that suits children best, but certain topics need to be addressed beyond all question. A possible outline of such a child-friendly manual is displayed in Figure 2.

1. **Emergency**
   a. Emergency numbers: Police, Fire Service, Ambulance, Children’s Helpline
   b. What to do in case of Emergency?
   c. What to do in case of Fire?

2. **Risks at Home**
   a. Danger of Falling
   b. Danger of Sharp Objects
   c. Danger of Electricity
   d. Danger of Poisoning
   e. Danger of Fire

3. **Risks outside the Home**
   a. Playground Safety
   b. Way to School
   c. Streets and Traffic
   d. Thunderstorms
   e. Dangers of Water

4. **Social Media**
   a. Safe Handling of Personal Information
   b. Bullying
   c. Peer Pressure

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**Figure 2 Possible Outline for a child-friendly Safety Manual**
5. Conclusion

To give children in Sri Lanka the best educational material on risk and injury prevention and thereby working against this socio-economic problem, a new manual needs to be developed. Specialising on the typical living standards in Sri Lanka and including modern topics will raise children’s awareness towards risks as well as strengthen their perception of actions and the following consequences.

In order to make it easily understandable but still informative, specialists regarding the mindset of children as well as specialist in the area of risk reduction have to work closely together. Ideas from the EU and WHO projects can be implemented in the Sri Lankan version, using games and puzzle to playfully teach children and support messages through colourful illustrations.

For the best possible outcome this guideline needs to be implemented in school practices and should be presented once every year to sensitize children on these topics and to reduce the number of unintentional injuries, especially those leading to death.

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References


Community Building through Capacity Building: An Intervention on Yan Oya Resettlement Project

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Abstract

Resettlement is a population transferring process implemented as a response to the displacement of people due to natural disasters, civil wars, ethnic or religious conflicts as well as owing to strategic development projects initiated by the state in line with broader national interests. In most of such resettlement projects, state and institutional actors tend to frame their strategies – and subsequent solutions – on a quantitative platform, prioritizing the numbers to be resettled as opposed to the qualities of life they ought to be provided, or ranking the speed and economy of the relocation process over the need of building communal relations, infrastructures, and capacities.

In other words, resettlement of people must not be treated as a mere task of distributing money and land among those displaced hoping, that the owner-builders would eventually construct their physical and cultural infrastructure at their own aptitudes, desires, and capacities. Especially in those communities with little or no access to well-cultivated resources, skills, and strategies of building planning and production, the displaced must be inhabited with a system of knowledge and techniques, which they could then use to build better housing and social infrastructure, establish livable settlements, and seek stronger communal relations. The end objective should be to build a community, not a dispersal of spatial volumes; to build people’s lives, not a conglomeration of sub-standard housing units.

By evaluating the Yan Oya Reservoir resettlement project, this study argues that a holistic approach to people resettlement must call for a greater input at planning level, not only in the laying out of spatial and communal volumes, but also in the planning of technical strategies for the eventual construction tasks, in the outlining of capacity building tactics on how to transfer technical knowledge to the owner-builders, and in delineating strategic policies on how to use the local industrial networks, capacities, and resources for the successful implementation of a resilient human settlement.

Keywords: Resettlement, resilience, community building, capacity building, industrial planning, strategic resourcing
1. Introduction

Yan Oya Reservoir resettlement is one of the largest resettlement projects initiated in Sri Lanka in recent times. This targets the resettling of people and communities who are displaced due to the Yan Oya Reservoir project. Such resettlement projects are naturally complex and dynamic, in terms of both the management of the built environment as well as the well-being of the people subjected to displacement. Subsequently, a greater responsibility is imparted upon the design and construction professionals to understand and accommodate diverse – and constantly shifting - spatial and cultural needs of the displaced population, to tackle the physical challenges of the resettlement sites, and to strategies the technical responses for the eventual construction processes. More specifically, a greater application of design and construction planning is required at a very early stage of project implementation to make sure that the relevant tasks are led in a direction, which upholds various spatial, cultural, technical, economic, environmental and administrative interests and aspirations of all the stakeholders involved.

Unfortunately, there seems to be little or no such planning awareness and application in the implementation of the Yan Oya Resettlement Project, thereby moving in directions that have become increasingly detrimental to the establishment of a resilient human settlement. From the outset, the government’s strategy has been merely a quantitative one. They have sought to provide a land area of one acre for the people whose houses and cultivation lands have been acquired by the reservoir project, and a land area of half acre for those whose have only lost their cultivation lands. People were also assigned a monetary compensation to re-build their physical infrastructure, and this money has been given to the beneficiaries as a one-off payment, seemingly as a persuasive incentive for them to vacate the lands that they had occupied. The authorities had also identified four sites around the Yan Oya Reservoir project - namely Wahalkada, Malporuwa, Kajuwatta and Omarakada – subdivided these sites very rigidly to accommodate the required number of plots and households, and handed them over to the displaced population together with the afore-mentioned one-off payment.

However, there have been no attempt to plan the settlement as a communal hub, or to respond to the physical and ecological specificities of the individual sites. Other than subdividing the sites into required number of plots, the only professional intervention by the state and institutional actors has been to design two type buildings – a community hall and a pre-school structure – which have been randomly placed in some of the sites; the siting of these buildings has not been given the due consideration in terms of the orientation to environmental factors and relations to the physical and social fabric, nor they have been designed to perform well with respect to structural, spatial, and environmental expectations of a reasonably appropriate building.

Other than for these two sub-standard building structures – and a primary school built in one of the four sites - the authorities have not been involved in the planning, design or construction of any other village buildings including the housing units. More critically, they have also not initiated technology transfer and skill building programs or strategies to propose and implement technological alternatives, thereby leaving the people themselves to determine how and what they should build and live.

Due to this lack of intervention and assistance on the part of the authorities and the ad-hoc manner in which the planning of the settlements has been treated, there are serious failings of the new villages, both in terms of the physical infrastructure of the
places and the cultural life of their people. On the one hand, the cultural resilience and the technological sustainability of the resettled communities are at a threat, while, on the other hand, the new settlers are at a risk of adapting to their new locations. Perilously, almost all of them are struggling to complete the housing units they have started building for themselves, some running out of resources while others failing to access the required levels of technical skills and capacities. The result is settlements of utter chaos, communal wise as well as in terms of the technical performance of the physical fabric. On the contrary, it has been required to identify the actual needs of the sites, available resources, methods to improve these resources, and share the subsequent knowledge among the community, and use that knowledge to make a resilient and sustainable settlement.

2. Challenges of Housing Resettlement Programmes

In general, the re-settlement/re-construction projects are impacted by many social, technical and economic challenges. There are many literature that sheds light on this, in particular on post-disaster resettlement situations, especially those following large scale disasters. The post-disaster context is characterized by a lack of access, logistical issues, and inadequate human resources thereby making the supply of spatial and cultural needs a daunting task (Davidson et al., 2007; Ophiyandri et al., 2010). However, there are structural challenges common to any resettlement effort, including institutional bureaucracy, corruption, inadequate coordination, inexperience of construction management, and pressures from government and humanitarian agencies for quick project completion (Barenstein, 2006; Ophiyandri et al., 2010).

In terms of the implementation of housing resettlement programs, issues of community participation, communication, resettlement and the cultural appropriateness of recovery measures, etc. have also been recurring challenges; these continue to cause housing resettlement projects to fail with the supposed beneficiaries modifying or outrightly rejecting the housing provided or, in some cases, dismantling the houses and selling their components. All of these challenges must be adequately managed in order to have a successful resettlement programme (Delany & Shrader, 2000; Barakat, 2006).

In developing parts of the world, where there is little or no access to cultivated resources and adequate technical knowledge, greater emphasis must also be placed on the need for technology transfer and capacity building. Particularly where the resettlement projects rely on owner-builders to construct facilities for themselves, a successful and resilient settlement would only be possible if a capacity building program is built within the overall planning strategy.

3. Capacity Building

The above position suggests that, the ability to build labour skills, and the subsequent capacity to improve the quality of technical knowledge and application, must be recognized as an important step in planning resettlement projects in countries like Sri Lanka. Key to this process is the idea of ‘capacity-building’, that is the provision of assistance to workers (mostly self-builders, in this instance) to develop a certain skill or competence for general upgrading of performance ability.
According to UNDP, however, capacity-building is much more than labour training and includes the following:

“(1) human resource development, the process of equipping individuals with the understanding, skills and access to information, knowledge and training that enables them to perform effectively, (2) organizational development, the elaboration of management structures, processes and procedures, not only within organizations but also the management of relationships between the different organizations and sectors (public, private and community), and (3) institutional and legal framework development, making legal and regulatory changes to enable organizations, institutions and agencies at all levels and in all sectors to enhance their capacities” (citation: Urban Capacity Building Network).

Such broad-spectrum definitions require more scrutiny to distinguish an acceptable form of capacity-building to the developing world. For example, in the context of increasing informalization of the construction process, the usefulness of rigorous legal interventions through capacity-building could be highly questionable. On the other hand, the construction industries in developing economies rely predominantly on labour intensive work practices where most work gangs comprise of ‘independent’, self-employed craftsmen assisted by labourers, with a distinctive skill differences between the two.

Clarke and Wall (2000) use the term ‘craft form’ to distinguish the production mode commonly refers to as labour-intensive technology. Accordingly, the ‘craft form’ is based on ‘controlling labour output’ through social organization of production related to a particular ‘craft’ or use of a technology. The quantity of workers, range of skills, employment status, complexity of work processes, type of site management, and the tools, machinery and energy sources used, etc., therefore, become the determinants of the ‘craft form’ of technology. The form of production that focuses on the ‘quality of labour input’ through industry-organized skill definitions, training systems, and wage structures is called ‘industry form’.

Clarke and Wall (2000) claims that, in a broader sense, the building production in England is craft-based, and characterized by low mechanization and prefabrication, and a trade-specific knowledge dissemination that leads to skilled workers in their chosen field. In Germany and Netherlands, on the other hand, labour is employed by the industry and has an industry-specific knowledge, as opposed to the trade-specific knowledge of the ‘craft form’. Work in such conditions depicts higher levels of mechanization and prefabrication leading to greater speed and labour productivity, complex work processes with specialism and interfaces, broader skills, extensive training, and an industry-wide graded wage structure.

4. Capacity Building in the Context of Local Resettlement Projects

The industry form of organization mentioned above has complex social interfaces – mainly due to increased systemization, pre-fabrication and mechanization - that require being precise in their application, therefore proving to be inapt in low-skilled construction sites of developing countries. On the other hand, construction skills in developing economies are still mainly acquired through informal apprenticeship systems than formal training procedures. This structure of informal apprenticeship is based on a close relationship between the master craftsman and his helper – or the apprentice - who receives information while at work over a lengthy period of time.
However, the traditional apprentice training may fail to meet the requirements of present-day building demand for a variety of reasons. Firstly, the increasing tendency for labour-only subcontracting has defied the traditional loyalty structures between the master builder and his work gang, making it difficult to acquire skills informally; the workers now tend to be more loyal to the labour sub-contractor who finds them work and pays their wages. Secondly, the quality of training can be affected by the shrinking skills of the master craftsmen themselves. Thirdly, a big expansion in demand can strain the system by creating pressure to use apprentices for production, at the expense of training. Fourthly, the pressure for new and speedy building needs will require new technologies and skills that cannot be transferred through the traditional system.

These various idiosyncrasies in knowledge dissemination and labour training suggest that new approaches may be required to the process of capacity-building in developing countries. Critical in this line of thinking is to plan the technological environment taking into considerations local possibilities and limitations of Craft-versus Industry-based building production strategies. In a project like Yan Oya Resettlement, where the construction activities would be mostly carried out by owner-builders, the idea of capacity building must also reflect the need to build community capacity to find ‘local solutions to local problems’, while being technically proficient to maintain the settlement and support its incremental growth. Skills such as organizing and planning together, empowering themselves with appropriate technical knowledge, creating employment and economic opportunities for themselves, etc., become most useful in such social and technical context. (Atkinson, R., & Willis, P.,)

These capacities can even directly address the issues of social exclusion such as unemployment, low level of education, low incomes, welfare dependency, physical isolation, criminal activity and inadequate provision of services, etc. In fact, some researchers identify this type of capacity development as a kind of ‘Community Development’, and as an encouraging mechanism of the development of an active community. According to Atkinson and Willis (year) such a strategic approach can build the levels of trust, connectedness, resilience, enterprise, and the ability to join together in a common crisis; the modes of civic engagement, and local and political participation; the strength of local networks; the pride of place and self-worthiness of the community; and the presence and role of community leaders.

5. Issues and Challenges of Yan Oya Reservoir Resettlement Project

As mentioned above, resettlement projects are interventions and measures that respond to the provision of shelter to inhabitants who are victims of certain disasters or forced displacement. The main aim of such resettlement program is to restore the livelihoods of the displaced to be as close as possible to their former lives, if not providing them with better conditions.

Yan Oya, one of the major national-level irrigation projects currently being implemented in Sri Lanka, has caused a large number of families to be resettled following its implementation. Subsequently, the Irrigation Department has taken the initiative of resettling the displaced communities in the North Central and Eastern provinces of Sri Lanka. Accordingly, approximately 583 families are to be resettled in the four sites: Kajuwatte (210), Malporuwa (100), Omarankadawala (220) and Wahalkada (53) respectively. These sites have been already surveyed and sub divided accordingly. It was observed, however, that the subdivision and spatial planning
strategies utilized in the afore-mentioned four sites lack sustainable human settlement considerations, sensitivities to context-specific physical and environmental characteristics, and appropriation of community and social infrastructure. In addition, there were no participation of the community during the initial decision making processes, no strategy has been put in place to identify and establish an appropriate technological framework for the construction activities, and no attempt to pursue capacity-building initiatives to transfer knowledge and skills to the owner-binders.

As discussed above, the planning phase of the project must not only involve the planning and design experts but also the community who are inhabiting the settlement, so that all can collectively identify practical issues of the macro context and identify the areas where capacity needs to be developed. There has been a lack of such insight and input in the Yan Oya resettlement project, thereby demonstrating a clear gap between the practical and intellectual aspects of the entire procedure. Subsequently, not only the sub-division layouts are poor, but there is also no physical, social, or functional relationship between the four resettlement sites, leaving them to function separately as isolated villages. In addition, inadequate access to knowledge, infrastructure, and provision of resources have caused irregularities in the construction process and impacted on the quality of the final building units. Shoddy approaches to construction has in particular increased the vulnerability of the new settlements to withstand future disasters.

According to the literature, encouraging the affected communities to drive their own recovery is a pivotal attribute of a community capacity building process. Therefore, parallel to the construction activities, organizing training workshops and programs to build the local capacity is of utmost importance, thus building skills on technical applications, monitoring, and supervision. Also important is to formulate design solutions that are familiar with the communities, so that the subsequent technological applications are easy to be communicated, transferred, and built.

6. Methodology and Approach

The approach to this study was twofold. Firstly, it reviewed the drawbacks prevailing in the prepared sub division plans for the said sites and the subsequent project implementation strategies. Secondly, it outlined a set of applicable guidelines for targeted building interventions in similar cultural and physical contexts. In line with this second objective, the study further delineated a conceptual and technical framework for architectural design solutions aimed at each resettlement site, outlining methods for community building through capacity building and strategies for socio-technical restructuring of the local building industries. At the conclusion of the review, recommendations were provided to develop the sites according to appropriate resettlement standards, desirable communal aspirations, and satisfactory environmental and technical performances.

The architectural design solutions thus proposed rely on a set of principles identified as a result of a close scrutiny of the project-specific environmental, economic, and cultural possibilities, limitations, and aspirations. In general, these design principles can be categorized into two strands of intellectual and practical applications: technical and spatial.
6.1 Technical Principles

The technical principles, on the one hand, explore the constructional and environmental considerations of how the buildings can be put together in terms of the use of materials, labour and capital. A key intention here was to develop a kit-of-part strategy with multiple options for building systems to suit the diverse material and physical conditions of the four resettlement sites. By doing so, it was not only expected to use resources in a strategic manner, but also in a manner that would fit the economic and environmental expectations of the projects.

Such technical strategy is in-turn meant to be supported by a technical transfer and capacity building process where the locals are expected to be upskilled in alternative building system solutions, so that they would not only be technically equipped to build the proposed communal buildings but also to use the knowledge thus gained to build better houses for themselves. To this end, strategies such as ease of erection, easy maintenance and ageing, capacity to tolerate workmanship errors, etc. are projected as vehicles for the construction of better spatial structures for the targeted communities.

6.2 Spatial Principles

The spatial principles, on the other hand, look at how best the inside and outside of the buildings can be organized to perform well in terms of the functional, cultural, and environmental expectations of the building program. In the planning of the communal precinct, for example, the buildings are designed in such a way that most of their spaces open out to a central courtyard, which in-turn provides multiple functional uses, cultural possibilities, and social interpretations. The subsequent relationship between the indoor and the outdoor, and the ensuing resolution of public/private thresholds are meant to trigger greater communal interaction between diverse groups of users.

Another important objective of the spatial planning approach was to establish comfortable internal spaces that respond positively to the local climate via strategies such as cross ventilation, optimized use of natural light and air, use of trees for shading, appropriation of thermal masses to reduce internal heat gain, etc. Spaces are also designed to provide flexibility, adaptability, necessary privacy and adequate security, while celebrating the much-valued sense of place and community.

Following is an outline of the critical design principles identified as the basis for the development of architectural solutions for these projects:

Technical principles:

a) Kit-of-part building system for diversity of project context.
b) Strategic use of resources.
c) Sustainable use of building materials, components and systems.
d) Technical transfer / capacity building.
e) Labour up-skilling; ability to inhabit a self-learning capacity in the technological systems.
f) Ease of erection; devoid of unnecessary craftsmanship.
g) Ease of maintenance; graceful ageing.
h) Plenty of tolerances; and latitude for workmanship errors (robust).
i) Adequate environmental performance.
j) Economy; local availability and easy access to resources.
k) Ability to form permutations among different elements and components.
l) Environmental appropriateness.
m) Ability to trigger social innovation.

Spatial principles:
  a) Spaces opening out to a central court-yard, which provides multiple opportunities for play, gathering and infrastructural use.
  b) Court-yards designated to special functions.
  c) Indoor / outdoor; public / private threshold space for communal interaction.
  d) Proper environmental performance.
  e) Narrow floor-plates for cross ventilation.
  f) Optimized use of natural light / ventilation.
  g) Trees for shading.
  h) Maximized inside / outside connection.
  i) Adequate spatial privacy / security.
  j) Adaptable / flexible space.
  k) Legibility of functions.
  l) Diversity of outdoor rooms for communal use and gathering.
m) Sense of place / community.
  n) Economy and efficiency.

7. Craft vs. Industry

In outlining the design solutions, one of the critical aspects was to identify a kit of part building system that can be used as the catalyst for triggering the proposed capacity-building initiatives as well as for constructing the eventual building artefacts. In delineating these systems, it was important to identify a mix of craft-based and industry-based building solutions as means of providing a sound building supply intervention to fulfill the immediate building needs of the displaced communities, as well as to support the broader industrial re-structuring goals of the region as a whole.

Table 01. Building Systems

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<tr>
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<th>Craft</th>
<th>Industry</th>
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<tbody>
<tr>
<td>01</td>
<td>Roof System</td>
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<td></td>
<td>Clay Tiles on Timber Log Trusses</td>
<td>In-situ Ferrocement Vault</td>
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<td>Steel Roofing over Steel L Section Trusses</td>
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<td>Prefabricated Modular Ferrocement Vaults</td>
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<td>02</td>
<td>Wall System</td>
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<td></td>
<td>Clay Bricks (made on-site)</td>
<td>Rammed Earth / Sand bags</td>
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<td></td>
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<td>Stabilized Earth Blocks</td>
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<td>Bottom-ash Bricks</td>
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<td>Floor System</td>
<td>Cement Screed over Clay Brick Paving</td>
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<td>03</td>
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<td>04</td>
<td>Fenestration System</td>
<td>Timber Framed</td>
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<td>05</td>
<td>Foundation System</td>
<td>Rubble Masonry</td>
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<td>06</td>
<td>Structure System</td>
<td>Timber poles as load-bearing columns</td>
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Figure 1: Examples of Roof System solutions
Figure 2: Examples of Wall System solutions

Figure 3: Examples of Floor System solutions
Figure 4: Examples of Roof System solutions

Figure 5: Examples of Foundation System solutions

Figure 6: Examples of Structural System solutions
An additional requirement was to make sure that the selected building systems and their jointing mechanisms are resilient enough to withstand unforeseen natural disasters, especially given that all the four sites are located in the high wind zones of north Central and Eastern provinces of Sri Lanka. Presently, none of the house owners have a clue on how important resilient construction is; neither have they been supported in acquiring the necessary technical knowhow on how to build with resiliency in mind. Therefore, through the training and awareness programmes, the knowledge on resilient design and construction must be shared among the community in order to create safer human settlements.

8. Conclusion

To make resettlement projects successful, it is paramount to consider that: (1) construction is a ‘social process’, and (2) earlier the involvement of the end-user to the design and construction process, better would be the final outcome. Especially in situations where buildings are constructed by ‘owner-builders’ and informal labour gangs, involvement of the user (and community) in determining the spatial distribution of physical and cultural infrastructure - as well as in delineating the technological environment that eventually support the construction activities – must be deemed as an essential requirement. From a professional point of view, the technological landscape should be planned keeping in mind the capacity for technology transfer, as well as broader industrial development goals of the region.

Indeed, there must be a greater input at planning level, especially in delineating strategic policies on how to use the local industrial networks, capacities, and resources for the successful implementation of a resilient human settlement. In such light, resettlement projects must not be seen as a mere distribution of land and money, but as opportunities to build people’s lives, build communal capacities, and build stronger industrial cultures and relations.

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Study on Unstable Locations along Upcountry Railway Line
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Abstract

Sri Lankan railway is treated as the most scenic railway line in Asia. The main reason for building a railway system in Sri Lanka was to transport and coffee from the hill country to Colombo. However, due to insufficient attention and maintenance in the upcountry railway line, and unauthorized human encroachments into railway reservations, there has been number of reported cases of subsidence, landslides and severe erosion in this stretch causing delays and cancellations of train schedules. National Building Research Organization (NBRO) was requested to identify such unstable locations from Ambepussa to Badulla and propose possible slope rectification measures. NBRO developed a methodology to prioritize the locations previously identified by Sri Lanka Railway. This paper discusses the development of that criteria to select the most vulnerable locations considering the size, importance, vulnerability, maintenance cost etc. Further, the conceptual mitigation designs pertaining to those selected sites too are discussed. This study could be considered as a guideline for further maintenance work for the smooth run of trains in the upcountry railway line.

Keywords: Upcountry railway, slope instabilities; conceptual designs

1. Introduction

Sri Lankan railway line has a long history since 1864. The upcountry railway line, which technically starts from Polgahawela Railway Station and runs up to Badulla Railway Station with 56 stations in between, is treated as one of the most scenic railway line in Asia. The main reason for building a railway system in Sri Lanka was to transport tea and coffee from the hill country to Colombo (Sri Lanka Railways, n.d.).

The upcountry railway line has its own diverse socio-economic benefits not being limited to a mere mode of transportation, mainly serving as;

i. A major eco-tourism attraction itself and provides a cheap but scenic access route to many other tourist destinations in the hill country

ii. A public transportation route, especially beneficial for those living in remote hilly areas where other access routes are scarce
iii. A cheap alternative for the transportation of cash crops such as tea, vegetables, flowers, minor export crops from remote hilly area to major cities and to capital

iv. A major transportation route of fuel and general goods

Therefore, ensuring the transport continuity of the upcountry railway line is of very high importance. However, due to high amounts of rains received to the central highlands it has proven to be a challenging feat as constant rain induced landslides, cutting failures and other instabilities could be expected in these regions. Due to insufficient attention and maintenance, and unauthorized human encroachments into railway reservations coupled with its geographical position, there has been number of reported cases of ground subsidence, landslides, cutting failures rock fall incidents and severe erosions in this stretch causing severe disruptions to the rail transportation system over the past years.

This paper intends to discuss the development of a criteria to prioritize such locations in order to be mitigated with suitable structural mitigation measures under Reduction of Landslide Vulnerability by Mitigation Measures Project - Railway Package. Further, possible conceptual structural mitigation designs applicable to each location too will be explored.

This study could further be considered as a guideline for further maintenance work for the smooth run of trains in the upcountry railway line.

2. Similar Studies Carried out Related to Railway Routes

Similar studies have been carried out by Freeborough et al. (2016), a desk-based assessment of regional landslide susceptibility for the national rail network of Great Britain. Further, the Washington State Department of Transportation – Rail Division has published an action plan for landslide mitigation work along the Pacific Northwest rail corridor, Washington (Washington State Department of Transportation - Rail Division, 2014). A series of analyses to quantify the landslide risk along the road and railroad in the Nilgiri hills in Southern India had been carried out by Jaiswal (2011).

Measures of stabilization of side slopes, railway embankments and other measures such as ensuring that there will be no long term water logging or stagnation within the railway formation are provided through guidelines prepared for railway networks of India (Government of Indian Ministry of Railways, 2003) and in Norway (The Norwegian Railroad Administration, 2016).

3. The Need for the Development of Proposed Methodology

Though some previous investigations and studies have been carried out for some cases of instabilities along the upcountry railway line, a detailed and a more recent study of the total stretch giving special attention to all other associated risk elements was yet to be done. This study identifies this gap and provides a step-wise methodology to prioritize locations to be structurally stabilized considering the vulnerability and magnitude of associated risks and estimated cost.

Particularly, unlike a road network, many a practical difficulty lies in carrying out a comprehensive and thorough landslide investigations along this stretch of railway line due to accessibility issues and tight train schedules. Therefore, this study
is further expected to lay a groundwork for future studies and act as a guideline in identifying sensitive regions that require due attention and maintenance to avoid any potential instabilities.

4. Methodology

The total stretch of the upcountry railway line has reported around 90 cases of previous instabilities. The methodology followed for the screening process is illustrated in figure 1 through which a total of 20 locations could be singled out for the Project.

**Figure 1: Prioritization of most suitable locations**

4.1 Background Studies

A preliminary study was carried out by NBRO in 2017 for identification of unstable locations in terms of regional geological features and landslide susceptibility along the upcountry railway line. The assessment was a desk study essentially based on information gathered from 1:50,000 and 1:10,000 scale Landslide Hazard zonation Map of NBRO and 1:100,000 geology maps of Geological Surveys and Mines Bureau. A 500 m buffer zone on either side of the railway line was considered in the assessment. The 1:50,000 scale landslide hazard map of NBRO categorizes the landslide hazard in the country into four zones as follows:

1. Landslides are not likely to occurs (Zone 1),
2. Modest level of landslide hazard exists (Zone 2),
3. Landslides are to be expected (Zone 3) and
4. Landslides most likely to occur (Zone 4).
The study identifies that 59.7% (124 km²) area of the entire segment of the railway line (216 km) falls into Zone 1, 2 or 3 (Figure 1). The assessment of the regional geology it was revealed that the most abundant rock types found along the stretch are gneissic rocks. The study also identified geologically weak zones including shear zones, antiforms, synforms and fault zones along the railway line. Further, four locations along the railway stretch under the study have been previously identified to be in close proximity to active landslides at Ch: 154+5, 154+70, 160+3 and 174+13 mileage from Colombo-Fort railway station.

![Landslide Hazard Map](image)

**Figure 2: Landslide Hazard Map to cover landslide hazard along the upcountry railway line (Source: Preliminary report on landslide hazard potential associated with upcountry railway line, NBRO)**

4.2 Field Observations and Instability Categorization

Having followed the above background studies and other cross verifications with the Railway Department, the list could be narrowed down to 48 sites. For field verifications and further screening, the selected locations were visited by a team of landslide specialists from NBRO including senior engineers and engineers. Some notable unstable locations observed during the visits are shown in figure 3 to 10. Special attention was given for any other risk elements observed beside the railway line. The most common failure type was instabilities in the up slope or/and down slope side of the railway embankment. A number of failed steep cut slopes in close proximity to the rail track could be observed as well as unstable down slope embankments made on steeply dipping terrains posing a direct threat to the railway track, and, at some instances, to A grade or B grade roads lying close by.
While most instabilities display signs of poor maintenance and are a result of human interventions, there were some locations affected by natural phenomena like landslides or rock falls. Such locations are reported to show progressive failures requiring regular track maintenances, some instabilities running as far back as 50 years according to the Railway Department. Track subsidence on occasions where the track lies across landslides showing creeping movements was another type of notable instability feature, observed at Inguruoya railway station and Galaboda for instance (Figure 4 and 5). Further, unauthorized settlements could be observed at crests of unstable steep cut slopes contributing to destabilize the slopes further, either by diverting storm water down slope or over loading the crown area. The earth catchwater drainage network made above steep cut slopes by the British back then have been essentially disrupted by the encroachments giving rise to severe amounts of gully erosions at some locations. Further, there were two to three cases of mud pumping, severe water logging associated with landslide locations, at Ch 53+75km for instance.
Figure 6: Downslope failure and rock fall site at Balana
Notable features: Progressive failures of down slope, rock fall threat at LHS posing a threat to both the railway line and the Kandy road located at a lower elevation.

Figure 7: Potential landslide lying across the track at CH 93+15
Notable features: signs of an old landslide, water logging, recurring subsidence of rail track, side slope failures, failure of existing toe gabion wall

Figure 8: Cut slope and rock fall threat in between 144+4 and 149+39
Notable Features: Rock fall threat at either side of the tunnel, about 300m stretch of rail track subjected to cut-slope failures

Figure 9: Downslope failure at CH 160
Notable Features: Both the track and main road under threat, excessive erosions down slope

Figure 10: Cut slope failure at CH 168+55
Notable Features: Cut slope failure, severe gully erosions
From the field observation results, the locations could be categorized based on the nature of failure so as to decide upon the structural or non-structural mitigation measures required for each case. From those findings, the instabilities observed along the rail track could be broadly categorized as:

- Landslides
- Cut-slope failures
- Slope failures in natural slope
- Rock fall
- Ground subsidence
- Other instabilities including mud pumping and water logging

4.3 Conceptual designing, cost estimations

With field observations, sites requiring structural mitigation measures were filtered out, and based on the type and nature of instability conceptual designs were decided upon for each location. Accordingly, for landslide affected locations, modification of surface and subsurface water regime was chosen as the primary rectification process and they may further require earth retaining structures where enough stability levels could not be achieved with lowering of ground water table in the failure mass. Instrumentation and monitoring were also proposed with the establishment of early warning systems to alert nearest railway stations in case of instability, where necessary. For cut failures and natural slope failures where there are low to moderate slope heights and no space constraints, externally stabilizing earth retaining structures could be proposed. Where space constraints are present with higher slope heights, soil nailing was selected as a more suitable rectification measure.

For rock falls, mitigation measures including rock netting and anchoring, rock fencing could be utilized. For locations with more than one types of instabilities, a combination of different measures were proposed. Having decided upon the conceptual designs for each individual locations, the tentative costs were roughly estimated. The costs to be incurred against the amounts of risk elements to be benefited were assessed.

5. Results and Discussion

Around 90 unstable locations reported to NBRO were narrowed down to 20 locations in total to be rectified through the railway component of the Project. The proposed conceptual designs require to be verified with detailed geological and geotechnical investigations and further fine-tuned with instrumentation and monitoring results at the Project implementation stage.

Primary difference in between the prioritization process of unstable locations along a road and the upcountry railway line is prioritizing locations along a railway track for a mitigation is the unavailability of another alternative route. Therefore, in principal, the total stretch of the line is already prioritized making the governing factor in prioritization is the amount of risk and risk entities affected by the instabilities as well as costs involved.

Since this track was built through originally unpopulated hilly regions, long before most of the settlers started encroaching into the railway reservations, the route could be considered as the best possible trace to build a rail track. According to sources from Railway Department a systematic earth drainage network including catch water drains, side drains and culverts had been introduced during the construction of the
railway track. Unauthorized encroachments to railway reservations as well as lack of proper maintenance over the years have interfered this network, and therefore introducing of proper drainage system to all the unstable locations currently identified will be advisable.

6. Conclusion and way forward

NBRO was reported about 90 possible failure locations and subsequently, it could be narrowed down to 20 cases based on detailed studies. All the sites were visited by engineers and geologists of NBRO and mitigation measures were summarized considering the site observations. Locations identified and verified through the study to be vulnerable to instabilities, require due attention and maintenance to ensure the transport continuity of the upcountry railway line.

Acknowledgment

Special thanks are extended to Dr. H. A. G. Jayatissa, Dr. Pathmakumara Jayasinghe, Ms. H. Hemasinghe, the collaborating NBRO officials of the “Preliminary Report on Landslide Hazard Potential Associated with the Upcountry Railway Line” which provided a firm basis for the study.

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An Analytical Study on Shareable Knowledge Driven Risk Management Approach for Managing Supply Chain Risk in Construction Projects

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Abstract

Due to shortcomings in current project risk management processes, tools and techniques, construction industry still suffers from poor project performance. In increasingly complex and dynamic projects, the tendency is to use risk quantification and risk response planning. However, communication of construction project risks is poor, incomplete, and inconsistent throughout the construction supply chain. Further, members of a project team may adopt different terminology for describing risks and use different methods and techniques for dealing with risk analysis and management, thus producing different and conflicting results.

Proliferations of techniques and software packages have failed to meet the needs of project team members. The focus of quantitative risk analysis based on estimating probabilities and probability distributions for time and cost risk analysis does not encourage project team members to understand in-depth the underlying elements and structures which constitute project risk. It does not allow the risks, problems, remedial measures, and lessons learned from previous projects to be captured and re-used when developing new projects. A common language for describing risks based on a hierarchical-risk breakdown structure has been developed and it provides the basis for developing a sharable knowledge-driven approach to risk management. A need for better knowledge through research is present in many of the above areas, but what seems to be especially important is the present lack of frameworks for decision support within supply chain risk.

The work presented in this research is aimed at developing a comprehensive and continuous risk management framework that contributes to the knowledge on how to manage disruption risks in the supply chain through identifying the structure and to develop and test a generic, aggregate shareable knowledge driven risk management approach for managing project risks in the supply chain.

“According to Bernstein (1996) the argument boils down to one fundamental question: to what extent does the past determine the future?

We cannot quantify the future, because it is unknown, but we have learned how to use numbers to scrutinize what happened in the past. But to what degree should we rely on the patterns of the past to tell us what the future will be like? Which matters more when
facing a risk, the facts as we see them or our subjective belief in what lies hidden in the void of time? Is risk management a science or art? Can we even tell precisely where the dividing line between the two approaches lies?”

Keywords: Project risk; construction supply chain; Knowledge driven Approach

1. Introduction

There is constant pressure on managers to improve the efficiency of their supply chains, allowing materials move quickly. This pressure has encouraged a stream of new initiatives and methods. But there is a growing realization that these new methods also bring unforeseen problems. In particularly, they increased the supply chain’s vulnerability to disruption events; they create inflexible chains where even a small, unexpected event can bring everything to a standstill (Waterrns, 2007).

Supply of workers, materials or tools involved all parties direct or indirectly in fulfilling a customer request. This is known as the supply chain in the product or services. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves. Within each organization, such as a manufacturer, the supply chain includes all functions involved in receiving and full filling a customer request. These functions include, but are not limited to new product development, marketing, operations, distribution, finance, and customer service.

A supply chain is dynamic and involves the constant flow of information, product, and funds between stages. The primary purpose of any supply chain is to satisfy customer needs and, in the process, generate profit for itself. The term supply chain conjures up images of product or supply moving from supplier to manufacturers to distributors to retailers to customers along with a chain.

The objective of every supply chain should be to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer’s request. For most commercial supply chains, value will be strongly correlated with supply chain profitability or known as surplus, the difference between the revenue generated from the customer and the overall cost across the supply chain. The supply chain profitability or surplus is the total profit to be shared across all supply chain stages and intermediaries.

There are risks occur on to the supply chain and its impact to the supply chain profitability or surplus. A huge number of events can affect the operation of a long and complicated supply chain. These unexpected events define the risk, and supply chain risk management is the function responsible for managing them (Waterrns, 2007). For the managers, risk is a threat that something might happen to disrupt normal activities or stop things happening as planned.

Risk will occur because we can never know exactly what will happen in the future. It can use best forecasts and do every possible analysis, but there is always uncertainty about future. Different risk can be linked together and effect to the chain. (Waterrns, 2007).

The objectives are to develop a common language for describing risks throughout a construction supply chain and covering the complete construction project lifecycle; to develop a risk management paradigm involving identification, classification, assessment, analyses, action planning, tracking, control, and communication of risks
on a continuous and proactive basis using the common language; and to develop tools using knowledge-based systems techniques to support the framework.

The literature indicates that much focus has been on quantitative risk analysis based on estimating probabilities and probability distributions for time and cost risk analysis. With the increasingly complex and dynamic nature of projects coupled with new procurement methods, the tendency today is to use risk quantification and modelling more as vehicles to promote communication, teamwork, and risk response planning amongst multi-disciplinary project team members. However, communication of construction project risks is poor, incomplete, and inconsistent throughout the construction supply chain. Risk management tends to be conducted on an ad hoc basis and is dependent on the experience and risk orientation of individual key project participants within the industry supply chain.

The individual parties involved in a project adopt different terminology for describing risks, use different methods and techniques for dealing with risk analysis and management, producing different and conflicting results. Where risks have been identified, assessed and remedial measures agreed, they are not generally effectively communicated throughout the supply chain.

Project communication systems must be built upon common terminology, standard descriptions, defined metrics for measurement and consistent knowledge of processes and procedures. Current applications, which claim to improve communication efforts, do not define the framework in which managers and their teams should develop, sequence, co-ordinate or route project information. What is needed is a means of standardising and organising project management efforts through a framework that gives individual managers, project managers and their teams the methodology and structure required to support risk management in construction supply chain.

1.1 Problem statement

Managers need to ensure delivery of projects as agreed to cost, schedule and performance requirements. To achieve this involves identifying and managing the risks of the project at all project stages from the initial assessment of strategic options through the procurement, fabrication, construction and commissioning stages, whilst taking due account of subsequent operation and maintenance (and decommissioning and disposal). Risks to be considered include not just financial, commercial and management risks, but also quality, performance, health and safety and company image. Work is needed on methods of developing configurable risk management processes and skills needed to integrate risk fully into business strategy. The strategy should give recognition that balancing the ratio of risk and reward in a business is a key role for senior management. More holistic integrated comprehensive, inclusive and pro-active approaches to monitoring and management need to be developed to support the processes. For the approach to be comprehensive, it must cover five key aspects of business organisation: strategy, processes, products, technology, and people. It must be inclusive, involving all levels of the organisation. It must be proactive, aiming to anticipate risks in advance. It is clear that, tools and techniques must be developed to support managers at a strategic level to play a leading role in setting a clear risk framework. Appropriate ways of embedding risk management in organisational culture and behaviors need to be developed for risk management
techniques to be fully appreciated and applied. Sub-section headings should be in capital and lower-case italic letters, numbered 1.1, 1.2, etc, and left justified, with second and subsequent lines indented.

1.2 Objectives

The work presented in this research is aimed to;
- Explore the risks associated with construction supply chain and developing a comprehensive and continuous risk management framework capable of enhancing the probability of project success
- Identify a common language for describing risks based on a hierarchical-risk breakdown structure that has been identified and provide the basis for developing a sharable knowledge-driven approach to risk management

Risk management is still a problem area within the construction industry. Approaches have been suggested for dealing with the problems, but these for the most part have failed to meet the needs of project managers. Project communication systems must be built upon common terminology, standard descriptions, defined metrics for measurement and consistent knowledge of processes and procedures. Additionally, evidence suggests that current software packages do not handle the inherent subjectivity in risk assessment effectively. To help overcome this, fuzzy logic technique may help to address the problems associated with the quantification of vague linguistic terms.

1.3 Methodology

The first objective is fulfilled with the help of a search in literature within the areas of risk, risk management, supply chain management, and supply chain risk. The results from the literature review are then complemented with empirical material, and the existing knowledge within each area is summed up and analysed.

The identified research need is used as starting point for the fulfilment of objective two. A model, called the shareable knowledge driven risk management approach in supply chains, dealing with the risks of disruptions in the product flow in the construction supply chain from raw material to end market, is developed. The usability of the complete hierarchical risk breakdown structure, is assessed through a survey among risk managers, project managers, consultants, contractors and major suppliers etc.

2. Literature Review

2.1 Supply Chain Management

Supply chain management (SCM) is a concept closely related to logistics management. Researchers argue over the exact meaning of SCM. Larson and Halldorsson, (2004) have identified four perspectives of the relationship between logistics and SCM; (1) the traditionalist perspective, where SCM is a field within logistics, (2) the re-labeling perspective, where SCM is another name for logistics, (3) the unionist perspective, where SCM is a larger field containing the smaller logistics
field, and (4) the intersectionist perspective, where SCM and logistics are equally large fields that to some extent, overlap.

“Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies ...” (CSCMP, 2005). Others confess that they “do not distinguish between logistics and supply chain management...” (Simchi-Levi et al, 2000)

2.2 Defining and managing risk

The word “risk” derives from the early Italian word risicare, which means to dare (Bernstein, 1996). However, its meaning has evolved over time and appears to mean different things to different people appending on their individual perception of the word (Frosdick, 1997). The study of risk began in seventeenth century and is associated with the French mathematicians Blaise Pascal and Pierre de Fermat, who sought to apply mathematics to gambling (Frosdick, 1997). Their work led to the development of probability theory, which lies at the heart of the concept of risk (Bernstein, 1996).

Over the years, a number of well-used tools for quantifying and managing risk have been developed. These include: FMEA (failure mode effect analysis), CBA (cost benefit analysis) and RBA (risk benefit analysis). Though accepted and used by many managers, they have been criticized for removing the element of human judgment from decision making by disguising underlying assumptions with mathematical formulae (White, 1995). Adams (1995) clearly illustrates an opposing view of quantifiable approaches to risk decision-making: Rarely are risk decisions made with information that can be reduced to quantifiable probabilities, yet decisions somehow get made.

The current use of Project Risks Registers (PRR) is an important practice that can be seen as a repository of a corpus of knowledge or organisational memories where experiences about risks and responses are continuously recorded. However, the PRR fails to capture the inter-relationships between risks and the systemic structure within the risks (William, 1993).

Simon et al. (1997) suggest that, whilst there is a wide range of techniques available to undertake each of the three stages of the risk management process, these can be separated into three groups:

1. Qualitative techniques. These seek to identify, describe, analysis and understand risks.
2. Quantitative techniques. These seek to model risk in order to quantify its effect.
3. Control techniques. These seek to respond to identified risk in order to minimize risk exposure.

2.3 Supply chain management

Supply management becomes critical because the increasing dependence on suppliers makes companies highly exposed to supply risks. Tang (2006) classifies four basic approaches to supply risk management to mitigate the impact of such supply
chain risks: Demand management: coordination with downstream partners to influence demand in a beneficial manner; product management: change in product or process design in order to make more fluent the material flows in the supply chain; information management: coordination and collaboration among supply chain partners by sharing information; and supply management: collaboration with upstream partners to ensure efficient and effective supply of materials.

Risk analysis and management has attracted a lot of attention in the literature with more coverage on quantitative methods of analysis. A recent survey of the risk analysis packages currently used in industry in the United Kingdom showed that most of these packages use probabilistic methods to quantify uncertainty (A Guide to the project management body of knowlaje, 1996).

The current use of Project Risks Registers in practice is an important first step in this direction. Project Risk Registers (PRR) can be seen as a repository of a corpus of knowledge or organisational memories where experiences about risks and responses are continuously recorded. However, the PRR fails to capture the inter-relationships between risks and the systemic structure within the risks (William, 1993).

2.4 Project risk management

Cousins et al. (2004) suggest that there are two main types of supply chain risk to which companies can become exposed: technological risk – over-reliance on a single or limited source of a product, processor technology; and strategic risk – over-reliance on a single or limited number of suppliers. Cousins et al. also suggest that some of the measures which companies take to improve the efficiency of their supply base, such as de-listing under-performing suppliers, may increase their exposure to technological and strategic risk by increasing their reliance on the remaining pool of suppliers. As Hendricks and Singhal (2003) note, the failure to manage supply chain risks effectively can be very costly. Indeed, moving beyond supply chain risks and looking at the risks faced by organisations in general, Hood and Young (2005) maintain that many organizations may have gone out of business because of their failure to adopt effective risk management strategies (e.g. Railtrack, Barings Bank and Enron).

2.5 Risk assessing approaches

Uncertainty is a term which can be used to describe a multitude of phenomena. There are many reasons behind uncertainty such as incomplete information, conflicting information, approximations, linguistic imprecision, and variability. Typically, we are even uncertain about our degree of uncertainty.

From a more technical perspective, risk can be defined as the probability of an event multiplied by the (negative) consequences of the event. (Kaplan, 1997) suggests that risk is defined by the answer to the three fundamental questions:

(1) What can go wrong? (2) How likely is that to happen? and (3) What are the consequences?

The technical view of risk has, however, been criticized for neglecting important social, psychological, and cultural aspects. What people perceive as undesirable events depends on their values and preferences, the interaction and consequences of human activities are more complex than probability numbers can capture, and the calculation of risk with equal weights for probability and magnitude implies indifference between
high-consequence & low-probability and low consequence & high-probability events. This has been shown not to be true. Nevertheless, technical risk analyses serve a major purpose in facilitating decision making (Renn, 1990).

In summary, therefore, the study and application of risk management has a long antecedence. In terms of organizations, it tends to be associated with avoiding loss rather than seeking advantage, and though the process of risk management is well developed, there is much disagreement as to whether it is a subjective or objective process, or a combination of both. In addition, given the potential for stakeholder conflict and the lack of agreement as to risk reduction strategies, there is a tendency for managers to seek to keep their options open rather than adopting prescriptive approaches to risk management.

Given this, Harland et al. recommend that risk management should focus on positioning the organization to try to avoid such events, and to develop strategies to manage the impact of them should avoidance not be possible. However, their supply chain risk model is still at an early stage of development. They argue that more and better tools are needed to assist in risk assessment and management at the supply chain level and not just at the level of the individual firm, though they also acknowledge that it is very difficult to develop such tools. The model by Cousins et al. (2004) builds on recent initiatives concerning the greening of supply chains. Consequently, their model specifically concentrates on threats posed to supply chains by environmental risks. Their model seeks to relate the damage that exposure to environmental risks can cause for a firm – financial loss, loss of reputation, etc.

This review has shown that the study of risk and methods of managing it have a long history. However, as it discussed, there is much dispute as to the nature of risk, and though risk management is a well-understood subject in some areas of organizational life, e.g. finance, only relatively recently has risk management been seen as an important issue for supply chain management, though work on aspects of purchasing and risk stretches back to the 1960s. Nevertheless, there appears to be broad agreement that the risks and consequences of supply chain disruption are growing and cannot be understood and managed solely at the level of the individual customer and supplier.

Unfortunately, the present state of research and advice seems to be inadequate to the challenge (Lewis, 2003; Zsidisin et al., 2004), though there have been some commendable attempts to construct models and tools to understand and manage supply chain risk, (Cousins et al. 2004, and Harland et al, 2003).

3. Methodology

In all the presented cases there are supply chain flow-related risks, but the risk sources are of different kinds and the disruptions have more or less serious consequences. The ways the risks are handled also differ a great deal, as well as the degree to which the company is acting proactively. The rapidly increased importance of analyzing how risks easily spread and amplify up and down the supply chain, so called integrative risks, does not seem to have been matched by an equal increase in risk awareness, and definitely not in risk handling actions. The focus appears to be mainly on separate, limited risks within a single entity, and they are handled with traditional risk handling methods. This behavior is also supported by the tendency to split the risk responsibility between many different individuals and departments.
within each company. Hence there is a need for a better understanding of integrative risks and for collaborative risk handling processes.

Typically, construction supply chains only exist for the duration of a project (Cherns and Bryant, 1984). Where maintenance services are part of the contract, the supply chain can theoretically remain in existence for the life of the building (Reed, 1999). The growth in projects, procured under the private finance initiative (PFI), and under build own operates and transfer (BOOT) arrangements should increase the longevity of some supply chains.

Construction supply chains on larger projects typically involve hundreds of different companies supplying materials, components and a wide range of construction services (Dainty et al., 2001). A continued reliance on a fragmented and largely subcontracted workforce has arguably increased the complexity of this supply network and delimited opportunities for process integration.

The found evidence of growing trend towards partnering arrangements, but these were mainly focused on clients and main contractors rather than extending down the chain to subcontractors and suppliers. This arguably delimits opportunities for the complete integration of processes throughout the delivery chain and may explain the industry’s apparent inability to accelerate its rate of performance improvement (Strategic Forum for Construction, 2002). Indeed, construction partnering has been criticized for being a rather loosely defined term that actually masks a multifaceted practice (Bresnen and Marshall, 2000). Where attempts have been made to extend partnering and collaborative working throughout the supply chain, vested interests and a lack of desire to engender trust among supply chain partners often seem to have undermined their success.

These studies show that partnering implies the abandonment of traditional methods of procurement which often engender distrust and poor quality of service in the supply chain. Rather, partnering works best when the parties are committed to common goals and individuals offer mutual support to each other. Harland et al. (1999) have shown how firms can more readily attain long-term cost reduction by forming closer working relationships with key suppliers. Such findings are highly relevant for construction supply chain integration. More recently, Besant et al. (2003) have suggested that companies can learn best practice through leverage in their supply chains and this will contribute significantly to improved business performance.

The present study aims to explore how some of the industry’s leading public and private sector clients attempt to address the problems of integrating the construction supply chain. It also seeks to identify the efficacy and transferability of the approaches used to other client bodies responsible for major projects. The study provides an opportunity to explore a number of different tiers in the supply chains associated with major projects. In this way, the results provide insights into both the strengths and the weaknesses of the observed approaches and they enable the key requirements for efficient supply chain management.

This research considered public and private sector construction companies who were competent and highly qualified to undertake construction projects worth over 200 million. They were selected on the basis of their procurement experience, with each having long-standing familiarity in procuring large and complex projects over a period of last ten years. Although construction was not their primary activity, they were experienced secondary clients. This was considered important as they had a vested interest in the quality of the end product facility as well as the project objective itself.
Each client provided access to three projects, so that overall the research drew information from some separate supply chains. The nature of these projects ranged from contracts costing over 200 million of major building construction projects. This allowed a variety of supply chain relationships to be explored within the broad context of the clients’ construction procurement activities. The main form of data collection consisted of structured interviews which were carried out with senior staff of client, main contractor and subcontractor (major supplier) organizations. Typically, those interviewed were senior managers in strategic sourcing, construction procurement, construction engineering and project control. Within the main Major contractors (C1 & C2 Grade registered at ICTAD), the interviews focused on the project managers, quantity surveyors, risk managers and the senior purchasing managers. In total, more than 30 interviews spanning the different supply chains were carried out. The concern of the research was to gather multiple sources of evidence that would validate the general findings and remove any subjective bias that might arise from looking at either a single client or a single project supply chain. Questions were adapted to reflect the sub-unit of each chain under consideration and so separate interview schedules were produced. All interviews were conducted with structured questioner and they were then analyzed through the use of qualitative analysis. Following this analysis, the researchers returned to the individual cases to ensure that the findings were well grounded on the data. The results are presented below under headings drawn from the analysis. Where appropriate, illustrative quotations drawn from the interview transcripts have been used to convey the majority views of the informants interviewed.

3.1 Layout of the questionnaire

Construction supply chain risk management takes a broader approach than traditional risk management. It does not view risks as something delegated to separate functions such as insurance, treasury, finance or internal audit. Rather, understanding and managing risks become “part of everyone’s job”. Firms evolve by implementing a more systematic risk evaluation process, assigning accountability for managing risk areas to appropriate managers and applying proven risk management processes and techniques to all critical risks. Therefore, the researcher having after detailed literature review identified hierarchical risk breakdown structure in association with the construction supply chain.

3.2 Basic structure of questionnaire

The risks associated with construction supply chain have been identified, and each of them is broken down into 3 sub-sources:

1. **product related** (complexity, customization, impact on costs, impact on time, impact on quality)
2. **market-related** (low number of qualified suppliers, high degree of market saturation, general increase in price, high geographical concentration of the suppliers, low-cost countries suppliers, low level of supplier certification),
3. **supplier-related** (problems in the product innovation, delivery mistakes, delivery delays, conflict relationships, supplier contractually linked to other customers, qualitative problems, cost increases, difficulties in satisfying the
demand, technological backwardness, discontinuity of supply, under-
capacity, poor environmental performance, financial stability, information
technology backwardness, information technology incompatibility,
inadequate transport, inadequate inventory management, inability to quickly
implement technological changes, inability to quickly implement product
changes, poor mix/volume flexibility).

A four-point scale (low, medium, high, very high) was used to perform an overall
assessment, based on the number of the main supply risk sources considered and on
the total number of supply risk sources considered. An overall assessment was
performed using the above-mentioned four-point scale. An overall assessment was
performed using the four-point scale, based on the number of the main criteria
considered and on the total number of criteria considered.

These are the five sets of different factors identified that contribute towards the
“overall” supply chain risk and were then further classified to sub sectors as follows:

- Environmental risk (Political uncertainty, Policy uncertainty,
  Macroeconomic uncertainty, Social uncertainty)
- Industry risk (Input market uncertainty, Product market uncertainty,
  Competitive uncertainty, Organizational risk)
- Organization risk (Operating uncertainty, Credit uncertainty, Liability
  uncertainty, Agency uncertainty)
- Problem specific risk (Risk interrelationship, Objectives and Constraints,
  Task complexity)
- Decision making risk (Knowledge/skill/bias, Information seeking, Rules and
  procedures, Bounded rationality)

This is then used to develop a unifying framework for questionnaire.

4. Data Analysis and Interpretation

The survey forms and recorded discussions were carefully viewed and data were
tabulated to present findings on qualitative and quantitative analysis. Interactive
interviewing; the respondents – the internal staff and competitors and also suppliers’
key persons, were asked verbally to describe their experiences, views, ideas, and
suggestions. Qualitative studies carried out using tools understanding and describing
the construction supply chain risk management experience, exposure and knowledge.
The researcher maintained respect and gratitude throughout the interview to proceed
through the research process.

The strength of qualitative approach is the ultimate aim of the researcher that
reflects the researcher’s ability to describe the relevant phenomenon. One of the
greatest strengths of the qualitative approach is the richness and depth of explorations
and descriptions.

A four-point scale (low, medium, high, very high) was used to perform an overall
assessment, based on the number of the main supply risk sources considered and on
the total number of supply risk sources considered. An overall assessment was
performed using the five-point scale, based on the number of the main criteria
considered and on the total number of criteria considered. As personal data is collected
by the questionnaire, the data summary is rearranged for each sector before analysis.

The raw data collected from the field were transformed into a form that will make
them easy to understand and interpret. Describing responses of the respondents and
their observations is typically the first form of analysis done by the researcher. At the collection of data or the filled questionnaires, the impact on projects risks and how risks are managed in construction supply chains were explored.

There were considerable variation and disagreements by companies about the most significant risks associated with construction supply chain. The five main sets of construction supply chain risk sources were considered by those companies and their opinions on three projects they have undertaken were given. The graphical presentation of the data analysis is as follows.

I. Organizational factors

![Organizational Factors](image)

42% of them identified the high risk associated with organizational factors that directly impact on the project. And 33% indicated the medium risk associated with the project supply chain. Therefore, it is indicated that the factor considerably impacts on to the cost, quality and time targets. The organizations have recognized the importance of risk management and ventured into making suitable arrangements. Then the assumptions are that the benefits of risk management become so clear that the firm will quickly adopt its principles and it will eventually become a part of the corporate culture.

II. Industry factors

![Industry Factors](image)

The companies complained about industry uncertainty risks that impact on to the construction supply chain considerably. In their supply chains, 50% each was indicated for medium and high-risk involvements. Industry uncertainty cannot be controlled by the mangers in the general way of response and these issues were reduced through practical means such as keeping buffer stocks, adding spare capacities, increasing agility and improving forecasts etc.
III. Decision making factors

The level of risk on the set of the decision-making risk factors indicated a high significance. It was 54% in their projects. And 33% was indicated on the medium risk associated with decision making factors. The decision making is mostly very subjective to person and it will depend on the skill, knowledge and the experience of the project manager or the line managers. A variation on these factors has significance of a risk depending on the perceptions of the person considering it.

IV. Problem specific factors

These factors were very specific to the projects and their location. These problem specific factors indicated by the companies were 38% in high, 33% in medium and 29% in very high levels of risk involved in their supply chains of the projects. These risks to be addressed by using previous risk data on similar projects. Analysis of past events do not give sufficient information about future risks. The mangers have to collect new information to analysis specific problems. But this depends on the skills and knowledge as well as their ignorance, prejudice, inconsistency and general unpredictability.

V. Environmental factors

These are another set of factors considered by the companies and their opinions were given as 42% for each of the medium and the high risks associated with their projects. Comparatively, the environmental factors were lesser than other four risk factors, associated with the construction supply chain.
As per the above analysis, the said factors are to be highly considered and a methodology should be adopted to illuminate, minimize or respond to those essential for achieving corporate goals. And this is very much important to complete the projects successfully. The unsuccessful projects were mostly rated at high risk on these risks factors.

A proper risk management system in construction supply chain is required more to keep the projects in good phase, to maintain the quality and to deliver the comprehensive end product to the stakeholders. This analysis shows that it is high time to consider CSCR as an essential criterion for construction companies for benchmarking their supply chain risk processes against those of their competitors.

5. Conclusion

There is constant pressure on managers to improve the efficiency of their supply chains, allowing materials to move quickly and at a low cost. This pressure has encouraged a stream of new initiatives and methods. But there is a growing realization that these new methods also bring unforeseen problems. In particularly, they increased the supply chain vulnerability to disruption events; they create inflexible chains where even a small, unexpected event can bring everything to a standstill.

The objective of the every supply chain should be to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer's request. The supply chain profitability or surplus is the total profit to be shared across all supply chain stages and intermediaries: higher the supply chain profitability, more successful is the supply chain.

There are risks in the supply chain and they impact to the supply chain profitability or surplus. A large number of events can affect the operation of a long and complicated supply chain. These unexpected events define the risk, and supply chain risk management is the function responsible for managing them. For managers, risk is a threat that something might happen to disrupt normal activities or stop things happening as planned.

The construction industry still suffers from poor project performance due to risks, despite attracting a lot of attention in the literature. With the increasingly complex and dynamic nature of projects coupled with new procurement methods, the tendency today is to use risk quantification and modelling to promote communication, teamwork, and risk response planning amongst project team members.

However, communication of construction project risks is poor, incomplete, and inconsistent throughout the construction supply chain. Risk management tends to be conducted on an ad hoc basis and is dependent on the experience and risk orientation of individual key project participants within the industry supply chain. It is argued that the development of a common language for describing project risks will lead to consistencies in communicating risks allowing all project team members to a shared understanding of risks and interdependencies within risk chains. What is needed is a means of standardizing and organising project management efforts through a framework. It has been argued that the development of a common language for describing project risks will lead to greater consistencies in communicating risks allowing all project team members.

Managers need to ensure delivery of projects to cost, schedule and performance requirements. To achieve this involves identifying and managing the risks to the project at all project stages from the initial assessment of strategic options through the
various project stages, whilst taking due account of subsequent operation and maintenance including de-commissioning and disposal as well.

Today, projects are undertaken in an arena of immense dynamism, rapid change, and global competition. The resultant uncertainty and complexity have emphasized the need for effective risk management strategies. Work is needed on methods of developing configurable risk management processes and skills needed to integrate risk fully into business strategy. The strategy should give recognition that balancing the ratio of risk and reward in a business is a key role for senior management. For the approach, it is to be comprehensive; it must cover five key aspects of business organisation: strategy, processes, products, technology, and people. It must be inclusive, involving all levels of the organisation. It must be pro-active, aiming to anticipate risks in advance. It is clear that, tools and techniques must be developed to support managers at a strategic level to play a leading role in setting a clear risk framework.

This makes it an inadequate tool for the capture and representation of risks, and the basis for analysis and decision-making. Further work needs to build on the limited demonstrations of possibilities in the literature on the use of knowledge-based systems techniques. The development of a theoretical basis for the representation of risks and related concepts leading to the establishment of appropriate knowledge representation schemes should lead to the development of more robust and scalable knowledge-based systems. The appropriate synergistic combination of a hybrid of techniques drawn from both knowledge-based, soft, and conventional hard systems should be investigated to provide the basis for the quantification of risks and determining appropriate risk allowances and tolerances whilst embracing the notion that risk is subjective and allowing for human judgment.

6. Recommendations

The state of the art review revealed that supply chain risk management can be described as a new area under rapid development with several interesting "islands of theories" but yet without any common, solid foundation of basic concepts and generic models.

As seen from the angle of an individual company or a unit in the construction supply chain, the risk management framework covers all potential product flow-related disruption risks in the total supply chain. These risks are classified into different classes that are assessed and summarized into a total expected consequence value.

After analysis of the risk factors, researcher has prioritized the amount of attention that each deserves. 1. Industry uncertainty factors 2. The Decision making risks factors 3. Organizational Risk factors 4. Problem specific risk factors and 5. Environmental risk factors.

An industry-wide risk affects all organizations in the same industry in a similar way. The best responses are collaborative, with firms cooperating to resolve the mutual problems. In the macro-level, it is to be intervened by the policy level and survival of the industry to be ensured. The general way of response to these issues were reducing through practical ways such as keeping buffer stocks, adding spare capacities, increasing agility and improving forecast. Most of the companies lack of strategic approach to supply chain risk management and many firms lack of sufficient
market intelligence, skills, and information systems to effectively predict and mitigate supply chain risks.

The responsible operation managers or practitioners should be appreciative of decision making risk factors, significance of the risks and their consequences, and should have necessary knowledge, skills, information and motivation. The best way to manage risks associated with organizational and inter organizational networks is to have close and long-term relationships, partnerships and introducing more efficient information systems. A better approach to eliminate the risk associated with the operation is to improve visibility, giving more efficient flow of information and better controlled operations.

The managers have to be take actions to reduce the probability that a risky event will occur. The firms that are worried about environmental factors of risks can move to a location where these causes less concern. The environmental risks are outside the control of managers but it is better to be forecasting to a proper plan of response.

The best approach to supply chain risk management is not have each member of chain working in isolation, but have them working together in a coordinated effort to reduce the overall vulnerability of the whole supply chain.

Acknowledgement

This work is the mere physical evidence of the ride of the last few years, although only few names on the acknowledgement, a product to which many people have contributed in different ways. More important, however, is the internal knowledge that has been created in relationships with a great number of people; through inspiring discussions, creative insights, and pure friendship. Many people have made their contributions and I would like to take this opportunity to express my gratitude to all of them.

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Utilization of Textile Waste in the Manufacturing of Cement Based Products

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Abstract

Unrecyclable fabric is a major problem for textile industry in Sri Lanka. This study was focused on embedding shredded form of polyester spandex fabric waste into cement matrix for the manufacturing of interlocking paving blocks. Experimental investigation was carried out to find the optimum shredded fabric content to achieve highest flexural strength of the cement paste-fabric mix. Admixture type I was used to prevent particle segregation and admixture type II was used to improve the workability of the cement fabric mix. The length of shredded fabric samples was less than 10mm. Mortar prisms were cast by changing fabric content from 5% to 35% by solid volume and compressive and flexural strength were tested at 7 days and 28 days. Highest flexural strength and compressive strength were observed at 26% and 25% fabric content respectively. Manufactured sand, cement and shredded form of polyester spandex were used to cast paving blocks. It is focusing on improving water permeability of pavers while giving better foot comfort.

Keywords: Polyester spandex; textile waste; cement; paving blocks

1. Introduction

Apparel industry is the most significant and dynamic contributor for Sri Lankan economy. In 2015 apparel industry contributed to 61% of exports and 44% of GDP while focusing sustainable manufacturing processes (Steve Evans, 2017). However, there are no well-established textile recycling facilities in the country. Alternatively, some of the synthetic waste is being sent to a cement company where it is incinerated as fuel in the cement kiln. Increasing amount of waste will exceed the burning capacity at cement kiln. Consequently, the textile waste ends up being illegally dumped or burned in the landfills.

In apparel industry fabric offcuts are the biggest waste in volume. Sri Lankan apparel industry generates fabric offcuts approximately 44,100 tons per year (Steve Evans, 2017) and major portion of fabric offcuts are considered as a waste material. If there is a possibility to use fabric waste as a material for construction industry it will
lessen the fabric waste disposal issue. Spandex mix fabric offcuts are unrecyclable due it's to spandex blend, it can burn in cement kilns but it emits considerable amount of CO2 while increasing environmental pollution. Therefore, study on the use of spandex mix fabric waste as a material for construction products and it will be a solution for fabric waste disposal problem.

Polyester is a type of polymer which contains ester functional group in the main chain. Natural and synthetic polyesters are available. Natural polyesters and a few synthetic ones are biodegradable, but most synthetic polyesters are not. Polyester fibers are sometimes spun together with natural fibers to produce a cloth with blended properties. Polyester thread or yarn are commonly used in apparel industry. Polyester shows low water absorption property (www.whatispolyester.com, 2015).

Spandex is a synthetic fiber which is exceptionally used for elasticity. It is stronger and more durable than natural rubber. Spandex has been incorporated into a wide range of garments, especially in skin-tight garments due to its elasticity and strength (stretching up to five times its length) (www.fibersource.com, 2017). Polyester spandex is a type of fabric which shows elastic properties and contains 70-80% polyester and 20-30% spandex.

2. Methodology

2.1 Sampling of materials

Shredded form of polyester spandex samples were collected from one manufacturer and those samples were used for testing.

Manufactured sand was purchased from local market and those samples were used for testing.

2.2 Material properties

Material properties were tested prior to casting test specimens. Particle density of Ordinary Portland Cement and shredded spandex were measured according to SLS 1144 Part 2 (SLS1144, 1996). Size distribution of shredded spandex pieces was measured by mechanical sieving according to BS 812: Part 103.1 (BS812:Part103.1, 1985). Particle size distribution and water absorption of manufactured sand were tested according to BS 812: Part 2 (BS812:Part2, 1975).

2.3 Tests carried out

Prisms were cast with cement paste and shredded fabric for different mix proportions by changing fabric content and admixture type. Cast prisms were tested for flexural strength and compressive strength according to BSEN 196-1 (BSEN196-1, 2005). From the results, the suitable mix was selected which yielded the highest flexural strength to produce paving blocks.

Water content was altered to get the required consistency of fabric-cement mix. As a higher water content was required to achieve a homogeneous mix, Admixture type II was used to lower the W/C ratio to 0.5 Admixture type I was added to prevent segregation of fabric pieces from cement paste during compaction of the sample by jolting.
3. Results and discussion

3.1. Particle density and water absorption

Density of ordinary Portland cement was found to be 3276 kg/m$^3$ and that of shredded spandex was 1386 kg/m$^3$. Particle density of manufactured sand on oven-dried basis was 2.70. Water absorption of manufactured sand was 0.37 as a percentage of oven dry mass.

3.2. Size distribution of shredded pieces of spandex

Test results of size distribution of shredded spandex samples were shown in Figure 1. Shredded form of polyester spandex pieces are shown in Figure 2.

According to the results obtained by sieve analysis, majority of polyester spandex pieces (72%) were passed through the 5mm sieve and retained on the 1.18mm sieve.

Test results of particle size distribution of manufactured sand samples were shown in Figure 3 and Table 1. Accordingly, manufactured sand samples were complied with the requirements specified for medium graded fine aggregate according to BS 882: 1992 (BS882, 1992).

Table 1: Particle size distribution of manufactured sand

<table>
<thead>
<tr>
<th>Test Sieve (mm)</th>
<th>10.0</th>
<th>5.0</th>
<th>2.36</th>
<th>1.18</th>
<th>0.600</th>
<th>0.300</th>
<th>0.150</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing %</td>
<td>100</td>
<td>99</td>
<td>77</td>
<td>54</td>
<td>41</td>
<td>28</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>Specified Requirements for medium graded fine aggregate according to BS 882 : 1992</td>
<td>100</td>
<td>89-100</td>
<td>65-100</td>
<td>45-100</td>
<td>25-80</td>
<td>5-48</td>
<td>0-16</td>
<td></td>
</tr>
</tbody>
</table>
3.3. Properties of mortar prisms

Prisms with cement paste and shredded spandex were cast with 9 different mix proportions to optimize the fabric content which can incorporate into cement matrix. Fabric content was increased from 5% to 35% by volume. As shown in Figure 4 optimum compressive strength was achieved at 25% fabric content by volume.

Optimum flexural strength was observed at 26% of fabric content by volume. Compressive strength and flexural strength of prisms were increased up to certain level and then it was decreased with further increment of fabric content. Accordingly, these results proved that polyester spandex fabric pieces act as fibers in cement matrix.
The text discusses the testing of prisms with 8 different mix proportions to determine suitable admixture types for fabric cement matrix. Flexural and compressive strength were tested at 7 days, and the results are given in Table 2.

Table 2: Flexural and compressive strength test results

<table>
<thead>
<tr>
<th>MIX ID</th>
<th>Admixture Type I</th>
<th>Admixture Type II</th>
<th>W/C</th>
<th>Fabric % by volume</th>
<th>Flexural Strength (MPa)</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FV26/0.5</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>26</td>
<td>8.7</td>
<td>19.2</td>
</tr>
<tr>
<td>FV26/0.5/II</td>
<td>1.2%</td>
<td>-</td>
<td>0.5</td>
<td>26</td>
<td>6.8</td>
<td>15.2</td>
</tr>
<tr>
<td>FV26/0.5/I</td>
<td>-</td>
<td>0.6%</td>
<td>0.5</td>
<td>26</td>
<td>7.5</td>
<td>16.1</td>
</tr>
<tr>
<td>FV26/0.5/I, II</td>
<td>1.2%</td>
<td>0.6%</td>
<td>0.5</td>
<td>26</td>
<td>8.2</td>
<td>14.9</td>
</tr>
</tbody>
</table>

Flexural strength and compressive strength varied with the use of different admixtures, as shown in Figure 6a.

Figure 7 shows the cross section of cast prisms with different types of admixtures. There was no considerable variation in fiber dispersion on the cross section of different types of admixture used samples.
Admixture type II does not prevent segregation of fabric particles from cement paste. But it helps to improve the workability of mixture at low W/C ratios. Admixture type I increase the homogeneity of the mixture while preventing segregation of shredded spandex. Figure 8 illustrates the improvement of surface homogeneity of cast samples with different types of admixtures. It was decided to use both admixture type I and type II to achieve good workability and homogeneous mixture during casting of samples.

Fig. 8. Surface appearance of cast prisms

Normally cementitious products show brittle failure under compression load, but failure pattern observed for polyester spandex embedded samples were different from that conventional failure pattern. These samples did not show sudden failure and separation of particles under compression. Failure patterns under flexural test and compression test were shown in Figure 9 and 10.

Fig. 9. Failure of specimen under flexural load (a) Failure type (b) Fracture surfaces
According to the results obtained, it can be deduced that polyester spandex in a shredded form can be used to manufacture fibre-reinforced cement-based products with the appropriate use of admixtures.

3.4. Properties of paving blocks

Paving blocks were cast with optimum percentage of shredded spandex obtained by testing cement-spandex prisms (i.e. 26% by volume). The mix proportions of the mortar mix used to cast paving blocks are given in Table 3. Water content of the mixtures were adjust to achieve the required workability. Figure 11 shows the surface finish of cast blocks with different mix proportions. Surface smoothness was reduced with the increase of sand content in the mixture. It happens due to the reduction of binder content.
Cast paving blocks were tested for compressive strength according to the method specified in SLS 1425: 2011. Figure 12 shows a typical load deformation variation of a paving block. It can be seen that there is no clear failure point of the load-deformation pattern. However, it is possible to identify the linear and non-linear portions of the load-deformation pattern. As the failure is not brittle, the compressive strength was calculated based on the load corresponding to the change of load-deformation pattern form elastic plastic behavior as shown in Figure 12. Compressive strength and corresponding strain of blocks were summarized in Table 3.

Fig. 12. Load deformation variation of a paving block

Table 3: Test results of paving blocks

<table>
<thead>
<tr>
<th>MIX ID</th>
<th>Constituents percentage by volume</th>
<th>W/C</th>
<th>Compressive Strength (MPa)</th>
<th>Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fabric</td>
<td>Cement</td>
<td>Manufactured sand</td>
<td></td>
</tr>
<tr>
<td>FV26/MS05/0.5/I,II</td>
<td>26</td>
<td>69</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>FV26/MS10/0.5/I,II</td>
<td>26</td>
<td>64</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>FV26/MS15/0.6/I,II</td>
<td>26</td>
<td>59</td>
<td>15</td>
<td>0.6</td>
</tr>
<tr>
<td>FV26/MS20/0.6/I,II</td>
<td>26</td>
<td>54</td>
<td>20</td>
<td>0.6</td>
</tr>
<tr>
<td>FV26/MS25/0.6/I,II</td>
<td>26</td>
<td>49</td>
<td>25</td>
<td>0.6</td>
</tr>
<tr>
<td>FV26/MS30/0.6/I,II</td>
<td>26</td>
<td>44</td>
<td>30</td>
<td>0.6</td>
</tr>
<tr>
<td>FV26/MS35/0.7/I,II</td>
<td>26</td>
<td>39</td>
<td>35</td>
<td>0.7</td>
</tr>
<tr>
<td>FV26/MS40/0.8/I,II</td>
<td>26</td>
<td>34</td>
<td>40</td>
<td>0.8</td>
</tr>
<tr>
<td>FV26/MS45/0.8/I,II</td>
<td>26</td>
<td>29</td>
<td>45</td>
<td>0.8</td>
</tr>
<tr>
<td>FV26/MS50/1.0/I,II</td>
<td>26</td>
<td>24</td>
<td>50</td>
<td>1.0</td>
</tr>
<tr>
<td>FV26/MS55/1.3/I,II</td>
<td>26</td>
<td>19</td>
<td>55</td>
<td>1.3</td>
</tr>
<tr>
<td>FV26/MS60/1.6/I,II</td>
<td>26</td>
<td>14</td>
<td>60</td>
<td>1.6</td>
</tr>
</tbody>
</table>
FV26/MS20/0.5/I,II mixture satisfied the strength requirements specified in SLS 1425: 2011 for strength class 4 which can apply for pedestrian use. These blocks have an ability to absorb energy due to its plastic deformation property.

4. Conclusions

Spandex waste in the shredded form can be effectively utilized to produce cement based products which do not require high compressive strength. Shredded fabric pieces showed fiber effect with improvement in the flexural strength and compressive strength of cement paste. The optimum mix with respect to strength was obtained at 26% fabric percentage (by volume). Fabric, cement and sand mixture can use for foot paths which gives better walking comfort due to its energy absorbing capability.

Acknowledgement

The authors wish to express their heartfelt gratitude to personnel at BMRTD, NBRO and the Department of Civil Engineering of University of Moratuwa laboratory staff for the encouragement and the support given by them to carry out this research project.

References

Development of Rapid Method for the Determination of Sulphate Content in Ordinary Portland Cement

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Abstract

Sulphate content is an indirect measure of the amount of gypsum or calcium sulphate (CaSO4) in cement and also an indication of setting time. Excess amount of gypsum can cause expansion and corrosion of steel reinforcement and therefore sulphate content in concrete is a critical factor which needs controlling. Determination of sulphate (as SO3) in cement (Ordinary Portland Cement, Blended Hydraulic Cement, Portland Limestone Cement, Portland Pozzolanic Cement Portland slag cement, Portland Fly ash cement and fly ash) by SLS ISO 29581:2011-Part 1 is a gravimetric method. The method is time consuming (approximately 2-3 days) and is unfavourable for construction industry. Development of a test for Sulphate determination with a shorter testing time and validation of results traceable to the standard method are important aspects in developing alternative tests.

The estimation of Sulphate by turbiditometry in a conditioned BaCl2 medium was applied as the alternative test. The working range was selected from 0.2 to 17.0% m/m to capture sulphate content in cement in Sri Lanka and regulatory limits in SLS standard (maximum permissible limit is 4.0%, m/m). Ordinary Portland cement sample was spiked at three different fortification levels (2.5%, 7.5%, and 13.5%, m/m) and recovery percentage at three different levels was within 80-120%, m/m with intermediate precision limits 0.42%, 1.31% and 2.95%, m/m respectively. The Limit of Quantification and Limit of Detection of the test were 0.07% m/m 0.03% m/m respectively. Method performance was evaluated by proficiency testing programme (ITI/CHE & MEC/CEMENT/2018/01, Sri Lanka) and Z score of test results was 0.31 which was within satisfactory level. The testing time was measured for all tests and average time was two hrs. That is 96 % is shorter than the required time in SLS prescribed method.

**Keywords:** Ordinary Portland cement; Turbidmetric; Sulphate in Cement
1. Introduction

1.1 General

Concrete has become a major construction material due to its versatility, durability and sustainability in all over the world. Cementous material in concrete plays a major role in concrete that directly affect quality, durability and sustainability of concrete structure. Therefore, quality of cement should be critically assessed throughout the manufacturing to construction process.

Cement is a finely ground powder of Calcium Silicates and other Calcium compounds having important chemical reaction when mixed with water, called hydration that act as strong binding medium for the aggregate particles. Different type of pozzalanic materials are blended with cement as minor constituents such as fly ash, silica fumes, slag and etc. to enhance the resistance of structure against impacts from the environment.

Sulphate is listed as a minor constituent that mainly comes from addition of a small amount of gypsum (CaSO$_4$: 2H$_2$O) which is used to regulate setting time of the finished cement. The Cement manufactured in Sri Lanka has Sulphates in the range 1.0-4.0 %, m/m and the amount of allowable sulphate in cement as per SLS 107:2015 for ordinary Portland cement, SLS 1247:2015 for blended hydraulic cement and SLS 1253:2015 for Portland limestone cement are 4.0 %, m/m. Excess sulphate can lead to strength loss due to expansion (moisture trapping) and spall of surface layers in concrete structure. Ettringite (Ca$_6$A$_3$CaSO$_4$.32H$_2$O), thaumasite (CaCO$_3$.CaSO$_4$.CaSiO$_4$.15H$_2$O), and gypsum (CaSO$_4$.2H$_2$O) are three minerals that are identified as major three components for expansion of structures. Ettringite is found most prominent deterioration product among the other products. Ettringite formation is best expressed by the following ionic equation.

\[
6\text{Ca}^{2+} + 3\text{SO}_4^{2-} + 2\text{Al(OH)}_2^+ + 4\text{OH}^- + 26\text{H}_2\text{O} \rightarrow 3\text{CaO}.\text{Al}_2\text{O}_3.3\text{CaSO}_4.32\text{H}_2\text{O}
\]

The sulphate content should be controlled as per the SLS specifications as well as in international standards which should not be more than 4.0% m/m as sulphur trioxide (SO$_3$).

In construction industry, Sulphate in cement is determined gravimetrically as per SLS ISO 29581:2011. This method involves series of cumbersome steps, and takes a longer time. The calculated average time per test in a well experienced laboratory is around 48 hrs. This is a limitation in use of this test in industry as contractors have to wait long hours for concrete mix preparation until the test is passed. Reducing the time taken for the test, optimizing the test conditions to a less cumbersome procedure with required accuracy and precision were concerns in the construction sector stakeholders. Hence, development of an alternative method for sulphate determination and validation of the test according to international standards for analytical method validations was the aim of this research.
1.2 Alternative test methods

Determination of quantitatively formed barium sulphate by gravimetry and spectrophotometry are the most widely used tests in analytical chemistry. The SLS ISO 29581:2011 uses gravimetric method where formed BaSO₄ turbid in solution is gravimetrically determined. There is another method which use spectrophotometric determination where sulphate is reacted with barium chloride in a special conditioned medium containing acetic acid. In this medium the BaSO₄ forms a uniform suspension to cause turbidity in the medium. The amount light scattered through (absorbance) this turbid medium is directly proportional to concentration of BaSO₄. This method of SO₃ determination was used in the alternative method.

1.3 Method validation

According to International Standard Organization, method validation or method verification is required when developed or modified test methods are used for determination of constituents to assess its the performance against accepted standard method. Method validation criteria require computation of working range, limit of determination (LoD), limit of quantification (LoQ), accuracy, precision, selectivity and measurement uncertainty for validation of alternative methods that is stated in Eurachem guidelines (2014).

1.3.1 Working range

The working range is a measurable concentration interval bound by acceptable lower and an upper limit. There are two types of working ranges; Instrument working range: relates to instrument's liner response range corresponding to the concentration of the determinant and method working range is acceptable concentration of the determinant representing the test samples.

1.3.2 Limit of detection (LoD)

The lowest concentration of determinant that can be detected by the method at a specified level of confidence, but not necessarily quantifiable.

1.3.3 Limit of quantification (LoQ)

The lowest concentration of determinant that can be experimentally quantified by the method at a specified level of confidence.

1.3.4 Accuracy

Accuracy is an indication of closeness of a results to its true value. It is determined as two components: trueness and precision. Trueness is an expression of how close the mean of an infinite number of results (produced by the method) is to its true value. Since it is not possible to take an infinite number of measurements, trueness cannot be measured. Therefore, in practice the trueness is expressed quantitatively in terms
of ‘bias’. Bias is a quantitative term relating to difference between the average of measurements made on the same methodology and its true value.

Precision is an indication of how close is two or more measurements to each other or the spread of results obtained from under any criteria. The measures of precision are “measurement repeatability”, “measurement reproducibility” and “intermediate precision”. Measurement repeatability is a measure of the variability of results when a measurement is performed by a single analyst using the same equipment over a short timescale. Measurement reproducibility is a measure of the variability in results between laboratories. Intermediate precision provides an estimate of the variation in results made in a single laboratory but under conditions that are more variable than repeatability conditions reflecting all sources of variation that will occur in a single laboratory under routine conditions. Throughout the validation criteria, at least measurement repeatability and measurement reproducibility or intermediate precision should be evaluated.

1.3.5 Selectivity

Selectivity is an indication of the behaviour of a determinant in a mixtures or matrices without any interferences from other materials having similar behaviours.

1.3.6 Measurement uncertainty

Uncertainty of the measurement is a statistically dispersed value which is attributed to the quantity being measured.

2. Materials

2.1 Chemicals and regents

Hydrochloric acid (37%, sigma-aldrich in Austria, 1 mL), Barium chloride solution; Barium chloride dihydrate (99.9%, vwr-chemicals in Spain, 1.2 g) was dissolved in distilled water (type III, 100 mL); Sulphate stock solution (1000 mg/L); Anhydrous potassium sulphate (101%, sigma-aldrich in Germany, 0.90625 g) was dissolved in distilled water (type III, 500.0 mL); Sulphate intermediate stock solution (100 mg/L); Sulphate stock solution (1000 mg/L, 10 mL) was diluted with distilled water (type III, 90 mL) and buffer solution; Magnesium chloride hexahydrate (100.2%, vwr-chemicals in Belgium, 15.0 g), Sodium acetate trihydrate (99%, sigma-aldrich in Germany, 2.5 g), Potassium nitrate (99%, sigma-aldrich in Germany, 0.5 g) and Acetic acid (100%, vwr-chemicals in France, 10 mL) were dissolved in distilled water (type III, 500.0 mL).

2.2 Instrument and Equipment

UV-Vis spectrophotometer and glass cells (analytikjena-SPECORD 210 PLUS in Germany, 1 cm path length) were used for spectral measurements, analytical balance
innovation for build back better

(shimadzu-AUW 120D in Japan, 5 digit) was used for weighing samples and authentic samples, calibrated class A; bulb pipettes (10.0, 20.0, 25.0 mL), graduated pipette (5.0 mL), volumetric flasks (50.0, 100.0, 250.0 mL), measuring cylinder (50 mL) and glass beakers (500 mL) were used for volumetric measurements. 150 μm sieve, ashless filter paper (whatman no. 42) and oil sealed roughing pump were used for preparation of laboratory test sample and sample filtration.

3. Methodology

3.1 Preparation of laboratory test sample

Approximately 100g of the laboratory sample was obtained by cone and quartering method that was sieved through 150 μm sieve, and then collected the passed portion through the sieve. Whole process was carried out as quickly as possible to minimize the test sample exposure to ambient air.

3.2 Preparation of calibration curve

Solutions for five calibrating points (5.0, 10.0, 20.0, 30.0 and 40.0 mg/L) were prepared into 50.0 mL volumetric flask for the calibration curve. Each calibrators were treated with buffer solution (10 mL) and Barium Chloride solution (10 mL), and allowed to stand for 30-40 min with occasional inverted shaking. Then the absorbance was measured in UV spectrophotometer at 420 nm.

3.3 Sample preparation

Sample (1.00 ± 0.05 g to ± 0.0005 g) was weighed and treated with distilled water (90 mL) and concentrated hydrochloric acid (10 mL). Treated sample was digested (90 ± 5 °C) for 15 min while stirring and followed by washing with hot water (approximately 150 mL). The filtrate with washing containing sulphate ions was transferred quantitatively into a volumetric flask (250 mL) and made up with distilled water. Then a 20mL of sample was transferred into volumetric flask (100 mL) and treated with buffer solution (20 mL), barium chloride solution (20 mL) and finally top-up with distilled water. Then it was allowed to stand for 30-40 min with occasional inverted shaking. The absorbance was measured by UV-spectrophotometer at 420 nm.

3.4 Calculation for determination of Sulphate content as % mass

\[ W_{SO_3\text{(percent mass)}} = \frac{2.083 \times C}{V \times m_1} \]

\[ m_1 = \text{Mass of the test portion (g)} \]
\[ C = \text{Concentration of sulphate in sample (mg/L)} \]
\[ V = \text{Volume of sample (mL)} \]

3.5 Method validation

For the method validation, working range, LoD & LoQ, accuracy, precision, selectivity and uncertainty were determined as follows.
3.5.1 Working range

Absorbance of fifteen calibration points in the range of 1 to 100 mg/L sulphate were measured. The linear regression statistic of observed data were calculated for best fit curve (Instrument working range) at 95% confidence interval. The method working range was computed by the instrument working range and the maximum (50.0 mL) and minimum withdrawn volume (5.0 mL) for turbid formation at 95% confidence interval. Maximum and minimum volume were chosen to ensure the reliability of withdrawn volume and to reduce spectral interferences with colour and particulate matter.

3.5.2 LoD and LoQ

LoD and LoQ were fit by spiking ten regent blanks with 1 mg/L of sulphate independently. The measured concentration in the calibration graph were analysed for average (X) and adjusted standard deviation (S'), The LoD and LoQ were determined as LoD= X + 3. S' and LoQ = X + 10. S'. Adjusted standard deviation was calculated as S'/2 = S' x (1/n_s + 1/n_b) where S = standard deviation of observed results, n_s = number of replicate sample used in methodology (n_s = 2) and n_b = number of blank sample used in methodology (n_b = 1).

3.5.3 Accuracy

Accuracy of the method was determined by calculating % recovery, Bias and 2S statistic. For this the samples, 10 replicates of each were spiked corresponding to 2.5%, 7.5% and 13.5% m/m Sulphate respectively to cover the method working range. The corresponding % recovery was calculated by R% = X_{measured}/X_{spiked}; X_{measured} = Measured Quantity and X_{spiked} = actual spiked quantity. The bias was calculated as Bias = X_{spiked} – X_{average} for the three sets of replicates. Where X_{average} is average of measured quantity of 10 replicates corresponding to three spike levels interpreted as m/m %. Then the standard deviation S was calculated for 10 replicates corresponding to three spike levels and then calculated biases for three spike levels were compared with the 2S statistic.

3.5.4 Precision

Precision (measurement repeatability limit) and intermediate precision (measurement reproducibility limit) of test method were calculated for each spiking levels separately at 95% confidence interval; I (Repeatability limit) = 2.8 x S_r where S_r = standard deviation of repeatability that was calculated from data acquired for determination of method bias. I (Intermediate precision limit) = 2.8 x S_{within} + S_{between} where S_{within} = contribution to the total variation from the grouping factor. S_{between} was extracted from ANOVA test in Excel, performed for data obtained from two analysts at each spiking level.

3.5.5 Selectivity

Substantial differences in recovery at three different levels were evaluated in accordance to the observed results for bias analysis.
3.5.6 Uncertainty

Uncertainty of the test result was calculated for each spiking level in accordance to JCGM: Evaluation of measurement data-Guide to expression of uncertainty in measurement where k (coverage factor) was taken as 2 at 95% confidence interval.

4. Results and Discussion

4.1 Working range, LoD and LoQ

Instrument liner range was observed from 0.5 to 40 mg/L for 1 cm path length with liner regression coefficient greater than 0.9500. The corresponding method working range was 0.2% to 17.0% m/m that is sufficient to capture sulphate content in cement in Sri Lanka and regulatory limits in SLS standards. The calculated LoD and LoQ were 0.02%, 0.07% m/m respectively.

4.2 Accuracy

Observed results were summarized in table1. Recovery percentages were observed within satisfactory interval (80-120 %) at three different spike levels recommended in Eurachem guidelines. Calculated biases of test methodology fall within critical limits (±2S, S= Standard deviation of replicates data at specific spiking level) that shows, the average of measurements and its true value were very much close to each other.

<table>
<thead>
<tr>
<th>Determinant spike level (% , m/m)</th>
<th>Recovery range (%)</th>
<th>±2S (% ,m/m)</th>
<th>Bias (% , m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.50</td>
<td>83-100.5</td>
<td>0.29</td>
<td>0.18</td>
</tr>
<tr>
<td>7.5</td>
<td>83-101.2</td>
<td>0.91</td>
<td>0.70</td>
</tr>
<tr>
<td>13.5</td>
<td>88.9-108.9</td>
<td>2.02</td>
<td>0.28</td>
</tr>
</tbody>
</table>

4.3 Precision

Calculated measurement repeatability and reproducibility limits were summarized in table2. Measurement repeatability limits were narrower than the observed reproducibility limits because basis of variable components to reproducibility were significantly larger than repeatability.

<table>
<thead>
<tr>
<th>Determinant spike level (% , m/m)</th>
<th>Measurement repeatability limit (% ,m/m)</th>
<th>Measurement reproducibility limit (% ,m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.50</td>
<td>0.41</td>
<td>0.42</td>
</tr>
<tr>
<td>7.5</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>13.5</td>
<td>2.62</td>
<td>2.95</td>
</tr>
</tbody>
</table>
4.4 Selectivity

The recovery of the methodology was within 80-120 % where substantial differences in recovery at three different concentration ranges were not observed showing that matrix effect on determinant was not a significant factor.

4.5 Uncertainty

Expanded uncertainties at each spiking levels were calculated as 0.20 %, 0.60 %, and 1.06 % m/m respectively for three spike levels as per in JCGM.

4.6 Z score of method performance

Method performance was evaluated using proficiency testing programme (ITI/CHE & MEC/ CEMENT/ 2018/01, Sri Lanka), the Z score was 0.31 that was within the satisfactory level; |Z| < 2.

4.7 Reduction in testing time and power saving

On the average two hours was enough to be completed entire test for Sulphate analysis in the new method. That was 96 % shorter than analysis time required in the standard method: SLS 29581:2011 for which approximately 2-3 days was required to complete the entire test. Also, modified method was power saving choice when compared with standard method because muffle furnace used in standard method was omitted in modified method.

5. Conclusion

New methodology is validated according to standard validation criteria acceptable to ISO 17025 quality management system. It is capable to produce test results in par with the standard method; SLS 29581:2011 analysis by wet chemistry with required accuracy and precision. This method allows quantifying SO$_3$ in a range (0.2-17.0 %, m/m and has the capability to produce results within practical working range that represent Sulphate contents in Cements. The average testing time is 2 hrs. Which is 96 % lower than the testing time in method prescribed in the SLS 29581-1:2011.

6. References

Development of Fibre Cement Composites Reinforced with Natural Fibres
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Abstract

The study is focused on finding a suitable cellulose fibre available in Sri Lanka as a fibre reinforcement in the cement matrix to cast corrugated roofing sheets with a sufficient durability. The degradation mechanism of cellulose fibres in the cement matrix mainly consists of fibre mineralization and thus, embrittlement of fibres due to the hydration of cement. Besides, the amount of lignin, hemi-cellulose and cellulose from amorphous regions affects the degradation mechanism. The fibres were characterized with respect to the morphology by the scanning electron microscopic (SEM) images and density. The cement matrix was modified by incorporating coal fly ash in order to reduce the degradation rate by reducing or removing the alkaline compounds. The durability of fibres in the cement matrix were investigated by casting prisms followed by accelerated aging and strength test. The most suitable cellulose fibres and the matrix modification to improve the durability were identified based on the experimental data.

Keywords: cellulose fibres; durability; degradation; cement matrix; composite

1. Introduction

Fiber cement board is one of the known construction products that can be used as an internal/external wall as well as materials for roofing. Due to the identification of health hazards associated with asbestos, researchers have focused on cellulose fibers to exploit the position of asbestos in building materials. Cellulose fibers exhibit a set of important advantages, such as wide availability at relatively low cost, bio renewability, ability to be recycled, biodegradability, non-hazardous nature, zero carbon footprint, and interesting physical and mechanical properties (low density and well-balanced stiffness, toughness and strength) (Ardanuy, Claramunt, & Toledo Filho, 2015; Satyanarayana, Arizaga, & Wypych, 2009). Cellulose fibers can be found in a wide variety of morphologies – diameter, aspect ratio, length and surface roughness – and form – mainly strands, pulp or staple. Moreover, their surface can be easily modified
in order to have a more hydrophilic or hydrophobic character or to attach functional
groups (Faruk, Bledzki, Fink, & Sain, 2012).

The major advantage of fiber reinforcement is the behavior of the composite after
 cracking has started, as the fibers bridge the matrix cracks and transfer the loads. The
post cracking toughness may allow more intensive use of such composites in building.
Despite all the aforementioned advantages, the industrial production of cement-based
composites reinforced with cellulose fibers is currently limited by the long-term
durability of these materials. The durability problem is associated with an increase in
fiber fracture and a decrease in fiber pull-out due to a combination of the weakening of
the fibers by alkali attack, fiber mineralization due to the migration of hydration
products to lumens, and space and volume variation due to their high water absorption
(Ardanuy et al., 2015).

As it is known, the majority of the cellulose cement composites are based on
ordinary Portland cement (OPC). This agglomerate hardens by hydration of
anhydrous compounds giving rise to calcium silicate hydrate (CSH gel), ettringite and
calcium hydroxide or portlandite. Excess water evaporates during the curing period
leading to porous network hydrated cement paste. This porosity is one of the causes of
the lack of durability of the cement paste, given that it allows the access of water which
can contain different dissolved substances (chloride or sulphate salts or acids among
others) or gases from the outside into the cement matrix. Furthermore, depending on
climatic conditions, the pore network may be dry, semi-saturated and saturated (in
humid weather with >65% relative humidity). Under these conditions, the interstitial
water dissolves calcium hydroxide to form a buffered solution of pH>13. Many studies
have related the presence of this calcium hydroxide with the degradation of cellulose
fibres, and thus with the loss of durability of the cellulose fiber reinforced cement-
based composites (Ardanuy, Claramunt, García-Hortal, & Barra, 2011; Mohr,
Biernacki, & Kurtis, 2006; Romildo D Toledo Filho, Scrivener, England, & Ghavami,
2000; Tonoli et al., 2011). Mohr et al. (Mohr, Nanko, & Kurtis, 2005) recognized the
following sequence of damage which occurs in the cellulose fibres when the composite
is subjected to various wet–dry cycles: (a) loss of adherence between the fibre and the
matrix after the second wet–dry cycle; (b) reprecipitation of the hydrated compounds
within the void space at the former fiber–cement interface during the first ten wet–dry
cycles; (c) full mineralization, and thus the embrittlement of the cellulose fibres after
ten wet–dry cycles.

The two main strategies are suggested by the researchers for improving the
durability of the cellulose-fibre reinforced cement based composites. One possibility is
to modify the composition of the matrix in order to reduce or remove the alkaline
compounds. The second technique is to modify the fibres with chemical or physical
treatments to increase their stability in the cementitious matrix (Ardanuy et al., 2015).

In this study three fibre types were selected by considering the availability and
affordability in Sri Lanka. The fibres were characterized with respect to the
morphology and density. The matrix modification was adopted in order to improve the
durability of the composite by partial replacement of cement with coal fly ash by 30% of
weight. Mortar prisms were cast incorporating each fibre in varying amounts and
the 7-day and 28-day strengths and strength after 50 cycles of soak-dry were obtained.
2. Methodology

2.1 Raw materials

Three types of cellulose fibres, i.e. soft coir, hard coir and Palmyra fibres, were selected for the experimental investigation. Soft coir and hard coir fibres were purchased from Hayleys Fibre PLC and Palmyra fibres were purchased from Palmyra Development Board. The fibre strands were cut into small lengths (less than 10 mm). Most of the fibres were in 5 to 8 mm in length. Ordinary Portland cement and fly ash satisfying the relevant product standards were used for the casting of mortar prism and corrugated sheets.

2.2 Material Properties

The volume of a fibre strand was calculated by the dimensions taken from SEM images. Thereby, the density of each fibre type was calculated. The elemental composition of coal fly ash was analysed using X-ray fluorescence (XRF) method by Sri Lanka Institute of Nanotechnology. The density of coal fly ash was measured by using the density bottle as given in SLS 1144: Part 2.

2.3 Casting and testing of cement-fibre prisms

Prisms with cement paste and fibre were cast by using OPC, coal fly ash and cellulose fibres. In each mix, cement was partially replaced with coal fly ash by 30% (weight). The water: cement ratio of the paste was varied from 0.38 to 0.5 as given in Table 2. Type and amount of fibre in the mix was varied as given in Table 2. The cement-fibre prisms were cast in accordance with the procedure given in SLS 107: Part2. The cast prisms were cured in water at 27±3°C for 28 days.

Flexural and compressive strength of prisms were obtained at 7 days and 28 days in accordance with the procedure given in SLS 107: Part 2. Durability test was performed as per the ISO 10904: 2011(E) test method by completing 50 soak and dry cycles for the specimens having 2% and 4% of fibres.

2.4 Preparation of corrugated sheets

The optimum mix proportion which satisfied the durability requirement as per ISO 10904:2011(E) was used for the preparation of corrugated sheet. The selected size of the corrugated sheet is 480 mm × 480 mm × 8mm (length, width and thickness).

The cement-fibre mix was produced using the pan mixer having a frequency of 50Hz. Cement, fly ash and fibre were dry mixed for 60s (See Fig 1. (a)) and then 85% of the total water content was added and mixed well. After adding remaining water into the running mixer, the mixing was continued for another 3 to 5 min to obtain a uniform mix (See Fig 1. (b)).

For the casting of corrugated sheets, a plastic sheet was placed on the vibrating table having a frequency of 60Hz and the mix was spread on it followed by vibration for 45s-60s (see the Fig. 1.(c) and Fig. 1.(d)). The wet mix was carefully placed on a mould so that it takes the corrugated shape of the mould (see the Fig. 1.(e) and Fig. 1.(f)). Asbestos corrugated sheet was used as the mould. Then the wet sheet was covered by
another polythene sheet and kept for 24 hours in the laboratory air dry condition. Thereafter, the tile was removed from the mould and cured in the water. Curing was done for 14 days prior to testing. Then tiles were air cured for another 14 days at ambient temperature. Casting procedure is shown in Figure 1.

(a) Dry mixing of raw materials
(b) Machine mixing by adding water
(c) Spreading the mix on the vibrating table
(d) Vibrating the mixture
(e) Wet mix is carefully placed on the mould (corrugated asbestos sheet)
(f) Final shape of sheet

**Figure 1: Casting procedure of corrugated sheets**

2.5 Laboratory tests

The three point bending test was performed for the cellulose fibre cement corrugated sheets and the asbestos fibre corrugated sheets having the same dimensions as per the test method given in ISO 10904: 2011(E) where the test span was 460mm.
3. Results and Discussion

3.1 Fibre density

Calculated density of the soft coir fibre, hard coir fibre and Palmyra fibre were shown in Table 1.

<table>
<thead>
<tr>
<th>Fibre Type</th>
<th>Calculated Density (kgm⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft coir fibre</td>
<td>267.9</td>
</tr>
<tr>
<td>Hard coir fibre</td>
<td>355.0</td>
</tr>
<tr>
<td>Palmyra fibre</td>
<td>258.0</td>
</tr>
</tbody>
</table>

Figure 2 shows the SEM images which were used to obtain the fibre volume.

Figure 2: SEM images of cellulose fibres
3.2 Flexural strength, Compressive strength, Water absorption and Composite density of cement-fibre prisms

Flexural strength and Compressive strength test results of the three types of fibres and with no fibre samples are given in Table 2. As expected,

Table 2: Flexural strength, compressive strength, water absorption and the density of cement-fibre prisms

<table>
<thead>
<tr>
<th>Water Cement Ratio</th>
<th>Identification Mark</th>
<th>Fiber Amount</th>
<th>Fiber Type</th>
<th>Strength (N/mm²)</th>
<th>Water Absorption (%)</th>
<th>Composite Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexural 7 Days</td>
<td>28 Days</td>
<td>Compression 7 Days</td>
</tr>
<tr>
<td>0.5</td>
<td>C70/FA30/WC0.5</td>
<td>0</td>
<td>Palmyrah</td>
<td>8.4</td>
<td>45.4</td>
<td>19.74</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/P2/WC0.5</td>
<td>2</td>
<td>Hard Coir</td>
<td>7.6</td>
<td>38.9</td>
<td>18.25</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/WC0.5</td>
<td></td>
<td>Soft Coir</td>
<td>6.2</td>
<td>40.2</td>
<td>18.25</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/SC2/WC0.5</td>
<td></td>
<td>Palmyrah</td>
<td>7.5</td>
<td>37.2</td>
<td>19.03</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/P4/WC0.5</td>
<td>4</td>
<td>Hard Coir</td>
<td>11.6</td>
<td>32.2</td>
<td>22.05</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/HC4/WC0.5</td>
<td></td>
<td>Soft Coir</td>
<td>10.3</td>
<td>35.0</td>
<td>22.09</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/SC4/WC0.5</td>
<td></td>
<td>Palmyrah</td>
<td>8.4</td>
<td>39.5</td>
<td>22.1</td>
</tr>
<tr>
<td></td>
<td>C67/FA30/P5/WC0.5</td>
<td>5</td>
<td>8.9</td>
<td>23.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.45</td>
<td>C70/FA30/WC0.45</td>
<td>0</td>
<td>Palmyrah</td>
<td>8.1</td>
<td>58.1</td>
<td>19.43</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/P2/WC0.45</td>
<td>2</td>
<td>Hard Coir</td>
<td>7.1</td>
<td>42.3</td>
<td>20.45</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/WC0.45</td>
<td></td>
<td>Soft Coir</td>
<td>7.4</td>
<td>40.5</td>
<td>19.57</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/WC0.45</td>
<td></td>
<td>Palmyrah</td>
<td>8.3</td>
<td>55.4</td>
<td>16.72</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/P2/WC0.4</td>
<td>2</td>
<td>Hard Coir</td>
<td>7.3</td>
<td>54.4</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/WC0.4</td>
<td></td>
<td>Soft Coir</td>
<td>8.3</td>
<td>75.5</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/WC0.4</td>
<td></td>
<td>Palmyrah</td>
<td>7.8</td>
<td>56.2</td>
<td>16.86</td>
</tr>
<tr>
<td>0.4</td>
<td>C70/FA30/WC0.4</td>
<td>0</td>
<td>8.3</td>
<td>65.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C70/FA30/P2/WC0.4</td>
<td>2</td>
<td>Palmyrah</td>
<td>7.3</td>
<td>54.4</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/WC0.4</td>
<td></td>
<td>Soft Coir</td>
<td>8.3</td>
<td>75.5</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/WC0.4</td>
<td></td>
<td>Palmyrah</td>
<td>7.8</td>
<td>56.2</td>
<td>16.86</td>
</tr>
<tr>
<td>0.38</td>
<td>C70/FA30/SC2/WC0.38</td>
<td>2</td>
<td>Soft Coir</td>
<td>3.9</td>
<td>83.3</td>
<td>14.96</td>
</tr>
</tbody>
</table>
3.3 Flexural strength and Compressive strength of cement-fibre prisms subjected to wetting and drying process under the durability test

Table 3 shows the flexural and the compression strength of the specimens subjected to wetting and drying process as per the durability test specified in ISO 10904: 2011(E). The percentage strength reduction after the specified number of wetting and drying cycles was calculated with respect to 28-day strength results. Less than 30% flexural strength reduction can be considered as satisfactory for the durability requirement of cement-fibre composite according to the ISO 10904:2011 standard.

Table 3. Strength results that obtained after the durability test.

<table>
<thead>
<tr>
<th>Water Cement Ratio</th>
<th>Identification Mark</th>
<th>Fiber Amount</th>
<th>Fiber Type</th>
<th>Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Days</td>
<td>Aged S.R.</td>
</tr>
<tr>
<td>0.5</td>
<td>C70/FA30/P2/ WC0.5</td>
<td>2</td>
<td>Palmyrah</td>
<td>7.6 2.8 63 53</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/ WC0.5</td>
<td></td>
<td>Hard Coir</td>
<td>8.3 2.9 65 58.2</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/ WC0.5</td>
<td></td>
<td>Soft Coir</td>
<td>7.3 2.7 63 53.1</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/P4/ WC0.5</td>
<td>4</td>
<td>Palmyrah</td>
<td>12 5.2 57 81.5</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/HC4/ WC0.5</td>
<td></td>
<td>Hard Coir</td>
<td>10.3 7.7 25 49.2</td>
</tr>
<tr>
<td></td>
<td>C68/FA30/SC4/ WC0.5</td>
<td></td>
<td>Soft Coir</td>
<td>11.6 2.6 78 57.0</td>
</tr>
<tr>
<td>0.45</td>
<td>C70/FA30/P2/ WC0.45</td>
<td>2</td>
<td>Palmyrah</td>
<td>9.65 4.3 50 70.42</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/ WC0.45</td>
<td></td>
<td>Hard Coir</td>
<td>9.65 5.9 39 65.5</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/ WC0.45</td>
<td></td>
<td>Soft Coir</td>
<td>9.4 4.55 52 70.625</td>
</tr>
<tr>
<td>0.4</td>
<td>C70/FA30/P2/ WC0.4</td>
<td>2</td>
<td>Palmyrah</td>
<td>8.6 4.1 52 75.5</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/HC2/ WC0.4</td>
<td></td>
<td>Hard Coir</td>
<td>8.65 5.15 40 73.6</td>
</tr>
<tr>
<td></td>
<td>C70/FA30/SC2/ WC0.4</td>
<td></td>
<td>Soft Coir</td>
<td>9 3.3 57 75.0</td>
</tr>
<tr>
<td>0.38</td>
<td>C70/FA30/SC2/ WC0.38</td>
<td>2</td>
<td>Soft Coir</td>
<td>3.7 1.71 54 80.5</td>
</tr>
</tbody>
</table>

% S.R.: Percentage Strength Reduction

3.4 Breaking load results of three point bending test of corrugated sheet

Table 4 shows that the average breaking load per meter of width of the sheet for both cellulose fibre and asbestos cement corrugated sheets for the comparison. According to the ISO 10904:2011 standard, the sheets falls under category C where the sheet corrugation height is in between 40 mm and 80mm. According to ISO 10904 standard, minimum breaking load requirement for category C is 1400 N/m.
Table 4. Test results of corrugated sheet three point bending test

<table>
<thead>
<tr>
<th>Type</th>
<th>Breaking load per meter of width (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C70/FA30/P4/WC O.45</td>
<td>1100</td>
</tr>
<tr>
<td>C70/FA30/HC4/WC O.45</td>
<td>1400</td>
</tr>
<tr>
<td>Asbestos</td>
<td>2300</td>
</tr>
</tbody>
</table>

4. Conclusions

According to the cement-fibre prism test results, Palmyrah fibre-cement composite has given the better flexural and compressive strengths and lowest composite density at 4% fibre and 0.5 water/cement ratio. The fibre length should be less than 10 mm preferably 5m to 8 mm, to avoid the anisotropic behaviour of composite. According to durability test results, hard coir fibre-cement composite which contains 4% fibre and 0.5 water/cement ratio gave better flexural strength and lowest strength reduction in the durability test. Corrugated sheet with 4% hard coir fibre in OPC-Fly ash (30%) binder with w/c of 0.45 gave sufficient strength to satisfy breaking load requirement for roofing sheet Category C specified in ISO 10994:2011.

Acknowledgement

The authors wish to express their heartfelt gratitude to the Building Materials Research and Testing Division of NBRO, the University of Moratuwa laboratory staff for the encouragement and the support given during this research project.

References


Development of Guidelines for Selection of Materials and Products for Construction Industry

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Abstract

This project is on compiling a handbook on the selection of various construction materials and products indicating their applications, properties and the test methods or technical specifications to which the materials are required to test for. The objective of this research is to assist professionals in construction industry by giving awareness of available construction materials and products and thereby reducing the misuse of materials, improving the selection of appropriate materials and products by giving relevant specifications and standards to be specified in contract documents. This will ultimately help to improve the performance, safety, durability and cost effectiveness in construction practices. Furthermore this will assist to select and specify essential requirements of construction products and materials appropriate for energy efficiency and sustainable use. In the proposed handbook, materials are mainly categorized into four volumes, viz., Building works, Sanitary Installation, Electrical/Data and Building Services.

Keywords: handbook; construction professionals; materials; products; sustainability

1. Introduction

Recently, several buildings were collapsed in different parts of the country as a result of substandard construction practices. Decades ago, such building collapses were quite unheard of. One of the reasons apart from poor workmanship for such mishaps is the improper material selection for construction. With the emerging construction sector in Sri Lanka, there are numerous new construction materials and products available, either imported or manufactured locally, but many of those are novel to engineers, architects, quantity surveyors, building contractors and house builders. Hence, it is necessary to have information on construction materials and products compiled into a single document, indicating their applications, properties and the test methods or technical specifications to which the materials are required to test for. Thus, in future, this document, which is essentially a material and products selection handbook, will assist construction professionals to select the most suitable
material among a wide range of available materials and specify the essential requirements and relevant standards to refer the material/product to be satisfied in the contract/documents.

2. Objectives

Development of a handbook for selection of construction materials and products which will enable construction industry professionals to be aware of available construction materials and products and this will assist them in the selection of appropriate materials necessary for a specific requirement.

3. Mode of Intervention

At present, there is no country specific construction material and products selection handbook or guidelines for the construction industry professionals in Sri Lanka, to ensure that the most appropriate materials and products are being used in civil engineering constructions, which necessitates the need for NBRO to take a proactive measure in formulating this handbook.

Building Materials Research and Testing Division (BMRTD) laboratory of NBRO is one of the oldest testing laboratories established for testing of construction materials in Sri Lanka. Presently its services has expanded considerably, making itself as one of the leading and reputed laboratories in Sri Lanka. BMRTD’s services include physical and mechanical testing of laboratory samples, and conducting building investigations, awareness and training programs and R & D in the field of construction materials. Due to its existence, NBRO possesses a comprehensive technical knowhow on construction materials in the aspects of methods of testing, requirements for compliance and specific usages. NBRO holds a database on the test results of those materials which helps to interpret the quality of materials available in the market. Furthermore, many project consultants impose contractors to obtain NBRO test reports prior to a new material is being used in the construction. Over the past few years NBRO has tested such materials for applicable standards and given its compliance and in many cases the client was unaware of such specifications or test methods.

Hence, NBRO wishes to compile this construction materials and products selection handbook using in-house data and data from market survey and with the assistance of relevant authorities and technical experts in the field to gather necessary information in formulating the handbook.

4. Methodology

The handbook will be formulated in four volumes. The first two volumes (I and II) cover the materials and products given ICTAD publication on Building Works Volume I (Construction Industry Development Authority, 2004) which essentially include the materials and products that go into the foundation, substructure and super structure of a building. Volume III comprises of products which are related to electrical and data installation such as switches, sockets, wires and cables etc., The Volume IV consists of materials and products related to building services such as elevators, fire fighting, air conditioning etc.,
The four volumes will be published under the following titles.

**Volume I** - **Building Works** (Include Aggregate, Cement, Water, Fresh concrete, Hardened concrete, Aluminium, Glass, structural Steel, reinforcement, Water proofing, sealants etc.)

**Volume II** - **Sanitary Installations** (Include Tiles, PVC pipe, Ceramic items Water closets & etc)

**Volume III** - **Electrical/Data Installation** (Include Wires & Cables, Electrical Conduits & Fittings, Electrical enclosures, Circuit Breakers, Electrical Boxes and lugs etc.)

**Volume IV** - **Building services** (Include Elevators & Escalators, Fire fighting system, Heating, ventilation & air-conditioning system, Gas supply and Lightning protection system etc.)

*Table 1* is the basic structure of the information will be provided. As shown in *Table 1*, application is mentioned right after the material or product. The same material/product can have different specific usages in building construction. In this handbook under the “Material/Product” item, all these usages relevant to a particular material/product which goes into building construction are listed. Consequently, for each usage, related properties, test methods and requirements are given by referring to all the available local and international standards (i.e. SLSI, BSEN & ASTM). Thereby, the user can have an easy access to the material/product to the given usage and properties to be tested and relevant requirements.

The collection of data was carried out by referring to local/international standards, manufacturer’s specifications. NBRO has in-house knowledge and competent people to formulate the Volume I and Volume II because most of such materials and products are tested at NBRO. For the compilation of Volumes III and IV, it is expected to consult professionals who are having specific knowledge on electrical and building services.
<table>
<thead>
<tr>
<th>Item no</th>
<th>Materials/Products</th>
<th>Application</th>
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<th>Relevant standard/s</th>
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<td></td>
<td>Resistance against manual attack</td>
<td>Description</td>
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<td>- Hard body drop test</td>
<td>See note(^1)</td>
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<td>- Axe test</td>
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<td>For controlling the lighting, heating and cooling properties</td>
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<td>Luminous and solar characteristics of glazing</td>
<td>BS EN 410:2011</td>
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<td></td>
<td>- Light transmittance</td>
<td>Requirement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Light reflectance</td>
<td>BS EN 1096-4:2018</td>
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<td></td>
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<td>- Energy transmittance</td>
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\(^1\)The user may decide as per the design specification

BS EN 356 :2000

BS EN 1096-4:2018
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<th>Relevant standard/s Property</th>
<th>Description</th>
<th>Test methods</th>
<th>Requirements</th>
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<td>Determination of thermal transmittance (U-value)</td>
<td>Calculation method</td>
<td>BS EN 1096-1:2012</td>
<td>BS EN 673:2011</td>
<td>See note 1</td>
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<td>Emissivity</td>
<td>BS EN 12898:2001</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Glazing and airborne sound insulation</td>
<td>BS EN 12758:2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>To vertical partition, to fully insulated, partially insulated &amp; uninsulated vertical doorsets and shutter assemblies, to ceiling membranes and to glazed elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Determination fire resistance</td>
<td>BS 476-22:1987</td>
<td>BS 470-20</td>
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*The user may decide as per the design specification*
<table>
<thead>
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<th>Item no</th>
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<th>Application</th>
<th>Specific usage</th>
<th>Physical &amp; mechanical characteristics</th>
<th>Relevant standard/s</th>
</tr>
</thead>
</table>
| 1.1     | Basic soda lime silicate glass products | For windowpanes | Fire resistant glazing | - Density  
- Hardness  
- Young’s modulus  
- Poisson’s ratio  
- Characteristics bending strength  
- Specific heat capacity  
- Average coefficient of linear expansion between 20°C & 300°C  
- Resistance against temperature different & sudden temperature change  
- Thermal conductivity  
- Emissivity (corrected) | BS EN 572-1:2012  
BS EN 572-9:2012  
BS EN 572-1:2012 |

*The user may decide as per the design specification*
<table>
<thead>
<tr>
<th>Item no</th>
<th>Materials/Products</th>
<th>Application</th>
<th>Specific usage</th>
<th>Relevant standard/s</th>
</tr>
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<td>Property</td>
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<td>Description</td>
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<td>Test methods</td>
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<td>Requirements</td>
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<td>Mean refractive index to visible radiation as per BS ISO 13474:2014 (380nm to 780nm)</td>
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<td>Bending test</td>
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<td>Chemical composition</td>
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<td>Light transmittance</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td>General quality criteria and their evaluation</td>
</tr>
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<td>Optical quality</td>
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<td>Appearance</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>Other materials</td>
</tr>
</tbody>
</table>

1The user may decide as per the design specification.
5. Discussion

It was noted when material standards were referred, sometimes in particular materials, the same property is referred by different names in different standards. For an example, for concrete testing, BS EN 12390-8 standard specify Depth of Penetration Under Water Pressure and for the same property in DIN 1048 refers as Water Permeability. Hence, in such instances a lot of scrutiny is required to identify the primary property that the standard represents because not all the standards are referring the same property by the same name. However, once the handbook is compiled, there should be more clarity with regards to such variations.

Furthermore, sometimes it was difficult to find relevant standards for imported novel products. In such cases it may be necessary to refer to manufacture’s specifications and recommendations.

It is necessary to have the facility to access the current version of standards to ensure that superseded standards are excluded in the handbook. Since the current version of most of the standards are not freely available in the web, it necessary to purchase all the relevant standards for materials and product which will help to maintain a comprehensive database at NBRO for material testing. The revisions of the handbooks will be made once the standards are superseded and also to include new products and materials.

6. Concluding Remarks

In developing this handbook, competent persons with specific knowledge on standards and construction materials and products shall gather information to ensure relevant data are included in the handbook. This handbook will ultimately help to improve the performance, safety, durability and cost effectiveness in construction practices. Furthermore this will also assist to select and specify essential requirements of construction products and materials appropriate for energy efficiency and sustainable use.

Acknowledgement

The authors wish to express their heartfelt gratitude to BMRTD, NBRO staff and the University of Moratuwafor the assistance and guidance given during this research project.

References

ENGINEERING APPROACHES FOR RESILIENCE
Creating a Safe Building Environment through Geotechnical Clearance

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¹Scientist, National Building Research Organisation, Sri Lanka
²Senior Lecturer, University of Moratuwa, Sri Lanka

Abstract

After a 3-decade civil war in the country, Sri Lanka is now at a state of rapid development especially in the infrastructure and its related matters. Many constructions are happening in and around Colombo. This construction phase has even penetrated in to other areas through megapolis development projects. Most of these structures include basements which require excavation and earth support systems. Further, a careful attention must be paid for the construction in hilly areas where there is a susceptibility to landslides and other slope failures.

In this context, it was observed that extensive excavations and loading done on the ground are affecting the safety of adjacent structures. Urban Development Authority (UDA) has requested National Building Research Organization (NBRO) to assist them in the clearance process related to geotechnical matters prior to their approval for construction. During this process, NBRO learnt that the awareness on required documentation is lacking and hence it takes a longer time for processing. This study focuses on addressing that need after following related literature and guidelines. Findings are summarized into several sub topics; preconstruction survey of adjacent buildings, preparation of site investigation report, designing excavation support system, foundation designs, dewatering plans, blasting methods, monitoring process during and after construction, contingency plan and construction in hilly areas. Required documentations to be submitted are summarized according to their relevant submission stage and finally the authorized personnel for signing these documents are indicated.

Keywords: Geotechnical clearance, constructional impact, adjacent structures

1. Introduction

Buildings are ‘live assets’ which are intimately interactive with human lives on their day-to-day lives. Therefore, it is expected that a building must be designed and constructed to preserve the safety at an extremely high level not only for the building occupants but also for the adjacent properties.
It is alarming to see how the buildings are being built in a haphazard manner in Sri Lanka in the ongoing construction projects. It is very common to detect obvious non-compliances such as the construction without properly assessing the underground geological condition and without following a proper contingency plan and an appropriate construction sequence. Consequently, as a result, adverse impacts caused to surrounding built environment cannot be limited and controlled. In most instances, buildings are constructed without following proper geotechnical investigation. In addition, sub-structure of the buildings are designed in a manner contradictory with the geotechnical parameters of the site. Consideration of geotechnical parameters in designing the substantive building structure is not sometimes seriously considered by other professionals.

A comprehensive filtering process through an introduction of a sound guideline must be immediately established to grant or issue clearance in terms of geotechnical engineering related matters.

As the mandatory agency to streamline the process of providing geotechnical clearance of building approval process by assessing the impact of the proposed development on adjacent properties, NBRO decided to develop comprehensive geotechnical guidelines to ascertain the safe construction of proposed developments while ensuring the minimum impact on adjacent properties.

2. **Scope and Objective**

2.1. Scope

This study is focused on identifying the current standards and practices followed by the local and international civil/geotechnical engineering practitioners to maintain safety standards of the proposed and adjacent buildings during construction and their operational stages.

2.2. Objectives

- To establish a guideline for geotechnical clearance by assessing the impact of the present development on adjacent properties
- To streamline the process of providing approval for building construction or improvements and hence to reduce the time for approval process
- To enhance the safety of proposed/adjacent buildings and the public as a whole.

3. **Methodology**

In preparation of this guideline, existing procedures for building approval was identified and the existing system was analyzed to identify any loopholes and drawbacks. Accordingly, necessary documents required are identified to make sure that the construction is in accordance with the accepted codes and standards, at different construction stages, depending on the type of the proposed development. Considering all the information, a draft document of the guideline was prepared and it was reviewed by academia, practitioners and as well to all the relevant bodies before publishing. The methodology is summarized in Figure 1.
4. Results and Discussion

During the initial stages of the study, following sub-categories related to constructions were identified as presented in Figure 2.
4.1. Pre-condition survey

The proposed development may induce number of disturbances on the ground of the construction area as well as on the adjacent structures. In this regard, it is mandatory to identify the type of adjacent structures and collect information with a higher degree of accuracy. When performing a pre-condition survey the key points to be considered are the distance from the proposed construction site to the adjacent building, types of foundations on which the adjacent structures are supported, age of the building and also the presence of an archaeologically important structure in the close proximity, the building materials and construction methodology etc. In addition, the subsurface conditions underneath the structure is also a critical factor as it has a direct influence on the rate, distance and types of waves propagate from the construction site during excavation, machine movement and vibration due to piling etc.

The aforementioned factors and their influence on the adjacent structures were closely examined in the preparation of the proposed guideline for pre-condition survey. The prevailing conditions of the structures are to be assessed and recorded during the pre-construction stage.

Pre-conditioned survey converges various information from different backgrounds to ensure that all the critical points are addressed in an adequate and appropriate manner. Accordingly, such approach will eliminate any possible risk on adjacent structures related to formation, development and formation of cracks as well as any structural failures that can be arisen due to the ongoing construction activities. Hence, it ensures the safety and resilient construction while guaranteeing the safety of adjacent structures.

4.2. Geotechnical investigation

Geotechnical investigation is the focal point of any civil engineering construction. A comprehensive geotechnical design should be capable of merging all the pre-conditions of the proposed construction into single document. Therefore, it must be well planned based on the extent of the proposed construction, terrain conditions, geology and geomorphology and etc. A comprehensive geotechnical investigation report should provide the required design information to the design engineer in both qualitative and quantitative manner. It is of utmost important to identify the conditions of the bearing ground, type of soil strength parameters which could be used to idealize the subsurface. In the simplest terms, the geotechnical investigation must produce the subsurface model of the proposed site with necessary information pertaining to site reconnaissance. (Guideline for Geotechnical Investigation of Road works, 2011) (Guidelines for Site Investigations for foundation of Buildings (1994))

Required samples, sampling procedures and methods should be pre-determined in order to ensure that all the necessary information are grabbed during a site investigation. In addition, necessary safety precautions to be implemented during the site investigations clearly stated.

A comprehensive geotechnical investigation is a must to ensure the safety as well as the serviceability of proposed and adjacent structures. The lack of geotechnical investigation or complete omission of the same may lead to undesirable situations inducing either ultimate or serviceability failures.
4.3. Excavation and lateral support system

With the scarcity of the lands, especially in urban areas most of the developments in modern days comprise of basements. Constructing a basement in a heavily congested area is a huge challenge. In constructing basements, deep excavations are to be carried out with adequate supports through different means of earth retaining systems. In this regard, it is important to consider the possible deformations that can be induced in the ground from the modifications that are to be introduced. These guidelines are formed in a way that guides and helps the designer to address all the necessary points in designing the excavation support system confirming to the most methodical implementation of the same with inclusive of all the required monitoring.

Improper design of excavation support systems would lead to catastrophic failures. Especially, the lateral deformations of adjacent structures due to the loss of passive resistance arising from excavations would sometimes cause total collapse of the adjacent properties. These proposed guidelines provide a sound platform for the designers and as well as for the practitioners to ensure that all the relevant codes and standards are followed during the design stage and proper methods are implemented during the construction stage. Thereby it totally eliminates the risk of improper use of practices.

4.4. Foundation design

The prime concern for a safe and long-lasting structure shall be to provide a well-designed foundation to transmit the load from the superstructure to the soil underneath. The type of foundation to be chosen for a particular structure, depends on various factors among which the geotechnical properties encountered by the geotechnical investigation of the land being most important. Type of foundation suitable for proposed construction must be mentioned in the geotechnical investigation report, which is a pre-requirement for the foundation design.

Foundations are generally categorized into two, as shallow and deep foundations. In case of shallow foundations, the loads are transferred to the underneath soil directly under the foundation with a lateral load distribution. In general, the size of the shallow foundation is determined based on the bearing resistance of the supporting soil/rock and the permissible level of settlement. The foundation depth shall be decided as such the foundation reaches an adequate bearing stratum. In deep foundations, the loads are transferred to firm soil or rock at some depth with a vertical load distribution. Deep foundations are required when induced stress or settlement on the soil from shallow foundation is exceeding the allowable bearing capacity of the soil or allowable settlement with respect to the considered shallow foundation type.

Foundation design report, including allowable bearing capacities/end bearing/skin friction, allowable settlements and detail calculations which is certified by a qualified professional shall be submitted to facilitate the process of assessing the geotechnical risk.
4.5. Construction dewatering monitoring and contingency plan

Controlling ground water level is essential in construction project sites that extend construction activities below the ground water level. Dewatering leads to workably dry, stable and safe construction environment with enhanced efficiency of construction operation. Accordingly, temporary and permanent dewatering are two types of dewatering systems classified based on the duration of dewatering. Mainly, ground water level can be controlled by exclusion (Eg: cut off walls or other barrier), by pumping (Eg: sump pumping, deep well, well points and etc.) and combination of both. Selection of a suitable dewatering technique is site specific and a challenging task during construction planning and should be appropriate mainly to the hydro geological condition of the subsurface and required draw down of ground water level (i.e. type and depth of excavation). (Groundwater Engineering, 2014) Also, it should be planned by considering level of impacts for the adjacent structures/properties due to the dewatering process adopted. Subsurface geology and properties of the underlying soil and initial state of the adjacent structures should be assessed to determine the influence due to dewatering, required flow rate to achieve the required drawdown and potential ground settlement.

The purpose of monitoring is to check the validity of predictions of performance made during the design stage and to ensure that the structure will continue to perform as required after completion of construction activity. Monitoring of ground water level, settlements/ deformations, cracks and vibration should be carried out to assess the impacts on adjacent structures due to the proposed development activities.

Contingency plans are required to establish and to mitigate project risks identified during risk assessment process and during the monitoring process. Specific procedures and measures for the identified risks should be included in the contingency plan. The purpose of providing specific procedures is to ensure that certain tasks are carried out in a specific way by key people or units in the event of an emergency. (Contingency planning guide, 2012)

4.6. Construction related blasting

Construction related blasting may be required for removal of rock, and hard soil formations which are difficult to remove using other machineries due to its hardness. Blasting related activities are quite common in basement related constructions and as well as in road projects. Blasting activities should be well planned and executed so as to eliminate unnecessary risk and fatalities. Hence this guideline addresses all the blasting related activities pertaining to each construction stage. Further, it defines the required documents to be submitted at each construction stage and also the necessary authorizations for validation of the documents are clearly stated. This step by step procedure will ensure the safe and resilient construction of the proposed development and the structures and it will reduce the nuisance to the inhabitants in the close proximity.

4.7. Construction in hilly areas

Construction in hilly area has increased tremendously in Sri Lanka due to the lack of suitable flat land. Frequent occurrences of slope failures and landslide in hilly areas
during the rainy season have been increased significantly due to less attention paid by the stakeholders of such developments in vulnerable areas. Also, lack of maintenance of slope and other retained structures can trigger the slope failures. Impacts to the natural slope due to the changes made with construction activities should be evaluated during the approval stage. Disturbances to original slope and natural drainage paths with the construction should be eliminated. If any construction is planned in an area demarcated in hazard zonation maps which are developed by NBRO, necessary clearance for the proposed construction must be obtained from NBRO. Geotechnical input by the engineer during planning, design, construction and maintenance is very important to produce safe hill-site development.

Considering all the sub categories it is recommend to submit the relevant document as presented in Table 1 when assessing the geotechnical risk related with the building construction. As for the submission stages two stages were identified. “Submission stage I” should be done with a minimum of 60 days before commencement of the construction as it involves with major parameters associated with the geotechnical risk induced from the proposed construction. “Submission stage II” should be done with a minimum of 14 days before commencement of the proposed construction where method statements and other necessary documents need to be submitted.

| Table 1 required Documents for assessing the geotechnical risk associate with the proposed construction |
|-------------------------------------------------|---------------------------------|---------------------------------|
| **Report**                                       | **Submission Stage** | **Certified by**     |
| Pre-condition survey report                      | Submission stage I      | Chartered Engineer       |
| Condition survey report during construction      | If any complains made   | Chartered Engineer       |
| Post construction condition survey report        | After construction      | Chartered Engineer       |
| Geotechnical investigation report                | Submission stage I      | Qualified Geotechnical Engineer |
| Design reports                                   | Submission stage I      | Chartered Engineer in relevant field |
| Excavation and lateral support system / Foundation design / Dewatering Design / Blasting Design etc. |                             |                                 |
| Land slide Risk Assessment Report (if necessary) | Submission stage I      | LRRMD-NBRO               |
| Method Statement related to Construction of excavation and lateral support system/ Construction of foundation /dewatering / monitoring etc. | Submission stage II | Chartered Engineer in relevant field |
5. Conclusion

This study was done to develop guidance to assist any stakeholder involved in the construction projects to assess the impact of the development on adjacent structures considering the geotechnical aspects. A comprehensive geotechnical investigation of the project site should be carried out in order to establish the subsoil conditions, ground water conditions and provide information to facilitate the identification of geotechnical risks. Based on the information gathered from detailed investigation, design of excavation support systems, foundation and dewatering system should be designed according to the criteria given in the internationally accepted codes by qualified professionals. Monitoring of each construction activity is extremely important and should be conducted in an appropriate manner in which the monitoring programme addresses the every possible parameter that needs concern. Contingency plans should be developed to mitigate project risks identified during risk assessment process and during the monitoring process. Blasting during construction and construction in hilly areas are too discussed. Submission of such documents is summarized and the respective submission stage is also presented.

Acknowledgement

The support and guidance provided by NBRO staff and as well as all the relevant bodies, during the preparation of this guideline are gratefully acknowledged by the authors.

References

Preparation of Technical Guidelines for Building Demolition work in Sri Lanka

TN Gamage¹
¹Scientist, National Building Research Organisation, Sri Lanka

Abstract

This study sought to formulate a set of safe practices in the form of technical guidelines on demolition of low-rise buildings of masonry and reinforced concrete framed structures with infilled walls, to be adopted in urban/ congested locations in Sri Lanka.

In line with the global transformation, urban development in Sri Lanka has also shown a rapid increase in constructing high rise/ high density buildings and developments especially in cities such as Colombo over the recent past. In order to meet the demand for buildable space within a context of high land scarcity, not only existing obsolete structures but also structurally and functionally acceptable structures are being demolished and replaced by newly built structures.

There had been tragic incidents recently associated with building demolition work in Sri Lanka for which unavailability of statutory technical guidelines, codes of practice, safety standards or regulations and lack of involvement of relevant professionals in planning and direction, monitoring and supervision in ensuring safety of life and property, appeared to have been the main reasons.

This study focused on selected building demolition processes of different scale recently carried out in Colombo while reviewing relevant on-going practices in Sri Lanka as well as globally adopted codes of practice on building demolition.

Keywords: concrete; safety; demolition techniques; debris; top down; dismantle

1. Background and Rationale

History of building demolition work may be tracked back to several thousand years and for several decades now, it can be observed that cities in most parts of the world, have rapidly transformed over time, as employment / service centres with high level of population density and the same has created an urgent necessity for buildable space for regeneration of urban centers with high density/ high rise modern buildings and infra-structure facilities. This trend of urban revival appears to have been in rapid increase since the end of the twentieth century where demolition of existing buildings mostly low rise/ low density or obsolete, have been very common. However, rehabilitation/retrofitting of existing buildings appeared to have not been identified as the most economical solution.
Together with the above global transition, Sri Lanka also has shown a rapid increase in urban development during the last decade, especially within the Colombo district with high rise/ high density buildings and developments have become rampant in urban areas of the Colombo city.

<table>
<thead>
<tr>
<th>Province</th>
<th>District</th>
<th>Total Population</th>
<th>Urban Population</th>
<th>Percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sri Lanka</td>
<td>Colombo</td>
<td>2,324,349</td>
<td>1,802,904</td>
<td>77.6</td>
</tr>
<tr>
<td>Western</td>
<td>Gampaha</td>
<td>2,304,833</td>
<td>360,221</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>Kalutara</td>
<td>1,221,948</td>
<td>109,069</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Source: Table 6.2 Census of Population and Housing 2012 Final Report by Department of Census and Statistics, Sri Lanka

Above statistics reveal that in 2012:

(i) Around 50% of the total urban population of Sri Lanka (1,802,904) was living in Colombo District and it was also the highest urban population and
(ii) 77.6% of the total population of Colombo district were living in the urban areas.

The above fact has been amply supported by the records of the Condominium Management Authority (CMA), that show a significant yearly increase in the number of certificates issued for completed buildings (primarily residential) over the past few years.

![CMA Certificate Issued for Completed Buildings](image)

**Fig. 1. CMA Certificate Issued for Completed Buildings 2012-2017** (Source: CMA website)

Since urban spaces have almost been saturated with buildings and structures, vacant buildable lands are highly scarce at present. As a commercially viable option, such required high density developments have been compelled to be constructed as re-
erections on prime locations mostly by demolishing the existing buildings / structures whether new or obsolete.

According to the Code of Practice - BS 7543(1992) nominal design life of buildings generally considered to be around 50 to 60 years. Due to factors such as construction quality, the environment/exposure conditions where the building is located and degree of maintenance, the useful life of a building may well exceed the nominal design life; or in some cases fall short of it. Sometimes not only obsolete buildings but also buildings which are structurally and functionally acceptable are being replaced by new buildings with the growing requirement for habitation.

Records of building demolition contractors in Sri Lanka reveal that number of building demolition projects in Sri Lanka had increased. Therefore, introduction of careful and systematic demolition activities would ensure safety of life and properties and prevent tragic incidents such as seven fatalities caused due to partial collapse of a warehouse in Grand Pass, Colombo 14 in February 2018 as a result of demolition of an adjoining building that had taken place without following proper safety standards, as shown in Fig.2 (a).

![](image)

(a) An improper demolition site with unsafe free-standing walls; (b) Partially collapsed warehouse building adjoining the demolition site

There have been similar cases reported in the recent past also. At present, no guidelines are available in Sri Lanka for building demolition and such works appear to be carried out mostly without professional involvement. Further, it was revealed that no institution has been formally made responsible by the government for monitoring and supervision of building demolition work in order to ensure safety of life and property.

During the Industry Consultation Meeting organized by National Building Research Organisation (NBRO) in February 2018 in Colombo with the participation of Urban Development Authority (UDA), Central Environmental Authority (CEA), Universities and many other state and private sector stakeholder agencies, one matter highlighted was the need for preparation of Guidelines for Building Demolition work. Also, at this meeting, UDA commented that building demolition work was considered as a construction activity to be carried out with the prior approval of the respective local authority.
Hence, preparation of a set of Technical Guidelines on Planning and Execution of Safe Building Demolition Work in Sri Lanka, has become an urgent need.

2. Scope and objective of study

2.1 Scope

To identify the governing factors when planning and executing building demolition work
To formulate a manual on Technical Guidelines for Building Demolition work

2.2 Objectives

To introduce a regularized set of Safe Practices on Building Demolition work for the construction industry in Sri Lanka. This will be a multidisciplinary professional approach and will be formulated as a comprehensive document to be used by the construction industry professionals.

3. Methodology

i. Literature Survey/ Study of different codes and practices adopted globally on building demolition work and documentation of survey findings

ii. Literature Survey/ Study of planning & execution processes of building demolition work currently adopted in Sri Lanka and documentation of survey findings

iii. Analysis and synthesis of above survey findings

iv. Synthesis of the above factors and formulation of a set of Technical Guidelines on Planning & Execution of Building Demolition work with special reference to the urban context of Sri Lanka, in view of introducing to the country through relevant authorities.

3.1 Study of different codes and practices adopted globally on building demolition work

In the process of preparing guidelines for local conditions it is important to study the different codes of practice adopted by other countries. Many countries are adopting their own code of practice for building demolition work.

British standards, Hong Kong, Australian and Indian codes were selected in the process and Hong Kong code appeared to be more relevant to this study since it addresses more on technical guidance rather than legislation.

3.2 Study of planning and execution process of building demolition work currently adopted in Sri Lanka

Demolition work requires experience and techniques to be adopted at site as the demolition procedure varies with site constraints.

Two contractors were selected as mentioned below as Contractor 1 and Contractor 2 and two case studies were carried out in the study of planning and execution process of building demolition work currently adopted in Sri Lanka. Only one has been presented in the paper.
3.3 Analysis of survey findings under 3.1 & 3.2

(In progress)

3.4 Synthesis of the above findings and formulation of a set of technical guidelines on planning and execution of building demolition work with special reference to the urban context of Sri Lanka

(In progress)

4. Recommended general demolition procedure for reinforced concrete & masonry buildings

Demolition procedure shall be determined according to the prevailing site conditions, restraints, original building layout & its construction system. Demolition shall begin from the roof and be continued downwards (Top Down Method). The concrete of each structural element shall be broken down gradually. The reinforcement shall be left in place until the concrete is broken away and when its supports are no longer needed.

In general, following sequence shall apply;

4.1 Demolition Sequence
   a. All cantilevered structures, canopies, verandas and features attached to the external walls shall first be demolished prior to demolition of main building and its internal structures on each floor;
   b. The roof structure shall be removed in the following order:
      i. Remove roof covering
      ii. Remove roof structural elements such as reepers, purlins, rafters, wall plates, ridge plates, etc.;
   c. Non-load bearing walls shall be removed prior to demolition of load bearing walls, if not external walls first (push inward direction) and then, internal walls;
   d. Demolition of the floor slabs shall begin at mid span and be continued towards the supporting beams.
   e. Floor beams shall be demolished in the following order:
      i. Cantilevered beams;
      ii. Secondary beams;
      iii. Main beams.
      If structural stability of beams is affected, e.g., due to loss of restraints, the affected beams shall be propped prior to loss of supports or restraints;
   f. Columns and load bearing walls shall be demolished after removal of beams on top and
   g. If site conditions permit, after removal of upper floors the first-floor slab directly above the ground floor may be demolished by machine sitting on ground level and mounted with demolition accessories.
   (Reference: Code of Practice for Demolition of Buildings, Department of Buildings, Hong kong, 2004)
5. A Case Study

5.1 General Description

This building is located at Main street, Pettah, Colombo 11 which is a highly congested area [Fig.3(a) & (b)] and presently, demolition work is in progress. General details of same are as follows:

- Ground coverage - 1200ft²
- Number of floors - 05 (G+4)
- Area of a typical floor - 1200 ft²
- Type of structure - RCC column, beam, slab frame with brick infill walls
- Usage - Commercial

![Fig.3. (a) - Sketch layout plan showing demolition site & its surroundings; (b) - Building prior to demolition (Source: Google Street View 2015 Nov)](image)

5.1.1 Demolition Procedure at site being adopted by the contractor

![Fig. 4. General Arrangement of the Building](image)
a. Removal of 2’ wide strip slab along the left-hand side wall to prevent transmission of vibration to the adjoining wall;

Fig. 5. A 2’ wide strip of the Slab being removed from 2nd floor to 5th floor

b. Removal of around 4’x 4’ portions of slabs to dispose down debris directly to the ground floor;

Fig. 8. removal of around 4’x 4’ portion of slab being removed from 1st floor to 5th floor

c. Removal of roof, doors, windows and curtain wall using pneumatic hammers and labour intensive demolition methods (without careful separation of bricks for re-use in future);

d. Toppling of right side columns in 5th floor along west site boundary by pulling same on to the floor slab;

e. Demolition of 5th floor slab except intermediate beams using 3 Ton excavator with breaker placed at the 5th floor slab (by a crane) allowing free fall of debris on to the 4th floor slab;

f. Cutting reinforcement steel of slab using LP Gas cutter for safety and easy handling;

Fig. 7. Removal of slab concrete and reinforcement using LP gas cutter
g. Moving of the excavator to the next floor below by mounting debris to form a temporary ramp;

![Image of debris on roof](image1)

![Image of excavator](image2)

**Fig. 8. Debris accumulated on the slab for formation of a ramp to move the excavator down**

h. Cutting and lowering of intermediate beams;

i. Repetition of the same procedure at the lower floors;

6. **Discussion**

Excessive load had been imposed on the slab due to debris accumulation and movement of the excavator using the ramp made by the debris was not a safe and acceptable method of practice. Safety of not only the public but also the workmen at site was not within acceptable level. No personnel protection equipment had been used by the workmen at site and a potential danger of falling through the openings of slab was observed. Demolition sequence had been planned and executed by the contractor with his own experience in similar demolition projects and he was confident of the process.

However, no propping arrangement had been made to support the slab on which debris had been stacked up to more than 5’ high at some locations. According to the contractor's statement, prior approvals have not been taken when executing the demolition activities and contractor have no insurance covering on third party, contractors all risk or workmen compensation. No responsible party/supervisor had been deployed at site for monitoring public safety and health which would draw special attention by the relevant statutory authorities in the future.

7. **Concluding Remarks**

It is observed that no institution had so far been formally made responsible for monitoring and supervision of building demolition work and no guidelines were available in Sri Lanka for building demolition work. However, according to the Urban Development Authority (UDA) building demolition work is considered a construction activity to be carried out with prior approval of the respective local authority.

In Sri Lanka, presently the low-rise structures (up to 5 storeys) are being demolished rather than high rise structures since the tendency to replace a high-rise structure by a structure which is higher than the existing one is much lower. Also, most of the structures which are demolished currently, consist of RCC column, beam, slab with brick infill walls (low rise buildings) and masonry structures (residential
houses). Therefore, it is intended to pay special attention to above-mentioned type of structures which are in congested areas when preparing the guidelines.

Debris accumulation at upper floor levels shall not be allowed in the guidelines unless the debris accumulation is justified by engineering calculations. Restricted time targets, site constraints, budgetary allocations etc. of the demolition projects appeared to have led to poor work planning and provision of safety precautions at site for preventing fatalities during demolition.

Therefore, the Author is of the opinion that these Technical Guidelines shall spell out a regulatory framework of safe practices on building demolition work in Sri Lanka for adoption by the respective statutory bodies.

8. Acknowledgement

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I would also like to thank all the research team members Eng. Dhammika Silva Structural Consultant/Project Management Division, Eng. Ms. Ishani Kulasekara (Assistant Director, Technology and Research-CIDA) and Eng. Ms. K.M.D.N.K. Kahahengoda (Senior Scientist-PMD) for their contribution on this research. Specially I am grateful for the contractors for enabling me to visit their sites to observe their operations and I am grateful for Dr. Sudhira de Silva from University of Ruhuna for his advice and time on reviewing this paper.

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References

Rectification of Landslides and Unstable Slopes under

RLVMMP - Phase I

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Abstract

Under Phase I of Reduction of Landslide Vulnerability by Mitigation Measure Project (RLVMMP) funded by the Asian Infrastructure Investment Bank (AIIB), 27 critical landslide vulnerable locations are expected to be mitigated to reduce, minimize or eliminate any potential risks to human lives and important infrastructure in the country. This paper expects to narrate the approach used for the planning, investigating and designing of structural mitigation measures for each individual location under the Project. The selected 27 critical sites mainly include locations under landslide, slope failure, cutting failure, rock fall and debris flow threat. Initially selected list of critical sites was revised due to several reasons such as, incapability in conducting detailed investigation and monitoring for complex landslides within given time frame, practical difficulties in applying of mitigation measures and lack of important background data in some cases. Finally selected critical sites are included cutting failures and landslides which have already failed or activated with the failure surface visible enough to clearly identify the slip surface, and the soil profile. With the available timeframe, detailed investigations could be carried out for two potential landslides. Accordingly, structural mitigation measures were designed for the sites based on above data duly incorporating other aspects like socio-environmental concerns/safeguards mandated through the Project. Several criteria were followed in design of mitigation measures for each type of failure and Limit Equilibrium method was used for assessing the slope stability. Proper site selection, detail investigation and monitoring, planning and the availability of good amounts of background data as well as history of instability were identified to be crucial factors in designing rectification measures with a considerable degree of accuracy.

Keywords: landslides; cutting failures; rock fall; debris flow; mitigation; slope stability
1. Introduction

Notably during and after the last quarter of 20th century, landslides have become a major natural disaster in Sri Lanka, in the hill country during the monsoons with heavy rainfall (Ratnayake & Herath, 2005). According to the available records, nearly 1000 human lives were lost while over 300,000 people were made homeless due to cataclysmic landslide events occurred during the last period. Loss of property and infrastructure and the damage caused to the national development was enormous.

Landslides, slope failures and rock falls have become increasingly frequent and severe, seriously affecting communities in the hilly central region of Sri Lanka since 1970s, causing loss of life, damage to infrastructure, destruction of property and impacts on livelihoods and local economy.

Given the emergency nature and the devastating impacts of landslides on people’s lives, infrastructure and the environment, the project “Reduction of Landslide Vulnerability by Mitigation Measures” was incepted with the funding from Asian Infrastructure Investment Bank. Under Component I of the project, National Building Research Organization (NBRO) undertook the investigations and designs for the implementation of landslide rectification, risk mitigation and slope stabilization measures at selected critical 27 sites representing 8 landslide affected districts in the country.

2. Scope and Objective

This study is focused on the approach used for the planning, investigating and designing of structural mitigation measures for each individual location under the Project Phase I. The 27 critical sites were mainly categorized into four according to the type of failure as, landslides, cutting failures, and rock fall and debris flows. The objective of this paper is to discuss the different approaches used to achieve the different tasks of the designing process of landslide risk reduction in Sri Lanka.

The project work had to be finished within a very tight time frame and detailed site investigations at initially selected locations proved them to be either economically, socially or technically viable locations to be included in the project. This was due to several reasons as, incapability in conducting detailed investigation and monitoring for complex landslides within given time frame, practical difficulties in applying of mitigation measures and lack of important background data in some cases.

Therefore, within the scope of the project, the critical site list was revised to include cutting failures and landslides which had already failed or activated with the failure surface visible enough to clearly identify the slip surface, and the soil profile. With the available timeframe, detailed investigations could be carried out for two potential landslides.

3. Methodology

The designing process of structural rectification mitigation works for the 27 sites required the accurate identification of the nature and the causes of failure as its initial step which will serve as the basis for the measures being selected.

The design concepts followed in selection of suitable countermeasure works were based upon many factors including technical effectiveness, financial viability, environmental impact and amount of maintenance required.
In case of rain induced failures, infiltrated water trapped inside the soil mass should be moved out immediately to reduce the risk of further failures. Therefore, the rectification process should primarily involve improvement of surface and subsurface drainage. In addition, reinforcement of the slope material will also be necessary. In order to ensure the stability, reshaping by cutting back the slope is the most economical solution. This reduces the weight of the overburden soil mass and thereby reduces the driving force on the failure plane enhancing the stability of the slope.

Where some unstable slopes cannot be stabilized only with reshaping and lowering of the water table with subsurface drains, strengthening the slope with retaining structures or soil nailing will be essential. Retaining structures such as gravity, cantilever and gabion retaining walls will be used in general practice. The selection of the most suitable wall type was done considering the available space, purpose, cost and stability of the overall slope (Geotechnical Engineering Office - Hong Kong, 2000). In order to provide the most economical design for the soil nailing, possible drill hole and reinforcement bar diameters were tried out.

4. Observations

Causes of landslides are usually related to instabilities in slopes and it can include geological factors, morphological factors, physical factors and factors associated with human activities (Prasad, 1995). In Sri Lanka, most of slope failures trigger by excessive rainfall because most landslide disasters occur in the country in monsoon period (Ratnayake & Herath, 2005).

In order to decide the design approach and methods of rectification among various rectification measures, nature and cause of the failure was identified. In case of landslides and cutting failures, several design options were taken in to account, considering the complexity of the failure and degree of vulnerability of affected parties. Site specific rectification measures were proposed for debris flow and rock fall events. This paper describes the design approaches applied for major failures locations designed under RLVMMP – Phase I (See Fig. 1).

![Fig. 1. Location of the sample sites](image-url)
To give children in Sri Lanka the best educational material on risk and injury prevention and thereby working against this socio-economic problem, a new manual needs to be developed. Specialising on the typical living standards in Sri Lanka and including modern topics will raise children’s awareness towards risks as well as strengthen their perception of actions and the following consequences.

In order to make it easily understandable but still informative, specialists regarding the mindset of children as well as specialist in the area of risk reduction have to work closely together. Ideas from the EU and WHO projects can be implemented in the Sri Lankan version, using games and puzzle to playfully teach children and support messages through colourful illustrations.

For the best possible outcome this guideline needs to be implemented in school practices and should be presented once every year to sensitize children on these topics and to reduce the number of unintentional injuries, especially those leading to death.

5. Results and Discussion

Several representative case studies out of the design work of 27 critical locations are presented below to illustrate the design concepts of landslides, cut slope failures, debris flows and rock falls.

5.1 Case Study – Location between culvert No. 5/11 and 5/13 along the Dehiovita-Deranilyagala-Noori road

5.1.1 General Instability Features

This failure can be identified as a cutting failure propagated into a landslide. After the recent road widening, nearly vertical road side cut has been left without providing proper retaining structure, making the upper slope which extends about 30m up to a rocky ridge, vulnerable to failure. Tension cracks had developed in the upper slope in which, the average uniform slope angle is about 300-350, detaching the unstable soil slope from the rocky ridge at the top of the slope.

This area experiences intense rainfall mainly due to the South-West monsoon during May-July in every year. The particular failure occurred during South-West monsoon in 2016, causing socio-economic impacts to the surrounding households and Dehiovita-Deranilyagala-Noori (B039) road. After identifying the possibility of future failures and the impacts associated with possible mass movement, rectification of the landslide was carried out under RLVMMP.

5.1.2 Assessing the existing stability

The first task of the process of design of mitigation measures was to collect the background information required for the design. Topographic Survey, Geotechnical Investigation and Laboratory Testing were carried out in order to fulfill that requirement. A detailed cross section survey was carried out in order to gain an idea on geomorphology and to determine and locate the important features, including utility and infrastructures in the failed region and in its vicinity. Geotechnical investigations were carried out with the objective of providing information on subsurface condition including soil types, stratification, geology and bedrock
properties for designing of mitigation measures. Laboratory testing were done at the Geotechnical Engineering Laboratory of NBRO to identify mechanical properties of soil.

Slope stability analysis was carried out with the aid of Limit Equilibrium approach by Geo Studio (2016): Slope/W software for the existing cross sections taken at critical locations. First, back analysis was carried out in order to establish the sub-surface profile along with soil parameters which were prominent for the failure (See Fig. 2(a)). The critical water table for the existing geomorphology was identified by obtaining a Factor of Safety (FoS) around unity. According to the analysis the FoS was 0.981, which indicates that the slope is susceptible to further failures (See Fig. 2(b)). Therefore, suitable rectification measures should be implemented to minimize the risk of future failures.

![Fig. 2. (a) Back analysis results; (b) existing stability of the slope]

5.1.3 Design of Rectification Measures

For the design of rectification measures, several possible mitigation activities were taken into account, considering the surrounding morphology, space availability and minimum disturbance to the functionality of the Dehiwita – Deraniyagala – Noori road. Triggering factor of this landslide was identified as infiltration of storm water and upsurge of ground water table during rainy season. Hence, lowering the ground water table was considered as the first option which can be achieved by means of providing surface and subsurface drainage. It was assumed that the ground water table could be lowered by 2m with the improvement of the surface and subsurface drainage system. According to the analysis results, a proper FoS cannot be achieved by only the drainage improvement and internal stabilization is required for the upper slope.

Hence, soil nailing technique was introduced to stabilize the upper slope. Analysis was carried out considering soil nailing against critical water table, 1m drop of water table after introducing surface drainage and 2m drop of water table after introducing surface and subsurface drainage. The types of counter measures and resulting safety factors are presented in Table 1.

**Table 1: Counter measures and resulting safety factors**

<table>
<thead>
<tr>
<th>Option</th>
<th>Counter measure</th>
<th>Effect</th>
<th>FoS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Critical water level</td>
<td></td>
<td>0.981</td>
</tr>
<tr>
<td>2</td>
<td>Improvement of Surface and Subsurface drains</td>
<td>2 m drop of WT</td>
<td>1.045</td>
</tr>
</tbody>
</table>
According to the analysis results, the FoS for the critical slip surface can be significantly increased by lowering the water table. Therefore, providing surface and subsurface drainage is essential together with internal stabilization. A FoS greater than 1.25 can be accepted as safety margin for cut slopes along local highways. Hence, Option 5 can be taken as the best combination of countermeasures since it will ensure the reduction of rain water infiltration and ground water table at the same time.

5.2 Case Study – Location at CH 77+100 of the Galle – Deniyaya – Madampe Road

5.2.1 General

This failure consists with two parts a cutting failure at the upper slope and gabion wall failure at the lower slope of the road. During the road widening tope slope of the road which is a steep cut slope about 500 angle and maximum of 8 m height, was left without any slope stabilization measures or drainage improvements. A single storey house is located at the top of the road cut, about 2.5 m from the crest, and slope is extended further with an average angle of 350 to 400. A gabion wall was constructed at the bottom slope of the road as toe wall to provide the required road with.

The failures have triggered at heavy rainy period and occurred in both top and bottom slope of the road. The upper slope failure is a shallow cut slope failure, extended about 30 m along the road, with maximum height at the middle about 8 m and reducing the height towards the both ends. Reduction of shear strength of the soil and loss of matric suction, with the high ground water level were the main causes for the failure. Gabion wall at the bottom slope was failed as a sliding failure and shifted away about 15 m down the slope. Increasing the active earth pressure with high ground water level and reduction of the soil shear strength parameters were the main causes of failure.

Since there is a possibility of further failures in future, considering the socio-economic effect with the disturbance to the transport continuity of the main road and possible damages to the houses located surrounding, the mitigation measures is carrying out under RLVMMP.

5.2.2 Assessing the existing stability

A detailed topographical survey consists with contour and cross sections as described in previous chapter, and geological survey was carried out to fulfill the requirement of background data for the design. Since the soil condition of the slope clearly visible, no geotechnical investigation was carried out. Sub soil profile and soil parameters were determined by the geological survey, field observations and experiences gained through similar site condition. Back analysis was used to verify the soil properties used for the analysis. The slope consists with residual soil on scarp slope with an average thickness of 6 m.
Slope stability analysis was carried out with the aid of Limit Equilibrium approach by Geo Studio (2016): Slope/W software. Since the top and bottom slope failures are individual cases, existing stability for top and bottom slope was assessed separately and it shows that the FoS less than 1 for both cases in high ground water level, which indicates that slopes are susceptible to further failures (Fig. 3). Therefore, suitable rectification measures were introduced to minimize the risk of future failures.

Fig. 3. (a) Existing stability - top slope; (b) Existing stability - bottom slope

5.2.3 Design of rectification measures

Several possible alternatives were considered for stabilization of the slope, as described in previous chapter. Required safety margin of 1.25 cannot be achieved only by lowering the ground water level for both top and bottom slopes, because of the steepness of the slope.

Reshaping the top slope is not possible due to the existence of the house at the top and gravity retaining walls are also not possible. Therefore, reinforcing the slope with soil nails is selected as the best alternative for stabilizing the slope with FoS value of 1.520 (Fig. 4 (a)).

Since the road carriageway was damaged due to the failures, sufficient road with is required to be provided with the mitigation measures for stabilization. Gravity retaining wall is not possible, due to the steepness of the bottom slope, difficulty of finding good bearing layer for foundation and fact that the previous gravity wall was also collapsed. Therefore, it was decided to reinforce the steep slope which would be left after removing the debris, by soil nails. Then reinforced concrete cantilever retaining wall to be used for providing the required road width. Soil nails to be extended up to the face of the wall and provide additional support to the wall by anchoring. This composite action will give FoS value of 1.320 (Fig. 4 (b)).

Fig. 4. (a) Stability of slope with mitigation - top slope; (b) Stability if slope with mitigation - bottom slope
Improvement of the FoS values with the mitigation measures can be summarized as follows in Table 2.

**Table 2: Counter measures and resulting safety factors**

<table>
<thead>
<tr>
<th>Location</th>
<th>Condition</th>
<th>FoS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Slope</td>
<td>Existing</td>
<td>0.962</td>
</tr>
<tr>
<td>Top Slope</td>
<td>Soil Nailing</td>
<td>1.520</td>
</tr>
<tr>
<td>Bottom Slope</td>
<td>Existing</td>
<td>0.995</td>
</tr>
<tr>
<td>Bottom Slope</td>
<td>Soil Nailing</td>
<td>1.419</td>
</tr>
<tr>
<td>Bottom Slope</td>
<td>Soil Nailing + Cantilever Wall + Road Widening</td>
<td>1.320</td>
</tr>
</tbody>
</table>

According to the analysis results, the FoS for the critical slip surface can be significantly increased by providing internal stabilization measures. Therefore, providing soil nailing is proposed to stabilize the top slope. In case of the bottom slope, it is essential to keep the required road width while stabilizing the slope. Therefore, cantilever wall shall be provided to facilitate the road widening together with providing soil nailing.

5.3 Case study–Rock fall – Semidel Govipalakanda (Matara)

In Semidel Govipalakanda site, it was observed bed rock exposure at the upper region of the slope and separated boulders were present in the rock exposure area as well as along the slope. In addition, minor cutting failures were also observed in downslope area. Hence, there can be anticipated boulder/rock failures. During the preliminary site visit, drone survey was conducted to gather more information on the whole area.

By considering these circumstances, it was essential to propose rectification measures to prevent future failures by providing an appropriate design of control works. In that regard, several possible mitigation measures were taken in to account considering the surrounding morphology, space, cause of failure, land value. Rock fall barrier was selected as appropriate option to mitigate the lower slope which is congested with houses, from rock fall threat. Therefore, 4 m high rock fall barrier with minimum capacity of 3000 kJ was adopted along the foot path located in the middle of the slope in the design in view of applicability of mitigation measures suited to the actual site condition.

5.4 Case study–Debris flow – Athwelthota Landslide

Athwelthota is an already occurred landslide where it is possible to clearly identify the main escarp, slip surface, depth to slip surface, the soil type, and the bedrock geology in particular as the bedrock is exposed at the crown area with the landslide event. In case of a future failure, a similar debris flow assuming the same debris flow path can be expected causing damage to the temple which is situated at the right edge of the debris flow path depositional area. The effect upon the temple due to was basically considered when proposing the countermeasures while potential damage or blockage of road due to a future failure was not addressed through the design.
Accordingly, a boulder packed wall of sufficient height constructed with the material from landslide debris is proposed to divert any potential flows away from the temple. Further, the depositional area of the previous debris flow is proposed to be vegetated with Swietenia Macrophylla (Mahogany tree type) and other vegetation types commonly found the area to intercept and reduce any debris movement affecting the temple and road. This was further envisaged as a green concept where the proposed vegetated area can serve as a restoration of the disaster site into its previous natural state.

6. Conclusion

Different approaches are used for implementing mitigation measures for reducing, minimizing or eliminating any potential risks to human lives and important infrastructure in Sri Lanka due to landslide risk. The selection of the most suitable approach essentially require best engineering judgements and assessment of different available options paying special attention to cost and other socioeconomic constraints which could be highly sitespecific.

Further, designing work of this nature often associates with time constraints, and in order to come up with economically and technically sound engineering designs within the given project targets, proper project planning is vital importance at the early stage of the project.

References

Adverse Impacts of New Construction Projects on Adjacent Structures and Implementation of Mitigatory Measures

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Abstract

With rapid development of construction industry and urbanization, high-rise buildings and urban areas congested with buildings have become a common occurrence in Sri Lanka. High-Rise building construction projects require deep excavations and the use of heavy vibrating equipment like pile drivers often working in close proximity to adjacent properties. Such activities require careful planning and engineering innovations to prevent causing damages to neighbouring properties. This review study describes the impacts of urban constructions on adjacent structures and mitigatory measures that can be used to avoid such impacts by analyzing the previous studies carried out under the same field of studies and also by analyzing the documents submitted to National Building Research Organisation for the Geotechnical Clearance Process. Major impact sources can be identified as deep excavations, draw down of the water table and vibrations generated by construction machinery. Though there are several mitigatory measures available, it still remains as a doubt how well those measures can resist adverse impacts related to the adjacent structures. Therefore, it is important to analyze carefully about the available problems and provide practical solutions that can be carried out in the site itself in an efficient and effective manner. Identifying the characteristics of the existing adjacent structures plays a major role apart from the major mitigatory measures like, shoring systems, controlled dewatering systems, advanced foundation construction, damping of the vibration impacts and proper workmanship.

Keywords: adjacent structures; urban constructions; Pile driving; vibration impacts; dewatering;

1. Introduction

Rapid developments in urban areas of Sri Lanka has resulted in an increased density of construction projects in a congested land area. Construction activities in close-proximity to adjacent structures have become a serious issue which require the involvement of relevant parties including National Building Research Organisation (NBRO). Deep excavation, dewatering and construction related vibrations can be considered as the major factors that could cause problems to adjacent structures. Condition of the existing structures is also really important when analysing the
impacts of the adjacent construction works. Therefore, understanding the existing structures and classifying the construction induced impacts with the existing defects (Table 1) in the structure will help managing the risks in an effective manner.

Table 1: Classification of the impacts

<table>
<thead>
<tr>
<th>Construction induced impacts on adjacent structures</th>
<th>Impacts of existing structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of construction equipment used and vibrations induced from machinery.</td>
<td>Foundation settlement</td>
</tr>
<tr>
<td>Method of construction – deep excavations, piling, diaphragm walls etc.</td>
<td>Issues with the usage of poor construction materials</td>
</tr>
<tr>
<td>Excessive or uncontrolled dewatering/ (without close monitoring and observation).</td>
<td>Poor workmanship</td>
</tr>
<tr>
<td>Changes in ground conditions (soil + rock)</td>
<td>Uneven stress distribution</td>
</tr>
<tr>
<td>Ground movements (vertical – settlement &amp; heaving &amp; lateral)</td>
<td>Thermal expansions</td>
</tr>
<tr>
<td>movement of shoring systems</td>
<td>Inadequate structural requirements</td>
</tr>
<tr>
<td>ground subsidence due to dewatering</td>
<td>Excessive loads</td>
</tr>
<tr>
<td>movement of finer soil particles with seepage water creating voids</td>
<td>Natural disasters (adverse impacts due to landslides, floods and high winds)</td>
</tr>
<tr>
<td>heaving (upward movement) of the ground</td>
<td></td>
</tr>
</tbody>
</table>

After close monitoring of the impact classification indicated in Table 1, it is convenient to differentiate undergoing long term settlements and defects of the nearby structures and impacts due to adjacent construction works. In this review study, it is focused on both the adjacent construction induced impacts on existing structures and undergoing problems in the existing structures. Finally, practically applicable solutions will be discussed in order to overcome such impacts (Volonnino, 2017).

2. Understanding Issues in Existing Adjacent Structures

2.1. Identifying the problem

With the rapid increase in construction works in congested environments, possibility of safely extending the life of existing infrastructure is a matter that has become of increasing importance to the work of structural engineers. In order to understand safety of the structure, it requires prediction of future structural behavior in detail and at a high accuracy level. So that, proper initial assessment of the existing structure can be identified as the best mechanism to mitigate subsequent impacts.
2.2. Preventive measures

2.2.1. Pre-construction surveys

Conducting a pre-construction survey can be identified as the most suitable way to assess existing features and structural issues of adjacent structures. When there is a demolition of any building, or piling or foundation works, tunnelling works, or site formation works (including excavation works) are to be carried out, the builder shall, before commencing such works, carry out a pre-construction survey to establish the condition of existing buildings and structures adjacent or in otherwise close proximity to the building works. Then it is logical to differentiate between exiting structural issues and structural issues that can arise due to the adjacent construction, so that at the initial stage, relevant preventive measures and rectifications can be implemented. It is the responsibility of the adjacent residents to conduct a pre-construction survey or allow help developers and contractors to conduct the survey by providing them necessary information. In the event that the developer is unable to gain entry to the properties in the zone of preconstruction survey, the developer shall, survey the exterior face of the property, keep records of attempts to contact relevant owners for permission to conduct pre-construction survey and keep record of refusal by the adjacent owner to allow access to conduct survey. (Smith, Vatovec, & Gumpertz, 2015)

Following subsections outline the minimum zones of pre-construction survey to be conducted for project developments involving demolition, piling and excavation works. Photographic surveys and data collection methods shall be adopted after identifying the relevant effective areas in order to collect the necessary information regarding the existing structures. However, qualified professionals in charge of each project shall implement an independent assessment and verification to determine an adequate and sufficient criterion depending the nature of the project and the construction site. (Guidelines on Preconstruction Survey, 2016)

2.2.1.1. Demolition works

**Table 2: Suggested pre-construction area before commencing any Demolition Works**

(Guidelines on Preconstruction Survey, 2016)

<table>
<thead>
<tr>
<th>Type of Development</th>
<th>Minimum zone of pre-construction survey (from the edge of building to be demolished)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demolition for landed development</td>
<td>10 m</td>
</tr>
<tr>
<td>Demolition for building up to 5 storey height</td>
<td>35 m</td>
</tr>
<tr>
<td>Demolition for building more than 5 storey height</td>
<td>50 m</td>
</tr>
</tbody>
</table>
2.2.1.2. Piling works

Table 3: Suggested pre-construction area before commencing any piling work in *landed development (Guidelines on Preconstruction Survey, 2016)

<table>
<thead>
<tr>
<th>Type of Piles</th>
<th>Minimum zone of pre-construction survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-displacement piles and small</td>
<td>10 m</td>
</tr>
<tr>
<td>displacement piles such as micro bored pile, steel</td>
<td></td>
</tr>
<tr>
<td>H-piles</td>
<td></td>
</tr>
<tr>
<td>Displacement piles such as RC piles, jacked-in</td>
<td>20 m</td>
</tr>
<tr>
<td>steel pipe piles (closed ended)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Suggested pre-construction area before commencing any piling work in *non-landed development (Guidelines on Preconstruction Survey, 2016)

<table>
<thead>
<tr>
<th>Type of Piles</th>
<th>Minimum zone of pre-construction survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-displacement piles and small</td>
<td>40 m</td>
</tr>
<tr>
<td>displacement piles such as micro bored pile, steel</td>
<td></td>
</tr>
<tr>
<td>H-piles</td>
<td></td>
</tr>
<tr>
<td>Displacement piles such as RC piles, jacked-in</td>
<td>60 m</td>
</tr>
<tr>
<td>steel pipe piles (closed ended)</td>
<td></td>
</tr>
</tbody>
</table>

* Landed development refers to residential property where the owner has the title to the land. Non-landed property refers to apartments and condominiums, which are strata-titled, where the owners own the land in common.

2.2.1.3. Excavation works

Table 5: Suggested pre-construction area before commencing any Excavation works (Guidelines on Preconstruction Survey, 2016)

<table>
<thead>
<tr>
<th>Type of Development</th>
<th>Minimum zone of pre-construction survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landed development</td>
<td>15 m</td>
</tr>
<tr>
<td>Displacement piles such as RC piles, jacked-in steel pipe</td>
<td>60 m</td>
</tr>
<tr>
<td>piles (closed ended)</td>
<td></td>
</tr>
<tr>
<td>Non-landed development with basement or underground</td>
<td></td>
</tr>
<tr>
<td>space</td>
<td></td>
</tr>
<tr>
<td>Type of Soils</td>
<td>Minimum zone of pre-construction survey</td>
</tr>
<tr>
<td>Good soils</td>
<td>30 m or 3H</td>
</tr>
<tr>
<td>Soft soils (e.g. marine clay)</td>
<td>60m or 6H</td>
</tr>
<tr>
<td>Without fluvial/sand/peat/peaty clay</td>
<td></td>
</tr>
<tr>
<td>Soft soils with fluvial/sand/peaty clay</td>
<td>90m or 9H</td>
</tr>
</tbody>
</table>

Note:
1. Maximum excavation depth include localise pits;
2. For cases with two values, the larger of the two values should be adopted.
3. *Good soils refer to medium dense to very dense sand and gravel, and firm to hard silt and clay.
4. *Soft soils refer to very loose to loose sand and gravel, and very soft to soft silt and clay.
5. *H is defined as the maximum excavation depth.

2.2.1.4. Data Collection

Table 6 shows the required details of the structures located in the effective area to clarify the location and ownership details. Location of the relevant structure shall be included as an extracted image from the Google Earth (Version 7.3 or higher) and in that same image the radial distance from the structure to the proposed site shall be clearly marked. It is important to mark the other important features like historical structures, hospitals, manufacturing industries, highways, rivers etc. too in the image.

<table>
<thead>
<tr>
<th>Table 6: Location and ownership details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner of the building</td>
</tr>
<tr>
<td>Telephone</td>
</tr>
<tr>
<td>Address</td>
</tr>
<tr>
<td>Coordinate details</td>
</tr>
<tr>
<td>Inspected Date</td>
</tr>
<tr>
<td>Radial distance to the proposed site (m)</td>
</tr>
<tr>
<td>Existence of nearby highways? (If yes provide a brief description indicating the type, size and the connecting regions of the highway)</td>
</tr>
<tr>
<td>Existence of nearby river/ canal/ stream? (If yes provide a brief description indicating the type, size and the connecting regions of the water path)</td>
</tr>
<tr>
<td>Existence of nearby railway? (If yes provide a brief description indicating the route and the connecting regions of the railway)</td>
</tr>
<tr>
<td>Existence of nearby sensitive structure? E.g.: Historical buildings, Hospital, Manufacturing company and etc. (If yes provide a brief description indicating the type, size and the impact)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7: Other General details of an adjacent structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of the building/ structure</td>
</tr>
<tr>
<td>Foundation details</td>
</tr>
<tr>
<td>Number of floors</td>
</tr>
<tr>
<td>Approximate age</td>
</tr>
<tr>
<td>Floor area and details</td>
</tr>
<tr>
<td>Presence of equipment and machineries</td>
</tr>
<tr>
<td>Any structural failure? If yes, Specify</td>
</tr>
</tbody>
</table>
2.2.2. Rectifying existing damages of adjacent structures

Qualified Engineer should review the survey report and identify any pre-existing structural defects in all the buildings being surveyed. Engineer shall specify on plan the necessary preventive measures to be taken to prevent damages to the adjacent buildings arising from the works. Regular monitoring of the structural damages and cracks shall be carried out throughout the whole construction project.

3. Sources of Construction Induced Impacts

3.1. Demolition of existing structures

Demolition is the process whereby an existing building is destroyed partly or completely and is usually carried out on a temporary/short term basis. Demolition is carried out either manually or mechanically using large hydraulic equipment such as elevated work platforms, hammers, cranes, excavators or bulldozers. Larger buildings however may require the use of a wrecking ball or are destroyed by implosion. Newer methods may use rotational hydraulic shears and silenced rock-breakers attached to excavators to cut or break through wood, steel and concrete. Demolition of buildings is associated with environmental concerns which relate to noise and vibration, dust nuisance, solid wastes including waste debris, hazardous wastes and larger energy or water consumption (Environmental Guideline on Demolition of buildings, 2017).

3.2. Excavations

New large scale mid-rise and high-rise buildings in urban neighborhoods often require foundation structures 1 to 5 stories deep to accommodate underground parking decks and building mechanical systems. These new foundation systems are often much deeper than the foundations of previous structures as well as those of neighboring properties. As a result, construction activities require the excavation of deep pits, often with vertical faces. Damage to adjacent properties can result throughout this process from inadequately shored excavation walls, or from vibrations due to demolition, excavation, or pile driving activities.

Since most excavations in an urban setting occur on or near the property lines and flattened slopes (less than 45 degrees of vertical) are typically incompatible with design requirements, many applications require a temporary reinforced wall be constructed to retain soil and buildings on the neighboring lots (Smith, Vatovec, & Gumpertz, 2015).

Figure 1: The Possible settlement for existing foundation due to the lack of suitable retaining wall
3.3. Blasting and Vibrations

Vibration can occur from numerous construction activities, including; Blasting, Pile driving, Compaction / dynamic compaction, Jackhammering / chiseling, Pavement breakers, demolition, trenching activities, heavy vehicle movements.

Pile driving vibrations may affect the nearby structures or disturbed people in the neighbourhood of pile driving activity. Some previous literature results show that vibration effect was higher at the bottom of a building compared to the effect on the top of building. Also, the nearer distance cause higher vibrations compared to the one further from the building. However, the smaller pile creates more vibrations towards the nearby building. This could be due to pile density reaction towards resisting forces from soil. (Musir & Ghani, 2014)

3.4. Drawdown of the water table

Due to improper excavations and improper dewatering practices, there can be problematic drawdown in the exiting ground water table. This can cause serious damages to the soil profile and existing nearby structures due to settlements in the soil profile.

Apart from the above discussed sources improper workmanships can be also identified as a major factor that cause damaging impacts for adjacent structures.

4. Mitigatory Measures for Construction Induced Impacts

4.1. Shoring systems

While there are numerous temporary methods available to retain soil for an excavation, the soldier pile wall with tiebacks and wood lagging is the most common. Tie back soldier pile walls are constructed with wide flange steel beams, usually spaced 5 to 10 feet apart. The walls can be 50 feet in height or greater from the top of existing grade to the bottom of the trench. Tiebacks are installed integrally aligned with the soldier pile. The space in between the soldier piles is constructed with thick wood planks inserted between flanges of the piles and span from soldier pile to soldier pile to retain the soil. Groundwater cannot be tolerated and must be removed based on requirements set forth in geotechnical and subsurface hydrology reports. However, for larger basement constructions and deep excavations most of contractors have used diaphragm walls which will also act as a permanent element of the structure after the completion of the project. (Volonnino. 2017)

4.2. Proper dewatering system

Having clearly identified the subsurface profile and excavation details, required number of open sumps and observation wells should be designed with the use of submersible pumps and other required instruments that fulfill the required flowrates and capacities. Before commencing pumping, it is important to measure the water levels in all the wells. Throughout the dewatering process, deformation monitoring of the adjacent structures and ground water level monitoring should be continued. If
monitoring records indicate a significant drawdown of the water table, observational wells shall be used for recharging of the ground water level.

4.3. Damping vibration impacts

Permanent vibration barriers are effective for controlling long term vibrations such as traffic induced vibrations. In such a case permanent wave barrier can be used which is filled with a vibration damping waste material. However, in the case of piling induced vibration, it is a short-term vibration. Therefore, it is effective and economical to go for short term vibration controlling methods.

When considering about the research related effective control methods throughout the past decade, trench system can be identified as the best and effective control method. However, the applicability of a trench in modern day construction sites may cause several additional problems due to the insufficient land spaces. Another major control method available can be identified as damping the vibrations at the source. In order to fulfil that requirement, highly developed vibration damping machineries have to be used for the construction activities which also cost more investments.

4.4. Implementation of proper workmanship

There will be no use of the mitigatory measures if the quality and the workmanship of the work fails. Careful planning and sequencing of the construction from the most initial level of the project gives numerous advantages. Geotechnical site investigation stage can be identified as one of the most critical stages when considering about impacts on adjacent structures. Effective site investigation techniques shall be carried out by relevant professionals who are specialized in that field in order to obtain the most effective and accurate recommendations for important design criteria like foundation type, shoring type and details about the existing water table. After identifying the most relevant structural design requirements, each and every construction activity shall be carried out by following the method statements and specifications given by qualified engineers. Usage of quality construction materials will further enhance the quality of the workmanship. There should be a close monitoring and data collection procedure for the ground water table, vibration levels and any movement or failure of shoring systems so that the records can be used when implementing preventive measures.

5. Discussion

Identification of characteristics of the exiting adjacent structures has to be carried out by giving a prior consideration in order to overcome future problematic impacts. Aforesaid goal can be achieved successfully if both developer and adjacent building owners engage actively in the process of pre-construction surveys. Regular monitoring of the impact assessments shall be conducted by considering the major construction activities like excavations, dewatering and vibrations. Each construction activity shall be implemented with the close supervision of qualified engineers and following proper method statements for relevant activities.
6. Conclusion

Further research activities have to be carried out in order to identify the specific impacts on adjacent building construction works to match with the Sri Lankan construction context. Relevant solutions needed to be identified by carefully analyzing those impact parameters so that the implementation of the mitigatory measures provide more effective and efficient results.

References

Cut Slope Stability at Ch 19+000, Extension of Southern Expressway Project

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2Senior Engineer, National Building Research Organisation, Sri Lanka
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4Senior Professor, University of Moratuwa, Sri Lanka

Abstract

Extension of Southern Expressway Project (ESEP) is currently undergoing project under Ministry of Higher Education & Highways, Sri Lanka. Continuous seepage of water is occurring at the double cut slopes which are approximately 40 m high between sections Ch 19+000 and Ch 20+000 even during periods of dry weather. This may increase in the rainy season and could even lead to a massive slope failure. National Building Research Organization (NBRO) has been requested to investigate the stability of the cut slope at the above location. Number of boreholes were advanced into the slope to identify the sub soil profile that is necessary for a detailed study. Visual observation of the site aided by the data obtained from boreholes revealed that the site consists of complex geological conditions and it was idealized to consist of layers of residual soil and weathered rock of different levels of weathering over a depth of 30 m to 35 m. A typical cut slope section from each side of the expressway was used in the study.

Modelling of infiltration using different rainfall intensities was performed using Geo Studio SEEP/W 2016 to study the depletion of matric suction as the rain progress. The variation of the factor of safety of the cut slopes with the progression of rainfall was studied using Geo Studio SLOPE/W 2016 using the Spencer’s method, incorporating the results of the SEEP/W analysis. The results of the analysis revealed that the matric suction is depleted and pore water pressures increases reducing the safety margins and slope was approaching failure. The installation of sub horizontal gravity drains facilitated the release of ground water and dissipation of pore water pressure enabling to maintain the safety margins within acceptable limits.

Keywords: stability analysis; matric suction; infiltration; unsaturated soil; extension of southern expressway
1. Introduction

Extension of Southern Expressway Project (ESEP) is currently undergoing project under Ministry of Higher Education & Highways, Sri Lanka. The project encounters numerous geotechnical engineering related issues. As per the design, two cut slopes being formed between Ch 19+000 and Ch 20+000 in either sides of the road which are 30 - 35 m in height with respect to the road level. Site observations revealed that continuous seepage of water is occurring even during periods of dry weather.

These types of residual cut slopes generally exhibits an abrupt weathering pattern due to different mineralogical composition of bed rock. The situation is more complex with the presence of relict discontinuities. In case of a heavy rainfall, significant infiltration may cause loss of matric suction and development of perched water table which would lead to a significant reduction in the safety margins (Kulathilaka et.al., 2011). Thus, prevailing complex site geology and prolonged rainfall may lead to a slope failure.

National Building Research Organisation (NBRO) has been requested to investigate the cut slope stability. The study was done for two sections of cut slope and engineering solutions were proposed accordingly.

2. Objectives

The study comprises of the following objectives:

- To identify the conditions that may cause the instability of the cut slope
- To analyse and report future risk of failure
- To provide engineering solutions to keep the cut slope stable

3. Methodology

3.1 A study on Geology and Geological Structures in the area

The site is located in southern part of the Highland Complex in Sri Lanka. According to the field observation, fresh bedrock outcrop was observed in the few locations within the excavated area for road trace. Many structural features were observed during the field observation and primarily the study area belongs to a contact of two rock types namely Charnockitic Gneiss and Khondalite. Lithological condition of the underlain bedrock are given in Table 1.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Mineralogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charnockitic Gneiss</td>
<td>Biotite, Hypersthene, Garnet, Quartz, Feldspar</td>
</tr>
<tr>
<td>Khondalite</td>
<td>Graphite, Sillimanite, Garnet, Biotite, Quartz, Feldspar</td>
</tr>
</tbody>
</table>

The construction of the expressway road line is parallel to general strike of the foliation of the bedrock within the study area. Therefore, the Left-Hand Side (LHS) cut slope of the road line is situated in the dip slope while the Right Hand Side (RHS) cut slope is situated in the escarp slope. General strike of foliation of the bedrock is oriented to East-West direction and general dip slope is directed to South further, well-defined joint sets were observed North-South direction in the study area (Figure 1).
Furthermore, the cut slopes of two sides of the road line compose of mostly completely weathered rock to highly weathered rock which shows relict features of original bedrock. Several small scale and medium scale folds, shear zones and some other structural features have been observed within the cut slope planes as relics (Figure 2). Striations have also been observed in some of the excavated rock boulders, showing relative movements in some areas. In situ boudinages are common in the study area in smaller scale to larger scale and most of them are remains of Charnockitic gneiss bedrock and show spherical weathering.

It was found that some locations show surface erosions due to presence of erodible soil whereas some locations show local failures due to daylight condition of rock structural attitudes and peeling of weathered layers of the bedrock and boulders have been observed as a local failure mechanism (Figure 3). Moreover, Silt and Clay soils are the prominent soil types that can be identified in the study area. Pockets of clay and banded layers of clay are common in the study area (Figure 4).
3.2 Field Investigation

In the absence of available investigation data, NBRO decided to carry out a detailed field investigation to get an overall idea about the subsurface soil profile. The field investigation work consists of;

i.  Conducting a Geophysical Exploration

The geophysical exploration (seismic investigation) was focused to determine changes from overburden to weathered rock and from weathered rock to sound rock with changes of rock properties with depth. The refraction seismic profiling was carried out under the seismic investigation mainly along three sections. Table 2 shows the summary of layer present in the proposed site with respect to the P wave velocity.

Table 2: Summary of seismic investigation results

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Approx. Depth Range (MSL) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ch 19+710 to 19+874</td>
</tr>
<tr>
<td>Residual Soil</td>
<td>94-90</td>
</tr>
<tr>
<td>Completely Weathered Rock</td>
<td>90-70</td>
</tr>
<tr>
<td>Highly to Moderately Weathered Rock</td>
<td>&lt;80</td>
</tr>
<tr>
<td>Fresh Rock</td>
<td>&lt;78</td>
</tr>
<tr>
<td>Fresh Rock</td>
<td>&lt;78</td>
</tr>
</tbody>
</table>

ii.  Borehole Investigation

According to the results of the borehole investigation the study area consists of residual soil cover up to about 10 m to 20 m deep. Completely weathered rock is found underneath by the residual cover and it is extended up to about 10 m to 20 m below the residual cover. Area around the Ch 20+020, there is propensity to have a lowest thickness of soil cover and that makes the lowest depth to the bedrock within the area of study. Further to borehole investigation Silt and Clay soils are the prominent soil types that can be identified in the study area. Pockets of clay and banded layers of clay are common in the study area.

iii. Collecting undisturbed samples and Conducting laboratory tests

Undisturbed box samples were collected during the field investigation work and laboratory testing were carried out to determine the engineering properties of soil.

3.3 Infiltration analysis

The rainfall data over last 13 years was gathered from the rain gauge at Dandeniya Tank which is the closet to the study area. Rainfall was not extreme as per the rainfall data, where maximum recorded rainfall was around 10 mm/Hr. For the analysis,
actual rainfall measured was idealized and applied under appropriate slope boundary conditions.

Similar to the flow through a saturated soil, water flow through an unsaturated soil is generally governed by Darcy’s law (Fredlund and Rahardjo - 1993). However, comparing the water flow in an unsaturated soil with the saturated flow, two major differences stand out:

1. There exists a storage term which represents the variation of water content with matric suction; and
2. The water coefficient of permeability depends strongly on matric suction.

In the analysis the complex geological condition is idealized to a thicker layer of homogenous soil (Sandy Silt) is underlain by Highly Weathered Rock layer. It should be noted that no volume change in soil is considered during the infiltration process. The storage term in unsaturated flow is not a constant but dependent on the suction (or water content) in an unsaturated soil, and can be characterized by the Soil Water Characteristic curves (SWCC). Therefore, SWCC and water coefficient of permeability are the most important hydraulic properties for unsaturated soils. Soil water characteristic curve (SWCC) and permeability function for the soil forming the slope were obtained through laboratory tests done by Vasanthan (2016). The curves are shown in Figure 5 and Figure 6 respectively. The matric suction profile that prevailed prior to the rainfall could not be obtained. As such, the negative pore water pressures were given a cut-off value of 100 kN/m². The SWCC and hydraulic conductivity function for the highly weathered rock were taken from default values of Seep/W. Input parameters and boundary conditions were incorporated to the Geoslope Seep/W – 2016 software to generate the rainwater infiltration model of slope.

<table>
<thead>
<tr>
<th>Vol Water Content (m³/m³)</th>
<th>Matric Suction (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38</td>
<td>0.1</td>
</tr>
<tr>
<td>0.40</td>
<td>10</td>
</tr>
<tr>
<td>0.42</td>
<td>100</td>
</tr>
<tr>
<td>0.44</td>
<td>100</td>
</tr>
<tr>
<td>0.46</td>
<td>100</td>
</tr>
<tr>
<td>0.48</td>
<td>100</td>
</tr>
<tr>
<td>0.50</td>
<td>100</td>
</tr>
</tbody>
</table>

**Fig 5:** SWCC used for analysis - Sandy Silt - wetting path, Vasanthan(2016)

**Fig 6:** K function used for the analysis - Sandy Silt - wetting path, Vasanthan (2016)

The geometry of the predefined cut slopes (LHS – Ch 19+760 and RHS – Ch 19+820) were used in the analysis and the boundary conditions utilized in the transient seepage analysis are shown in the Figure 8 (Figures of Ch 19+760 are shown in this paper).

A boundary flux, q, equal to the estimate rainfall intensity, Ir, was applied to the surface of the slope. The nodal flux, Q, was taken to be zero at the sides of the slope above the water table and at the bottom of the slope to simulate a no flow zone. Equal total heads, ht, were applied at the sides of the slope below the water table (Rahardjo et al.2007). The broken line indicates the initial water table of the slopes and it was taken to be the same for all cases. The saturated hydraulic conductivities of the Sandy
SILT and Highly Weathered Rock layer are taken as $3.3 \times 10^6$ ms$^{-1}$ and $1 \times 10^7$ ms$^{-1}$ respectively. Analysis was carried out for rainfall intensities of a constant 10 mm/Hr and for varying rainfall with a maximum of 10 mm/Hr (Figure 7) over a five day period.

**Fig 7: Rainfall intensity variation**

The results of the analysis show that as rainfall continues, the matric suction values are gradually diminished approaching zero and the process extends to greater depths (Figure 9). Water reaching deeper levels cause a rise of ground water table and this effect is more prominent towards bottom levels of the slope. It reveals the development of thin perched water table at the surface as shown in Figure 10. Effect of progression of wetting front and the rise of ground water table is more prominent towards bottom levels of the slope.

![Diagram of initial PWP: Water Table](image)

**Fig 8: Cut slope geometry and boundary conditions at Ch 19+760**

<table>
<thead>
<tr>
<th>Color</th>
<th>Name</th>
<th>Model</th>
<th>K-Function</th>
<th>Kv/Kh Ratio</th>
<th>Vol. Wt. Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highly weathered rock</td>
<td>Saturated / Unsaturated</td>
<td>Impermeable Layer</td>
<td>1</td>
<td>Impermeable Layer</td>
</tr>
<tr>
<td></td>
<td>Sandy SILT</td>
<td>Saturated / Unsaturated</td>
<td>Sandy SILT</td>
<td>1</td>
<td>Sandy SILT</td>
</tr>
</tbody>
</table>

A–J–I–H = Ir (Rainfall intensity)
AB, CD, HG = Q = 0 m$^3$/s (No flow Boundary)
BC, FG = ht (Total head at sides)
Fig 9: The depletion of matric suction and development of positive pore water pressure at

Fig 10: Development of perched water table

3.4 Stability analysis

An analysis of the stability of the slope at the end of each day was done after incorporating the pore water pressure distributions obtained from the SEEP/W analysis. Analyses were done using the GEOSLOPE SLOPE/W (2016) software with the Spencer’s method considering circular shaped slope failures through the grid and radius approach. The Mohr Coulomb shear strength relationship developed for an unsaturated soil (Fredlund et.al.,1993) was incorporated in SLOPE/W analysis. The strength parameters of soil layers were assigned based on the field investigations & laboratory testing and experiences on similar soils are presented in Table 3. A $\phi$ value of 33° was used based on the studies done by Vasanthan (2016).

The variations in the pore pressure regime obtained under different conditions in the parametric analysis is incorporated in the stability analysis and variation of factor of safety as the rainfall prolonged is presented in Table 4.
Table 3: Strength parameters of soil layers

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Notation</th>
<th>$\gamma$ (kN/m$^3$)</th>
<th>$\phi'$ (degree)</th>
<th>$c'$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy SILT</td>
<td></td>
<td>19</td>
<td>34</td>
<td>09</td>
</tr>
<tr>
<td>HWR</td>
<td></td>
<td>22</td>
<td>45</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 4: Variation of factor of safety with the rainfall

<table>
<thead>
<tr>
<th></th>
<th>FOS of Ch 19+760 (LHS)</th>
<th>FOS of Ch 19+820 (RHS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 mm constant rainfall</td>
<td>10 mm varying rainfall</td>
</tr>
<tr>
<td>Day 01</td>
<td>1.343</td>
<td>1.347</td>
</tr>
<tr>
<td>Day 02</td>
<td>1.183</td>
<td>1.278</td>
</tr>
<tr>
<td>Day 03</td>
<td>1.081</td>
<td>1.190</td>
</tr>
<tr>
<td>Day 04</td>
<td>1.016</td>
<td>1.149</td>
</tr>
<tr>
<td>Day 05</td>
<td>0.985</td>
<td>1.126</td>
</tr>
</tbody>
</table>

It can be identified that the rainwater infiltration leads to instability of cut slopes. The factor of safety values are gradually reduced with the prolonged rainfall and Factor of Safety (FOS) values obtained are less than unity. The critical failure surface corresponding to the 5th day for Section Ch 19+760 under the influence of continuous rainfall of 10mm/hr are presented in Figure 11.

Fig 11: Stability analysis results of existing condition at Ch 19+760 for 10 mm/Hr constant rainfall

3.5 Proposed Mitigation Measures

In this case measures shall be taken for drain out infiltrated water minimizing building up of excess pore water pressure in the slope. It is achieved by providing an adequate surface drainage system and sub horizontal gravity drains.

Since a constant rainfall of 10 mm/Hr seems to be the more critical, it is considered when designing the mitigation measures. The idealization of arrangement of
horizontal gravity drains under the plane strain condition using SEEP/W 2016 software is presented in Figure 13 and variation of PWP with the depth is shown in Figure 12.

Stability analysis of the slope at the end of each day was conducted after incorporating the pore water pressure distributions obtained from the seepage analysis. With the installation of the horizontal gravity drains the ground water table reduced and the FOS improved. The FOS with continuing rainfall when the drains are present is summarized in Table 5. The critical failure surfaces correspond 5th day are presented in Figure 14 for Ch 19+760.

**Table 5: FOS values after installation of horizontal drains**

<table>
<thead>
<tr>
<th>Day</th>
<th>FOS of Ch 19+760 (LHS)</th>
<th>FOS of Ch 19+820 (RHS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>1.661</td>
<td>1.379</td>
</tr>
<tr>
<td>02</td>
<td>1.648</td>
<td>1.378</td>
</tr>
<tr>
<td>03</td>
<td>1.642</td>
<td>1.378</td>
</tr>
<tr>
<td>04</td>
<td>1.615</td>
<td>1.374</td>
</tr>
<tr>
<td>05</td>
<td>1.580</td>
<td>1.377</td>
</tr>
</tbody>
</table>
4. Conclusions

Many of the cuts made for expressway construction are cut through residual soil formation. These cut slopes would remain stable in dry weather condition as high matric suction that prevails in the unsaturated zone. However, instability may occur with prolong excessive rainfall. This condition is worse with the complex and variable geological formation. Thus, it is vital to take precautionary actions before any destruction happen.

Depletion of matric suction and development of positive pore water pressure with the infiltration of rainwater was studied and illustrated using SEEP/W 2016 to a two layer idealized soil profile. Since the layers have contrasting permeability values, water would remain stagnated at the boundary of layers so that a perched water table will be formed especially towards the toe of the slope.

According to the results of the SLOPE/W 2016 analysis, slope would become unstable if there are no preventive measures applied to release the pore water pressure generated.

As existence and maintenance of vegetation cover in slopes cannot be ensured and berm drains, cannot control the infiltration itself, horizontal gravity drains were proposed. As per the results of infiltration analysis introduction of horizontal gravity drains caused a significant reduction in pore water pressure development and prevent the formation of perched water table as well. Consequently, stability analysis showed a higher factor of safety greater than 1.2 of the cut slope which means risk of failure is comparatively low.

Furthermore, appropriate steps should be taken to seal the exposed joints and prevent ingress of water and local shotcreting together with doweling would be needed at the locations where erodible soil portions exist.

References

A Case Study of Evaluating Undue Settlement of Gabion Walls

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Abstract

Man-made canal systems are used in populated areas to ensure proper drainage while taking excess storm water away from the area and also as flood mitigation approaches. In this regard, nowadays, several projects have been implemented to rehabilitate existing canals flowing across the major cities of Sri Lanka in order to facilitate future flood events. It becomes a very challenging task when a canal is passing through the marshy lands creating the situation more adverse in selection of counter measures. In that case, different types of ground improvement techniques may be used for construction on soft ground. Consequently, detailed geological & geotechnical investigation, mitigation measures with tolerable design limits, duration and cost of the project are vital to incorporate safe and economical Engineering designs for retaining structures. Engineering approaches for design of retaining structures in canal banks in an area underlain by very thick soft soil layers is a challenging task with site constraints and it depends on applicability of design to overcome the problems such as low bearing, low passive resistance and excessive settlements accompanied with soft ground. Otherwise, during the construction phase, it becomes impracticable to apply the design and have to undergo design failures which will finally leads for a significant time wasting, money and manpower. Accordingly, seven design options were taken into account in the assessment by considering pros and cons to suit with the prevailing site condition. Finally, the main objective of this study is to aware the relevant parties, researchers and professionals involved with such rehabilitation works, on the special considerations in selecting, so that such problems related to existing subsurface formation which may be encountered during similar works be minimized or avoided.

Keywords: soft ground; canal bank protection method; flood mitigation
1. **Background**

Recently, several projects have been implemented to rehabilitate stream banks in some areas of the country. While implementing such projects, the subsurface variation with existence of soft soils can create geotechnical related problems due to lack of proper field investigations.

Similar situation was reported with experience of significant undue settlements and lateral displacements of already constructed gabion walls in the canal bank protection project of Moragoda Ela, Galle while implementing rehabilitation works. This project was implemented for the improvement of drainage system for an effective and efficient flood conveyance, since the area is situated over a flood plain and fulfilling future necessities. In this research, it is anticipated to study the causes for unexpected settlements, excessive deformation of retaining structures and to evaluate the design options which may be solutions for such problems.

![Fig. 1. Failures and failure causes of constructed gabion walls](image1)

2. **Research Problem**

The case focused on this study was the rehabilitation of Moragoda Ela project using gabion walls, which has been experienced a significant undue settlements along with a lateral displacements. Therefore, considerations for the possible design options to overcome such problems are discussed in the research.

3. **Study Method**

Study method consists of preliminary geotechnical assessment, field investigation works, laboratory testing and finally, evaluation of possible counter measures to select appropriate retaining structures for a particular case of rehabilitation of Moragoda Ela project.
3.1 Preliminary Assessment

Preliminary assessment consists with site inspection survey, discussion with relevant stake holders and evaluating available data used for the design and construction. During the preliminary assessment of available data used for the design, it was realized that the actual subsurface geological condition has not been thoroughly determined. In this regard, design works of canal bank has been done based on the results of Mackintosh test, which gives only the layer thickness of soft soil layers. With the available mackintosh test results, it can be clearly identified that there is a 6.0m to 8.0m thick soft soil layer below the existing ground level. However, it seems that the soft soil layer thickness had not been used with respect to the designed height of the existing gabion wall. Therefore, due to lack of geotechnical properties of subsoil layers, a detailed geotechnical investigation was proposed to identify the subsurface geological condition underneath by the gabion wall.

3.2 Field Investigations

Ten (10) numbers of boreholes locations were selected to cover both banks along the trace of the canal considering the locations of excessive settlements observed with already constructed gabion walls, in order to identify the subsurface geological condition underneath by the gabion wall. Continuous sampling and undisturbed sampling were done for further classification of soil.

![Fig. 3. Borehole drilling works](image)

3.3 Laboratory Testing

The following advanced testing were performed for determination of soil parameters (refer Table 1). In addition, classification tests and chemical tests were also carried out. The results obtained are used in the analysis for retaining structures.
### Table 1. Triaxial (UU) and Consolidation Test Results

<table>
<thead>
<tr>
<th>Borehole No.</th>
<th>Depth (m)</th>
<th>Soil Type</th>
<th>$C_U$ (kPa)</th>
<th>$\phi_U$ (deg)</th>
<th>$C_\phi$</th>
<th>$e_0$</th>
<th>$e_r$</th>
<th>$P_C$ (kPa)</th>
<th>$C_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH 8</td>
<td>5.0 – 6.0</td>
<td>Very soft PEAT</td>
<td>10 - 12</td>
<td>0</td>
<td>3.22</td>
<td>7.082</td>
<td>3.639</td>
<td>18</td>
<td>0.022</td>
</tr>
<tr>
<td>BH 9</td>
<td>5.0 – 6.0</td>
<td>Very soft PEAT</td>
<td>9 - 11</td>
<td>0</td>
<td>2.45</td>
<td>6.073</td>
<td>3.291</td>
<td>21</td>
<td>-</td>
</tr>
<tr>
<td>BH 10</td>
<td>5.0 – 6.0</td>
<td>Very soft PEAT</td>
<td>7 - 20</td>
<td>0</td>
<td>2.98</td>
<td>5.208</td>
<td>3.010</td>
<td>32</td>
<td>0.020</td>
</tr>
</tbody>
</table>

### 3.4 Analysis of the Results

#### 3.4.1 Results of preliminary Geotechnical Assessment

Followings were observed during the site inspection:

(a) Significant settlement along with a lateral displacement of the gabion walls in most of the locations of already constructed canal trace

(b) Sizes of the gabion filling material (rock pieces) is problematic

(c) The ground improvement method used at the site is not replacement as specified in the design drawings

(d) Instead of recommended method, the construction method followed at the site was displacing the soft soil (PEAT) underneath the gabion foundation level using boulders by means of excavator bucket until refusal

(e) Required investigation for proper identification of the existing soil condition were not made

![Diagram of gabion wall](image)

**Fig. 4. Gabion wall type constructed at the site**
According to the evaluating of available data used for the design and construction:

(a) 8 – 10 m thick low bearing soil layer was identified

(b) Internal stability of the gabion wall section was not taken in to account in the
design calculation

(c) Allowable bearing capacity of soil required for the design had not been
considered at the foundation level

3.4.2 Results of field Investigation

As per the findings of subsurface profile produced with the use of borehole drilled
at the site, top most layer extends up to a maximum depth of 1.9 m below the ground
level. Beneath by the top most soil layer, a very soft to soft PEAT/ Organic SILT of low
plasticity layer exists with maximum thickness of 6.0 m followed by the soft layer, sily
SAND/ sandy SILT or SILT layer is present with thickness of 0.3 m to 3.9m. Several
boreholes show firm to stiff sandy CLAY/ clayey SAND or CLAY of high plasticity
intermediate layer with thickness of 0.85 m to 1.2 m. The sily SAND/ sandy SILT
(completely weathered rock) layer is revealed at a maximum depth level of 5.3m
extending down up to the termination depth.

Based on the results of the ground investigations described above, geotechnical
profiles along the alignment were described in Fig. 5 and Fig. 6 as below.

---

**Fig. 5. Subsurface Profile along RHS Bank**
Fig. 6. Subsurface Profile along LHS Bank

According to the results of detailed geotechnical investigation carried out for the design review purpose, it was revealed that gabion wall was placed on top of a soft peaty soil layer. Hence, excessive settlement has taken place either during or after the construction stage due to low shear strength and high compressibility of this problematic soil layer. Therefore, it is obvious that major cause for this failure is due to the presence of a very soft peaty soil layer present (low bearing soil) underneath by the Gabion wall.

Further, adding correction layer for settled gabion wall is observed at the site, which may lead to shear failures by exceeding the design loads and inadequacy of bottom width of gabion to bear the additional load imposed.

In addition, it have been observed, some defects such as cracks, tilting, subsidence and upheaving with nearby structures which may be a result of ongoing construction activities of the project. Therefore, in such cases special attention must be required to ensure the stability and safety of the adjacent properties.

4. Assessment of Canal Bank Protection Measures

The stability of the canal bank protection options were assessed for all the borehole locations. Information gathered during the preliminary investigations were also incorporated for the analysis. Gabion wall, Cantilever wall, sheet pile wall, gabion supported on Gravel Compaction Piles (GCP), flood embankment, gabion with Reno mattress and staged construction method for gabion are the selected options, which have been evaluated.

In the analysis, mainly two types of soil layers were considered such as soft soil layer including top soil and silty SAND/ sandy SILT; SPT >= 10
4.1 Construction of gabion wall

Generally, construction of gabion wall is an ideal solution for founding subsurface which consist of low bearing soil and for withstanding large deformations due to the flexibility of the wall. In this case, underlying soft soil thickness varies between 8 to 10 m according to the results of detailed geotechnical investigations. Unless the subsurface soil has been improved, the structures will undergo excessive settlements under the prevailing site condition.

The proposed soft ground improvement method is the replacement by removing all unsuitable soft soil commencing from the existing ground level (Removal of soil shall be continued until sandy soil layer having SPT value of at least 10 is reached) and backfilling with 2m thick 6”x9” rock fill layer. Rock replacement and gabion wall construction should be carried out under water tight condition by adopting proper dewatering and shoring system.

According to the results of the analysis, the applicability of gabion wall design on top of the 2 m thick rock fill layer is not practicable since the height of the wall and bottom width of the wall are considerably high to be constructed.

4.2 Construction of cantilever retaining wall

Construction of cantilever retaining wall is also considered in the assessment of canal bank protection measure. However, under the prevailing site condition of revealing large thickness of problematic soil, removing and replacement of soft soil layer under water tight condition should be carried out as discussed under the option mentioned in section 4.1. The height of the wall is not economical under existing site condition.

In addition, the fluctuation of water table is highly influenced on the design and stability of the wall.

4.3 Sheet pile wall

Applicability of sheet pile wall varies widely, and especially used to stabilize the water front by preventing the erosion and undercutting the tides and waves. In this scenario, cantilever type sheet pile wall was assessed as the third option and obtained deeper embedment level due to the higher thickness of soft soil layer. If considering anchored sheet pile wall option, sufficient passive resistance of dead man anchor cannot be achieved since retained soil is also peat. Hence the installation of piles creates practical problems due to the proposed height of the wall. Further, durability of sheet pile wall is questionable with acidic content as revealed by chemical test on founding soil.

4.4 Construction of gabion with Reno mattress

On top of the 0.5 m ~ 1 m rock basement at the level of 2.5 m MSL, placing 1m×1m gabion box layer and after that laying Reno mattress into 1:1 slope up to finish level was proposed related to this case. However, this method of stabilization is not applicable for all the locations along the canal trace due to the lack of limited working space available.
4.5 Gabion wall supported on Gravel Compaction Piles

Gravel compaction pile is basically a ground improvement technique used to improve bearing capacity of soft soils. It accelerates the drainage, improves the strength and degree of compressibility of soft soil. For the gravel piles installed in square pattern which of 0.15, 0.5 & 0.75 m diameters with spacing of 1.0 to 1.5 m were assessed in the analysis. According to the results of analysis, the allowable bearing capacity on GCP improved soil strata is not adequately enough to bear the applied pressure from gabion wall and surcharge. Further, it also shows ineffectiveness in settlement reduction due to the considerably low area replacement ratio obtained.

In this case, several problems will be arisen during the construction stage such as high cost of construction, accessibility problems for the operating machine within the limited ROW and preparing working platforms to suit with the prevailing condition.

4.6 Construction of flood embankment

Due to presence of very thick soft soil layer, construction of flood embankment was also considered as the capacity enhancement method of canals. While processing the construction, it will undergo some settlement together with shear failures. Therefore, achieving designed finishing level of embankment is time dependant and staged construction process. It has a higher maintenance cost, which leads for social and environmental problems too. In this case, construction of embankment creates accessibility and stability problems for nearby houses and properties. In addition, some locations along the canal trace are congested with households and roads resulting inadequate space for construction.

4.7 Staged construction method for gabion wall

An excessive settlements and lateral displacements were observed with already constructed gabion walls which was done as per the design section in Fig. 4 due to placement of gabion wall on the top of thick peaty soil layer. Therefore, staged construction of gabion wall will avoid shear failures due to gaining of strength with existing soil over the time by consolidation. This option will be applied with design verification in terms of overturning, sliding and bearing.

Considering negative points, this method is heavily time dependent, and also it is difficult to estimate the BOQ in the tendering stage. Therefore, well planned construction management is essential at the project implementation stage to overcome the unnecessary delays and expenditures.

5. Conclusion

Original design work of this project has been undertaken without identifying the prevailing subsurface geological condition adequately. Hence, conduction of a detailed geotechnical investigation is a must for this type of mitigation projects for proper identification of subsurface profile before the design work finalized. Otherwise, time and cost would become unexpectedly and unnecessarily higher and will also lead for a disastrous situation similar to prevailing condition.

When very thick soft soil layer is presented at the subsurface of stream banks, the selection of retaining structure for canal bank protection is challenging and needed to
be resilient with existing subsurface condition in order to cope up with the excessive settlements and deformations of ground. Accordingly, considerations for some possible design options, which can be adopted under the prevailing site condition with respect to pros and cons of applicability are discussed in the research. Consequently, evaluation results of selected design options will be much useful for designers who engage with designing canal bank protection measures for similar cases in future.

In addition, it is a must to ensure the public safety as well as the stability and safety of the adjacent properties during construction stage which should be a one of the important considerations taken in to account in the planning and designing stage of any project.

Acknowledgement

The authors would like to express their gratitude to all personnel who contributes their immense commitment and knowledge to make the particular project successful.

References

Secondary Compression of Sri Lankan Peaty Clay
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²Scientist, National Building Research Organisation, Sri Lanka
³Consultant Engineer, National Building Research Organisation, Sri Lanka

Abstract

Secondary compression is high in peaty clay deposits. They have high void ratios and exhibit high values of compression index \( C_v \), and display the highest value of \( C_v/C_e \) among the geotechnical materials. Primary consolidation is completed in weeks or months in typical field situations. Secondary compression of Sri Lankan peaty clay was investigated by oedometer tests on disturbed (re moulded) and undisturbed specimens. This paper discusses the peaty clay secondary compression behaviour, in particular the \( C_v/C_e \) concept in the loading and reloading phases. For both disturbed and undisturbed samples, the \( C_v/C_e \) ratio is found to be in the range of 0.050-0.07 when the oedometer tests were conducted with a load increment ratio of 2. In remoulded samples, when load increment ratio was kept low \( C_v/C_e \) decreased, particularly for one day long load increments. When the load duration was increased to three days, the \( C_v/C_e \) ratio recovered to the normal range.

Keywords: Secondary compression, coefficient of secondary consolidation, compression index

1. Introduction

Soils are primarily formed by the decomposition of rocks. However, degradation of organic matter under anaerobic conditions also produces soil, commonly called “Peat”. In Sri Lanka, peat deposits mixed with inorganic soils are encountered in flood plains of main rivers and in water logged zones. Since they are mixed with inorganic soils, organic content is in the range 30-40% and the term peaty clay is more appropriate. In terms of engineering properties, peaty clay is very low in shear strength and highly compressible than inorganic soils. It is very important to study the behaviour of peaty clay because peat deposits are quite common in many suburbs around Colombo where new development projects are proposed.

While the magnitude of primary consolidation is controlled by the compression index, \( C_v \), the magnitude of secondary consolidation is theoretically calculated using the coefficient of secondary consolidation, \( C_s \). Mesri et al. (1977, 1997) proposed the \( C_v/C_e \) concept for organic and inorganic soils including peat. Published literature
(Mesri and Godlewski 1977; Mesri et al 1994) indicate the Cₖ/Cₑ ratios for various natural soils as summarised in Table 1.

CO₂ while increasing environmental pollution. Therefore, study on the use of spandex mix fabric waste as a material for construction products and it will be a solution for fabric waste disposal problem.

Polyester is a type of polymer which contains ester functional group in the main chain. Natural and synthetic polyesters are available. Natural polyesters and a few synthetic ones are biodegradable, but most synthetic polyesters are not. Polyester fibers are sometimes spun together with natural fibers to produce a cloth with blended properties. Polyester thread or yarn are commonly used in apparel industry. Polyester shows low water absorption property (www.whatispolyester.com, 2015).

Spandex is a synthetic fiber which is exceptionally used for elasticity. It is stronger and more durable than natural rubber. Spandex has been incorporated into a wide range of garments, especially in skin-tight garments due to its elasticity and strength (stretching up to five times its length) (www.fibersource.com, 2017). Polyester spandex is a type of fabric which shows elastic properties and contains 70-80% polyester and 20-30% spandex.

Table 1. Values of Natural Water Content, and Cₖ/Cₑ for peat deposit (after Mesri et al. 1999)

<table>
<thead>
<tr>
<th>Peat</th>
<th>Water content (%)</th>
<th>Cₖ/Cₑ</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrous peat</td>
<td>850</td>
<td>0.06-0.1</td>
<td>Hanrahan (1954)</td>
</tr>
<tr>
<td>Peat</td>
<td>520</td>
<td>0.061-0.078</td>
<td>Lewis (1956)</td>
</tr>
<tr>
<td>Amorphous peat</td>
<td>500-1500</td>
<td>0.0350-0.083</td>
<td>Lea and Brawner (1963)</td>
</tr>
<tr>
<td>Canadian muskeg</td>
<td>200-600</td>
<td>0.09-0.1</td>
<td>Adams (1965)</td>
</tr>
<tr>
<td>Amorphous to fibrous peat</td>
<td>705</td>
<td>0.0730-0.091</td>
<td>Keene and Zawodniak (1968)</td>
</tr>
<tr>
<td>Peat</td>
<td>400-750</td>
<td>0.0765-0.085</td>
<td>Weber (1969)</td>
</tr>
<tr>
<td>Fibrous peat</td>
<td>605-1290</td>
<td>0.0520-0.072</td>
<td>Samon and Larochell (1972)</td>
</tr>
<tr>
<td>Fibrous peat</td>
<td>613-886</td>
<td>0.0600-0.085</td>
<td>Berry and Vickers (1975)</td>
</tr>
<tr>
<td>Amorphous to fibrous peat</td>
<td>600</td>
<td>0.0420-0.083</td>
<td>Dhowian and Edil (1980)</td>
</tr>
<tr>
<td>Fibrous peat</td>
<td>660-1590</td>
<td>0.060</td>
<td>Lefebvre et al. (1984)</td>
</tr>
<tr>
<td>Dutch peat</td>
<td>370</td>
<td>0.060</td>
<td>Den Haan (1994)</td>
</tr>
<tr>
<td>Fibrous peat</td>
<td>610-850</td>
<td>0.0520</td>
<td>Present study (1997)</td>
</tr>
</tbody>
</table>

The data suggests a range of 0.06 ± 0.01 for peat deposits. These represent the highest values of Cₖ/Cₑ for natural soil deposits. It appears that the magnitude of Cₖ/Cₑ depends on the deformability, including compressibility, of soil particles. Peat deposits with highly deformable organic particles display the highest values of Cₖ/Cₑ whereas granular soils composed of space lattice silicates, and thus the least deformable particles, display the lowest values (Cₑ/Cₑ=0.02±0.01) (Mesri et al. 1990).

In this paper, a detailed investigation of the Cₖ/Cₑ concept of compressibility using remoulded samples (referred as simulated test in this paper) and undisturbed samples where Colombo Katunayaka Expressway (CKE) and Fish Market project (Peliyagoda) are also reported. Most of the studies correspond to fibrous peats. No such detailed
study had been previously carried out on Sri Lankan peaty clays. Hence, this paper discusses $C_o/C_c$ ratio for Sri Lankan peaty clay.

2. Methodology

2.1. Disturbed samples

A series of tests were conducted on remoulded samples of peaty clay collected from Kerawalapitiya-Kadawatha area. These tests were referred to as “Simulated Tests” in this paper. Loading durations of both one and three days were used for oedometer testing. Mostly, loading increments of three day duration rather than one day duration were used in order to capture secondary consolidation behaviour as secondary consolidation behaviour is sometimes not apparent within a day. In preparing a sample for testing, non-decayed pieces of wood and other impurities such as gravel particles were removed and peaty clay was remoulded to ensure uniformity. Then the sample was placed in a bucket in layer by layer and kept submerged in water for 28 days for stabilization or to allow for thixotropic strength gain before the testing commenced.

Some tests were carried out with doubling the stress level as in the conventional test whilst some tests were carried out with loading ratios of the order of 1.05 to 1.1 after loading the sample to some stress level with doubling. Also, after unloading the sample to a pre-decided stress level, reloading was also done along same stress values as in the loading increments.

2.2. Undisturbed samples

A few tests were carried out on undisturbed samples obtained from two projects where the peaty clay layer had been subjected to a fill load for some time. The two projects are the Colombo Katunayake Expressway (CKE) and Colombo fish market project. In these cases, one day duration consolidation tests were carried out with loading and unloading increments only (i.e. no reloading increments). Further, stress level was doubled at each loading increment stage as in the conventional manner.

3. Results and Discussion

3.1 Disturbed samples
3.1.1 Conformity with the $C_o/C_c$ Concept

For each loading increment, $C_o/C_c$ values were computed and in reloading increment the ratio $C_o'/C_r$ values were computed from the test data.

3.1.1.1 One day tests

The typical $C_o/C_c$ or $C_o'/C_r$ ratio for one day long tests is presented in Table 2.

Table 2 – $C_o/C_c$ and $C_o'/C_r$ values for different loading
The ratio $C_o/C_c$ is in the range of the 0.06 as prescribed by Mesri (1997) in the load increments where stress level was doubled. In the increments where ratios of 1.1 to 1.2 were used, the $C_o/C_c$ ratio is much lower.

### 3.1.1.2 Three day tests

The typical $C_o/C_c$ or $C_o'/C_r$ ratios for three day long tests are presented in Table 3.

**Table 3 – $C_o/C_c$ and $C_o'/C_r$ values for different loading**

<table>
<thead>
<tr>
<th>Load (kN/m²)</th>
<th>Void ratio</th>
<th>$C_o$ and $C_o'$</th>
<th>$C_c$ and $C_r$</th>
<th>$C_o/C_c$ or $C_o'/C_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$C_o$</td>
<td>$C_o'$</td>
<td>$C_c$</td>
</tr>
<tr>
<td>10</td>
<td>4.9389</td>
<td>0.106</td>
<td>1.4381</td>
<td>0.07</td>
</tr>
<tr>
<td>20</td>
<td>4.5060</td>
<td>0.110</td>
<td>1.4381</td>
<td>0.08</td>
</tr>
<tr>
<td>40</td>
<td>3.8463</td>
<td>0.114</td>
<td>1.9773</td>
<td>0.06</td>
</tr>
<tr>
<td>80</td>
<td>3.2849</td>
<td>0.114</td>
<td>1.9773</td>
<td>0.06</td>
</tr>
<tr>
<td>120</td>
<td>2.9029</td>
<td>0.130</td>
<td>1.9773</td>
<td>0.07</td>
</tr>
<tr>
<td>180</td>
<td>2.5463</td>
<td>0.141</td>
<td>1.9773</td>
<td>0.07</td>
</tr>
<tr>
<td>270</td>
<td>2.1450</td>
<td>0.146</td>
<td>1.9773</td>
<td>0.07</td>
</tr>
<tr>
<td>80</td>
<td>2.1883</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>2.1800</td>
<td>0.002</td>
<td>0.0818</td>
<td>0.03</td>
</tr>
<tr>
<td>180</td>
<td>2.1656</td>
<td>0.006</td>
<td>0.0818</td>
<td>0.07</td>
</tr>
<tr>
<td>270</td>
<td>2.1161</td>
<td>0.059</td>
<td>1.9773</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Generally, the ratio of $C_o/C_c$ is found to be in the range 0.05-0.07.

It should be noted that the $C_o$ value increased over the 3 day loading increment. The higher values towards the end of the loading increment were used in this comparison.
The $C_a/C_c$ ratio is not low for load increments with ratios less than 2.0, in contrast to observations made in one day long load increments.

In general, the ratios $C_a/C_c$ in reloading increments are lower than $C_a/C_c$ in the loading increments.

3.2 Undisturbed samples

3.2.1 Conformity with $C_a/C_c$ Concept

Attempts were also made to test the $C_a/C_c$ concept using the test data.

3.2.1.1 Tests on peaty clay from CKE

The typical $C_a/C_c$ values were obtained for each loading increment in compression stage and presented in Table 4.

<p>| Table 4 – $C_a/C_c$ and values for different loading – BH 2 (14.25m-15.00m) |</p>
<table>
<thead>
<tr>
<th>Load (kN/m²)</th>
<th>Void ratio</th>
<th>$C_a$</th>
<th>$C_c$</th>
<th>$C_a/C_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.492</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6.166</td>
<td>0.073</td>
<td>0.538</td>
<td>0.14</td>
</tr>
<tr>
<td>15</td>
<td>5.988</td>
<td>0.088</td>
<td>0.538</td>
<td>0.16</td>
</tr>
<tr>
<td>29</td>
<td>5.773</td>
<td>0.108</td>
<td>2.800</td>
<td>0.04</td>
</tr>
<tr>
<td>58</td>
<td>5.308</td>
<td>0.165</td>
<td>2.800</td>
<td>0.06</td>
</tr>
<tr>
<td>116</td>
<td>4.828</td>
<td>0.175</td>
<td>2.800</td>
<td>0.06</td>
</tr>
<tr>
<td>232</td>
<td>4.035</td>
<td>0.295</td>
<td>2.800</td>
<td>0.11</td>
</tr>
<tr>
<td>463</td>
<td>3.100</td>
<td>0.286</td>
<td>2.800</td>
<td>0.10</td>
</tr>
<tr>
<td>926</td>
<td>2.354</td>
<td>0.198</td>
<td>2.800</td>
<td>0.07</td>
</tr>
</tbody>
</table>

In the initial load increments the $C_a/C_c$ ratio is much greater than the usual range of 0.05 to 0.06. For instance, $C_a/C_c$ ratios of the order of 0.15 were found for certain tests including tests on remoulded samples. At this stage, the $C_c$ value is in transition and there is a difficulty in extracting the exact value. Mesri et al. (1977) also proposed that considerable care is required in interpreting $C_a$ Vs $C_c$ data from the Oedometer tests in which small pressure increments are applied following sustained secondary compression.

However, generally the $C_a/C_c$ ratio remains to be of the order of 0.05.

3.2.1.2 Tests on peaty clay from Fish Market site-Peliyagoda

The typical $C_a/C_c$ values obtained for each loading increment in compression stage are presented in Table 5.

<p>| Table 5 – $C_a/C_c$ and values for different loading – BH 6 (3.00m-3.50m) |</p>
<table>
<thead>
<tr>
<th>Load (kN/m²)</th>
<th>Void ratio</th>
<th>$C_a$</th>
<th>$C_c$</th>
<th>$C_a/C_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.711</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>5.395</td>
<td>0.024</td>
<td>1.149</td>
<td>0.02</td>
</tr>
<tr>
<td>15</td>
<td>5.049</td>
<td>0.051</td>
<td>1.149</td>
<td>0.04</td>
</tr>
<tr>
<td>Load (kN/m²)</td>
<td>Void ratio</td>
<td>C_a</td>
<td>C_c</td>
<td>C_a/C_c</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>-----</td>
<td>-----</td>
<td>---------</td>
</tr>
<tr>
<td>29</td>
<td>4.517</td>
<td>0.099</td>
<td>2.600</td>
<td>0.04</td>
</tr>
<tr>
<td>58</td>
<td>3.941</td>
<td>0.092</td>
<td>2.600</td>
<td>0.04</td>
</tr>
<tr>
<td>116</td>
<td>3.115</td>
<td>0.176</td>
<td>2.600</td>
<td>0.07</td>
</tr>
<tr>
<td>232</td>
<td>2.327</td>
<td>0.135</td>
<td>2.600</td>
<td>0.05</td>
</tr>
<tr>
<td>463</td>
<td>1.599</td>
<td>0.135</td>
<td>2.600</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Generally, the values are in the normal range of the order of 0.05.

4. Conclusions

Spandex waste in the shredded form can be effectively utilized to produce cement based products which do not require high compressive strength. Shredded fabric pieces showed fiber effect with improvement in the flexural strength and compressive strength of cement paste. The optimum mix with respect to strength was obtained at 26% fabric percentage (by volume). Fabric, cement and sand mixture can use for foot paths which gives better walking comfort due to its energy absorbing capability.

Acknowledgement

The authors wish to express their heartfelt gratitude to personnel at BMRTD, NBRO and the Department of Civil Engineering of University of Moratuwa laboratory staff for the encouragement and the support given by them to carry out this research project.

References

Rock Slope Stability Assessment; Kegalle - Bulathkohupitiya Road, Sri Lanka

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¹Scientist, National Building Research Organisation, Sri Lanka
²Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

The road network in the mountainous areas in Sri Lanka plays a vital role in transportation activities in country. Unplanned excavations due to road widening and constructions in hilly terrain may undermine the stability of rock slopes during torrential and prolonged monsoonal rains. Such rock slope failures disrupt in traffic and cause loss of properties and lives. Hence, stability of rocks and cut slopes in road cuts in hilly regions are concerned in this study.

Objectives of the study were to identify the mode of failures for rock slopes created as a result of the recent road-widening project carried out in between chainages 6 km to 16 km along Kegalle-Bulathkohupitiya road (A 21) in Kegalle District, and provide suitable cut slope designs as recommendations for remedial measure to withstand possible failures during a triggering event.

Planar, wedge and topple failures between chainages 11 km and 16 km were identified as possible rock instabilities during the Stereograph analyses. In places of potential planner failures, angle of the cut slopes must be determined giving consideration to the orientation of discontinuity planes. Conversely, for potential wedge and topple failures, a continuous slope mass rating can be used for further studies and categorizing the stability conditions in detail. Removal of soil overburden up to bed rock is proposed for few selected locations where the overburden thickness is very thin.

So that, mitigation methods such as removing unstable rock parts, rock bolting and rock anchoring methods can be recommended accordingly in the future.

Keywords: Rock slope Stability; Stereograph analysis

1. Introduction

Road cut failures have become one of the main geological disasters associated with road network in hilly terrains of Sri Lanka. These failures include slope failures, cut slope failures with soil mass and rock slope failures. Among them, rock slope failures have taken in to consideration in this study. Hoek and Bray categorized rock slope failures into different types based on failure mechanisms namely, Plane Failure, Wedge Failure, Toppling and Arc Sliding Failure.
Factors affecting slope stability can be divided mainly into two categories such as internal latent factors and external inducements. Internal latent factors such as slope type, geological properties, structures, discontinuities etc. are the most fundamental present causes affecting slope stability, especially on rock slopes while inducement factors are being heavy rainfalls, typhoons, earthquakes, human factors triggering the failure [3].

![Map Image](image)

Fig.1. Location map of the study area (source; Topographic map of sheet no. 60 published by Survey Department, 1996)

Even though Kegalle- Bulathkohupitiya road is an “A” grade road, its conditions was poor and it was very narrow and not developed up to 2017. Therefore, the
Government of Sri Lanka (GOSL) identified the poor condition of this road and decided to improve. Widening of Kegalle- Bulathkohupitiya (A 21) road is implemented under a China funded GOSL project by the Road Development Authority (RDA), Sri Lanka and as at present, project activities are in progress.

The study area is located in between 6+ 000 km to 16+ 000 km of Kegalle-Bulathkohupitiya road, A 21 (Fig. 1) which is running about 150 m to 400 m MSL. The road is a major access to Bulathkohupitiya, and the study area lies on Mideniya, Godigamuwa, Moronthota, Rotuwa, Moradana and Udugoda and it belongs to Kegalle Divisional Secretariat (DS) Division of Kegalle District. Only rock slope failures is considered in this study.

2. Methodology

 Orientations of the discontinuities of bedrocks and their cut slope directions and angles were measured along the road in between chainages 6 km to 16 km. To achieve the most reasonable discontinuity orientation as much possible, all the discontinuity orientations that were identified in the area were considered and values were averaged to get the maximum accurate data. Based on previous studies of rock stability and rock falling at Dolosbage area, the friction angle of charnockitic gneissic rock is estimated at 30°[1]. Hence, the friction angle of those rock exposures in the study area is considered as 30°.

Data on lithology of rock and their weathering grade, intensity and infilling (material separating the adjacent walls of discontinuities; the perpendicular distance between the adjacent rock walls is termed the width of the filled discontinuity) of discontinuity were obtained by visual observations of expert geologists. Weathering grade of bed rock was classified as highly, moderately weathered and fresh rock depending on their weathering stage. Joint intensities were measured by counting the number of joints within approximately 1 m length of rock in the field. Highly weathered zones, and existing rock failure areas were specially noted during the field investigation. Among those locations the most vulnerable areas for rock slope failures were selected for the stereo grams analysis in that study.

3. Results and discussion

3.1 Field observation

Hornblende biotite gneiss is the major rock type and charnockitic gneiss and quartz feldspathic gneiss also can be encountered in the study area. Quartz, feldspar, biotite and hornblende are the major minerals with traces of hypersthene and garnet minerals can be observed in the major rock types. The percentage and availability of above minerals varied according to rock type. About 3 m to 10 m high rock cuts were encountered and surface exposed rock cuts are a prominent feature in between chainage 9 km to 16 km. In most of above locations, overburden soil thickness is less than 0.5 m. In between chainage 6 km to 9 km, rock was exposed at the toe of the cut with 2 m to 6 m thickness of soil overburden.

General strike direction of the foliation plane in study area is in between 320° to 015°. Percentage of availability of existing orientations of discontinuity planes are shown in the rose diagram (Fig. 2). There are two major sets of joint planes that can be
observed and strike directions of these planes are 330°, 345° and 045°, 080°. Foliation plane is daylighting on the plane in chainages 13 + 560 km and 16 + 600 km.

Most of them are moderately to highly weathered rock with several joint sets. In some locations, rock discoloration could be seen due to weathering along the joints. Spheroidal weathering is a common feature that can be observed in charnockitic gneiss in the study area. Physical weathering also can be observed in some locations. Most of these joint planes have no separation or filling materials. But, some of these have filling materials mostly in highly weathered areas. In those areas, joints were filled with clay of weathered feldspar and they have 2-7 per meters intensity.

Fig.2. Rose diagram for discontinuity planes in study area (by GEO ROSE software)

3.2 Analysis of rock cut slope using Stereograph

Location L1 (in Chainage 11 + 970 km)

Moderately weathered hornblende biotite gneiss bed rock is exposed in the road cut (Fig.3.b) and about 1-2 m thick overburden soil layer is there. Unstable boulders are in the upper slope area (Fig.3.a) and some rock blocks are in unstable condition due to construction activities. There is a seasonal valley in end margin of that rock exposure, towards the Kegalle town. In rainy seasons, huge seepages can be observed through the weak planes of bed rock. There are three discontinuity planes including the foliation plane and two sets of joints (Table 1).

Fig.3. Views of location L1, (a). Top area of the road cut (b). Bottom part of the road cut
Table 1. Orientation of foliation and joint

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Dip</th>
<th>Dip Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>64°</td>
<td>071°</td>
</tr>
<tr>
<td>J1</td>
<td>80°</td>
<td>345°</td>
</tr>
<tr>
<td>J2</td>
<td>44°</td>
<td>255°</td>
</tr>
</tbody>
</table>

Stereographic Analysis

Three set of discontinuities which were observed in location 1 are plotted in stereo-net (Fig.4).

<table>
<thead>
<tr>
<th>Description</th>
<th>Dip/ Slope</th>
<th>Dip Direction/Slope direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut slope orientation</td>
<td>82°</td>
<td>270°</td>
</tr>
<tr>
<td>F</td>
<td>64°</td>
<td>071°</td>
</tr>
<tr>
<td>J1</td>
<td>80°</td>
<td>345°</td>
</tr>
<tr>
<td>J2</td>
<td>44°</td>
<td>255°</td>
</tr>
</tbody>
</table>

Fig. 4. Plot of discontinuities and slope at L1.

The pink coloured area indicates the critical zone of failure. The symbols used in figure are as, SL: Slope; F: Foliation; J1, J2: Orientation of joint, W1: Wedge formed by intersection of joints.

Considering the cut slope, the analysis made through stereo-net plot shows that (Fig.4), the most unfavourable condition is the result of intersection formed by the discontinuities J1/J2. Hence, it is a case of probable wedge failure. The plunge of that wedge is 44°/265°.

Location L2 (in Chainage 12+ 203 km)

Shallow slope failure (length- 60 m and width- 30 m) is periodically active during past years (2015-2017) in intense rainy period. It may lead to disturb the continuity of transportation. Rock contact, between charnockitic gneiss (SL3) and hornblende biotite gneiss (SL1) is running through the failure mass (Fig.5.). Hornblende biotite gneiss is in condition of moderately weathered and charnockitic gneiss is in highly weathered condition. There is clayey soil layer within the highly weathered charnockitic discontinuities. Three discontinuity planes including the foliation plane...
and two sets of joints (Table 2) can be identified and also there are three different cut slope orientations, SL1, SL2 and SL3 as shown in the Fig. 5.

![Fig. 5. Views of location L2](image)

**Table 2. Orientation of foliation and joint**

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Dip</th>
<th>Dip Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>60°</td>
<td>070°</td>
</tr>
<tr>
<td>J1</td>
<td>85°</td>
<td>355°</td>
</tr>
<tr>
<td>J2</td>
<td>32°</td>
<td>265°</td>
</tr>
</tbody>
</table>

**Stereographic Analysis**

Three set of discontinuities which were observed in location 2 are plotted in stereo-net (Fig.6).

![Fig. 6. Plot of discontinuities and slope at L2.](image)
The pink coloured area indicates the critical zone of failure. The symbols used in figure are as, SL1, SL2, and SL3: Slope F: Foliation; J1, J2: Orientation of joint, W1: Wedge formed by intersection of joints.

Considering the cut slope, the analysis made through stereo-net plot shows that, the most unfavourable condition is the result of intersection formed by the discontinuities J1/J2. Hence, it is a case of probable wedge failures. The plunge of that wedge is 32°/269°. Otherwise the analyses of stereo-net indicate that the F is found close to the SL2 and SL3 cut slope directions. Hence, those both situations are considered as toppling conditions.

**Location L3 (in Chainage 13+ 560 km)**

Highly to moderately weathered charnockitic gneiss bed rock is exposed to the road cut and Spheroidal weathering condition can be observed (Fig.7). Three discontinuity planes including the foliation plane and two sets of joints (Table 3) can be identified.

![Fig.7. Views of location L3](image)

**Table 3. Orientation of foliation and joint**

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Dip</th>
<th>Dip Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>53°</td>
<td>078°</td>
</tr>
<tr>
<td>J1</td>
<td>43°</td>
<td>270°</td>
</tr>
<tr>
<td>J2</td>
<td>73°</td>
<td>194°</td>
</tr>
</tbody>
</table>

**Stereographic Analysis**

Considering the cut slope, the analysis done with stereo-net plot shows that (Fig. 8), the most unfavourable condition is the result of intersection formed by the discontinuities J2/F. Hence, it is a case of probable wedge failure and plunge direction of that wedge is 44°/121°. Otherwise the analyses of stereo-net indicates toppling failure with J1 and planar failure with F together with SL cut slope direction.
Three discontinuity planes including the foliation plane and two sets of joints (Table 4) can be identified.

<table>
<thead>
<tr>
<th>Description</th>
<th>Dip/ Slope</th>
<th>Dip Direction/ Slope direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut slope orientation</td>
<td>$85^\circ$</td>
<td>$085^\circ$</td>
</tr>
<tr>
<td>F</td>
<td>$53^\circ$</td>
<td>$078^\circ$</td>
</tr>
<tr>
<td>J1</td>
<td>$43^\circ$</td>
<td>$270^\circ$</td>
</tr>
<tr>
<td>J2</td>
<td>$73^\circ$</td>
<td>$194^\circ$</td>
</tr>
</tbody>
</table>

**Fig. 8. Plot of discontinuities and slope at L3.**

The pink coloured area indicates the critical zone of failure. The symbols used in figure are as, F: Foliation; J1, J2: Orientation of joint, W1: Wedge formed by intersection of joints.

**Location L4 (in Chainage 16+ 000 km)**

Moderately to highly weathered hornblende biotite gneiss bed rock is exposed in the road cut and about 0.5- 1.5 m thick overburden soil layer is there. A seasonal valley in end margin of that rock exposure, towards the Kegalle can be observed.

Three discontinuity planes including the foliation plane and two sets of joints (Table 4) can be identified.

**Fig. 9. Views of location L4**
Table 4. Orientation of foliation and joint

<table>
<thead>
<tr>
<th>Foliation/Joint</th>
<th>Dip</th>
<th>Dip Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>60°</td>
<td>315°</td>
</tr>
<tr>
<td>J1</td>
<td>45°</td>
<td>270°</td>
</tr>
<tr>
<td>J2</td>
<td>0°</td>
<td>62°</td>
</tr>
</tbody>
</table>

Stereographic Analysis

![Stereographic diagram]

<table>
<thead>
<tr>
<th>Description</th>
<th>Dip/ Slope</th>
<th>Dip Direction/ Slope direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut slope orientation</td>
<td>56°</td>
<td>62°</td>
</tr>
<tr>
<td>F</td>
<td>68°</td>
<td>315°</td>
</tr>
<tr>
<td>J1</td>
<td>43°</td>
<td>270°</td>
</tr>
<tr>
<td>J2</td>
<td>0°</td>
<td>62°</td>
</tr>
</tbody>
</table>

Fig. 10. Plot of discontinuities and slope at L4

The pink coloured area indicates the critical zone of failure. The symbols used in figure are as, SL: Slope; F: Foliation; J1, J2: Orientation of joint, W1: Wedge formed by intersection of joints.

Considering the cut slope, the analysis done with stereo-net plot shows that (Fig. 10), the most unfavourable condition is the result of intersection formed by the discontinuities J1/F. Hence, it is a case of probable wedge failure and plunge direction of that wedge is 47°/019°. Otherwise the analyses of stereo-net indicates planar failure with F and SL cut slope direction.

4. Conclusion

Based on the results of the present study, the following conclusions about the rock cut slope along Kegalle-Bulathkohupitiya road (A 21) in between the chainage 6+000 km to 16+000 km due to road cut modification for the road widening project, are made.

- Even though, no any remedial measures have been proposed for rock cut slopes, daylighting (planar), wedge and toppling failures of rock cuts are possible.
• Further studies, based on continuous slope mass rating (SMR) should be carried out to study and categorize the stability condition of potential wedge and toppling failures. Based on future studies, above failures should be mitigated with countermeasures such as rock bolting, shotcrete, or access bench at the top of the cut.

5. Recommendations

When constructing or widening roads in mountainous terrains, due consideration should be given to the following:

• Site specific stability of rock cut slope should be assessed at planning and design stages of a project prior to application of mitigation measures.
• Stability assessment for rock cut slopes should be carried out to identify potential mode of failures and propose mitigation countermeasures.
• Daylighting condition at chainage 13+ 560 km, and 16+ 000 km should be avoided by maintaining the lower cut slope angle than the dip angle of foliation plane.
• Removal of unstable rock blocks should be carried out by using control or chemical blasting procedure.
• At chainage 12+ 203 km, Surface cleaning and trimming of loosen soil mass weathered material up to bedrock should be done.
• Proper drainage system should be implemented in identified critical locations.

References

Rainfall Variability and Water Stress Conditions in Anuradhapura District
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²Director, Environmental Studies & Services Division, National Building Research Organisation, Sri Lanka
³Senior Lecturer, University of Colombo, Sri Lanka
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Abstract

Drought and water stress in an area occur mainly as a consequence of Rainfall deficiency and variability. Sri Lanka should pay serious attention to drought hazard because IPCC (Bates et al, 2008), projects more severe droughts and water stress conditions as a consequence of anthropogenic climate change. Among several meteorological factors, Rainfall is the key deterministic factor responsible for shaping water stress and drought severity in an area.

This paper presents the effect of Rainfall variability on drought related water stress conditions in Anuradhapura district with a special reference to extreme events. The variability of annual, seasonal, monthly and daily Rainfall in Anuradhapura and Mahailluppallama weather stations, for a period of 9 years from 2008 onwards was analysed and interpreted using descriptive statistics: histograms, boxplots, and dot plots, coefficient of variation, skewness, and percentiles.

The results show a strong variability in seasonal (monsoon and inter monsoon), monthly and daily Rainfall patterns in both stations with high coefficient of variance (>30) and a positive skewness especially in the wet season. There is no notable variability in the annual Rainfall, but a larger fraction of annual Rainfall has been delivered by extreme events. Further, an increasing trend of extreme Rainfall events plus frequent long dry spells were apparent during the period.

Occurrence of extreme events (wet and dry) without a considerable change in annual Rainfall suggest drought related waters stress conditions providing strong scientific basis to invest on a wide range of water harvesting strategies to capture Rainfall, store securely and use for fulfilling water demands in relevant sectors.

Keywords: Drought; Rainfall variability, Extreme events, Water stress
1. Introduction

Water stress in an area occurs as a consequence of prolong drought. **Drought** is a creeping natural phenomenon which can occur any time without any indication. Drought related water stress differs in many ways from other weather related disasters because of its slow progressive nature, lack of clear borderline for its onset and end, and the adverse environmental and social impacts they cause. Prolonged drought and water stress, if disregarded can cause major drawbacks to economy, social wellbeing and environmental sustainability. The Intergovernmental Panel on Climate Change (IPCC; Bates et al, 2008) indicates that during the past 25 years the world has been more drought prone and their projections implies that droughts related water stress will become more frequent and severe as a consequence of anthropogenic climatic change.

Drought related water stress is a common feature in the dry zone of Sri Lanka since ancient times. A Great Famine “Beminitiya Saya” had hit the ancient Sri Lanka during King Valagambahu’s reign and persisted for nearly 14 years from 103-89 BC. The great ancient hydraulic water management which comprised cascade water tank systems were considered to be the solution in facing droughts in the ancient Sri Lanka. This system has been dilapidated over past centuries and today only few are functional.

According to the Disaster Management Centre (Desinventar.lk, 2018), in the period of 1974 – 2008, 42.9 percent of the people in the dry zone has been affected by drought and related water stresses. Also, about 43,000 hectares of rice have been destroyed (Gunawardhana and Dharmasiri, 2015). The real impacts of drought related water stress in these areas are multiple. Repeated crop failures (paddy, grains and vegetables), domestic water stress, drying up of natural wetlands and degradation of wetland ecology, human elephant conflict, and a wide range of social issues such as loss of income sources, food insecurity, malnutrition, impacts on health and wellbeing of the society are linked with prolonged droughts. Therefore, continuation of a drought without proper management can result in complete deterioration of health and wellbeing of both natural and human ecosystems.

This paper presents the effects of Rainfall variability on drought related water stress conditions in Anuradhapura district over the past years. The variability of annual, seasonal, monthly and daily Rainfall in Anuradhapura and Mahailluppallama weather stations for a period of 9 years from 2008 were analysed and interpreted using descriptive statistics such as histograms, boxplots, dot plots, coefficient of variation, skewness, and percentiles.

1.1 Rainfall characteristics and the drought severity in Anuradhapura district

The Anuradhapura district receives its water largely from Rainfall. In addition, some parts of the district are fed by Trans-basin water diverted from Mahaweli River Augmentation. Yet, many areas still depend on rainwater, and failure of rains on time has repeatedly hit the district with drought and water stresses.

Anuradhapura district receives Rainfall from two monsoons and inter monsoons (South-West Monsoon (SWM) and North-East Monsoon (NEM)) and two inter-monsoons (First (FIM) and Second (SIM) Inter-monsoon). NEM and SIM are the main
rainy seasons that nourish Anuradhapura area with water, and it accounts to about 60 percent of the total annual Rainfall.

Drought conditions and related water stress can occur when there is a variability in Rainfall such as not receiving the expected Rainfall in a particular Monsoon or inter monsoon period, significant variability in monthly and/or daily Rainfall distribution (with frequent dry spells and extreme Rainfall events) and etc. In an extreme precipitation a larger fraction of monthly or seasonal Rainfall occur within a very short period of time (about 1-2 days) while rest of the month there is low/no Rainfall. If excess water that falls on land during extreme events cannot be stored, the runoff ends in the sea causing unwanted inundation and floods. As storage capacity is inadequate to store wet season Rainfall, in the off season the system suffers from water stress mainly in agricultural and domestic sectors, and shortage of water for ecosystem sustenance.

Therefore, an in-depth knowledge is required on Rainfall variability (total, seasonal, monthly and daily), the trends and occurrence of extreme events such as dry spells and heavy rains to assess and manage the drought related water stresses and their impacts.

2. Materials and Method

2.1 Study area

Anuradhapura is the largest administrative and agricultural district in the country and it covers approximately 11% of total land area. Main streams running across the district are Malwathu Oya, Kala Oya, Modaragam Aru, Maa Oya and Yan Oya. These streams feed most of the tank systems in the district.

Average annual Rainfall in the Anuradhapura district is around 1225mm. North-west and Second Inter monsoon are the main rainy seasons in this area (Burt and Weerasinghe, 2014). High Rainfall is received from October to December (main rainy season) and in the months of June, and July the district receives the lowest monthly Rainfall.

2.2 Data

Daily Rainfall data of Anuradhapura and Mahailuppallama weather stations from 2008 to 2017 were obtained from the Department of Meteorology, Sri Lanka. The two stations represent relatively different landuse types; urban built and rural agricultural lands. Anuradhapura station is an urban built area whereas Mahailuppallama station represent mostly rural agricultural landuses (Fig 1).
Fig. 1. Weather stations in Anuradhapura district: Anuradhapura and Mahaluppallama

2.3 Data analysis techniques.

The annual, seasonal (monsoon/inter monsoons), monthly and daily Rainfall variability together with occurrence of extreme events (dry spells and high Rainfall) were analysed and interpreted using descriptive statistics such as histograms, boxplots, dot plots, percentiles, coefficient of variation (CV) and skewness.

Coefficient of variation expresses the variability of the Rainfall. A higher value of CV is an indicator of larger variability, and vice versa. It is used to classify the degree of variability of Rainfall events as: less (CV < 20), moderate (20 < CV < 30), and high (CV > 30) (Asfaw et al., 2018). The CV is computed as follows:

$$\text{Coefficient of Variation (CV)} = \frac{\sigma}{\mu} \times 100$$

where CV is the coefficient of variation; $\sigma$ is standard deviation and $\mu$ is the mean Rainfall.

The skewness is a measure of the deviation of the data from the symmetry of a distribution. It is an indicator of extreme events. Zero value of the skewness coefficient indicates that data shows normal distribution (low variability) while positive skewness coefficient indicates that data set is right skewed suggesting high variability (more dry events and few extreme wet events). Negative skewness coefficient indicates that data is left skewed indicating few extreme dry events and more wet events (Ihsan, 2003).
3. Results and Discussion

3.1 Annual Rainfall variability

The minimum Annual Rainfall of 1011mm (2009) and 1035mm (2016) were recorded in Mahailluppallama and Anuradhapura weather stations respectively, while maximum Rainfalls were 2065mm and 2483mm (2014) (fig 2).

Coefficient of Variation values were 22 percent and 29 percent in Mahailluppallama and Anuradhapura stations respectively. The values indicate moderate inter-annual Rainfall variability during the study period in both stations. Skewness values show symmetric distribution suggesting no notable variability in annual Rainfall during the period (Table 1).

[Diagram: Annual Rainfall variation]

**Fig. 2. Annual Rainfall variation**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>St Dev</th>
<th>CV</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mahailluppallama</td>
<td>1507</td>
<td>331</td>
<td>21.97</td>
<td>0.00</td>
</tr>
<tr>
<td>Anuradhapura</td>
<td>1658</td>
<td>482</td>
<td>29.04</td>
<td>0.28</td>
</tr>
</tbody>
</table>

3.2 Monsoonal Rainfall variability

Fig 3 and table 2 present the monsoonal Rainfall variations during past years. Both stations show more or less similar monsoonal Rainfall variation. The CV values of NEM, SWM and SIM Rainfall were comparatively high (CV > 30 Asfaw et al., 2018) suggesting higher Rainfall variability in these monsoonal Rainfalls. Further, right skewed positive values of skewness coefficient indicate high variability in NEM and FIM and SIM monsoonal Rainfalls with the occurrence of extreme wet events and more dry spells. As NEM and SIM are the main Rainfall seasons in the district, this variability can result in drought related water stress under poor water management conditions.
### Fig. 3. Variation of Rainfall in seasons at Anuradhapura and Mahailluppallama stations

### Table 2. Descriptive statistics of monsoonal Rainfall

<table>
<thead>
<tr>
<th>Monsoon</th>
<th>Mean AP</th>
<th>Mean MI</th>
<th>CV AP</th>
<th>CV MI</th>
<th>Skewness AP</th>
<th>Skewness MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEM</td>
<td>484.2</td>
<td>428.7</td>
<td>53.91</td>
<td>53.02</td>
<td>0.4</td>
<td>0.94</td>
</tr>
<tr>
<td>FIM</td>
<td>301.9</td>
<td>284.6</td>
<td>32.97</td>
<td>53.7</td>
<td>0.23</td>
<td>1.95</td>
</tr>
<tr>
<td>SWM</td>
<td>300.2</td>
<td>298.2</td>
<td>78.53</td>
<td>71.46</td>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>SIM</td>
<td>572.3</td>
<td>509.2</td>
<td>39.71</td>
<td>27.38</td>
<td>0.21</td>
<td>0.64</td>
</tr>
</tbody>
</table>

### Fig. 4. Percentage Rainfall delivery in main Rainfall seasons
Fig 4 shows the Rainfall during rainy season and off season as a percentage of the total annual Rainfall. The rainy season has captured over 50%-80% Rainfall of the total Rainfall except in year 2016. In 2016, the rainy season has captured only 40% of the total Rainfall. The total Rainfall in the year was as low as 1125mm and it is due to the reduction in rainy season Rainfall (NE & SI). In 2016, the district faced most severe drought and water stress in the decade.

3.3 Monthly Rainfall variability

October, November and December months are the main rainy months for Anuradhapura area, and the Rainfall received during June and July months was comparatively low. During past years, the Rainfall in rainy months show greater variability with outliers (Fig 5). Monthly Rainfall of February 2011, October 2012 and December, 2014 and May 2016 were record high extreme events which led to unexpectedly severe floods in the district.

![Fig. 5. Monthly Rainfall variation (Refer fig 3 for box plot explanation)](image)

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean AP</th>
<th>Mean MI</th>
<th>CV AP</th>
<th>CV MI</th>
<th>Skewness AP</th>
<th>Skewness MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>101.8</td>
<td>103.5</td>
<td>89.7</td>
<td>89.8</td>
<td>1.24</td>
<td>1.16</td>
</tr>
<tr>
<td>Feb</td>
<td>90.0</td>
<td>73.7</td>
<td>120.6</td>
<td>106.6</td>
<td>2.23</td>
<td>1.98</td>
</tr>
<tr>
<td>Mar</td>
<td>95.2</td>
<td>106.3</td>
<td>107.4</td>
<td>106.9</td>
<td>1.10</td>
<td>1.64</td>
</tr>
<tr>
<td>Apr</td>
<td>206.7</td>
<td>178.3</td>
<td>49.6</td>
<td>59.1</td>
<td>0.50</td>
<td>-0.02</td>
</tr>
<tr>
<td>May</td>
<td>126.4</td>
<td>128.0</td>
<td>122.1</td>
<td>136.0</td>
<td>1.28</td>
<td>2.02</td>
</tr>
<tr>
<td>Jun</td>
<td>4.1</td>
<td>5.9</td>
<td>93.3</td>
<td>86.1</td>
<td>0.40</td>
<td>1.55</td>
</tr>
<tr>
<td>Jul</td>
<td>10.0</td>
<td>16.6</td>
<td>78.3</td>
<td>116.6</td>
<td>0.08</td>
<td>1.05</td>
</tr>
<tr>
<td>Aug</td>
<td>73.0</td>
<td>61.6</td>
<td>90.2</td>
<td>89.7</td>
<td>0.49</td>
<td>0.05</td>
</tr>
<tr>
<td>Sep</td>
<td>86.8</td>
<td>86.0</td>
<td>122.3</td>
<td>119.7</td>
<td>1.02</td>
<td>0.72</td>
</tr>
<tr>
<td>Oct</td>
<td>267.6</td>
<td>247.6</td>
<td>69.2</td>
<td>49.6</td>
<td>1.25</td>
<td>1.84</td>
</tr>
<tr>
<td>Nov</td>
<td>304.7</td>
<td>261.5</td>
<td>36.3</td>
<td>32.4</td>
<td>-0.20</td>
<td>0.66</td>
</tr>
<tr>
<td>Dec</td>
<td>292.1</td>
<td>238.1</td>
<td>70.5</td>
<td>67.9</td>
<td>0.79</td>
<td>1.23</td>
</tr>
</tbody>
</table>
The CV values of eleven months except November (table 3) were greater than 70 which is much higher than the value (i.e.30) suggested by Asfaw et al, 2018 for high variability. High skewness values were reported in January, February, March, May, September, October and December months. This could be mainly attributed to the dry spells in these months. The analysis shows that monthly Rainfall data do not fall around the average, but, distributed between extreme values suggesting high variability in terms of dry spells and extreme Rainfall events. An area with variability of Rainfall in two extremes can result drought related water stress under insufficient water storages.

3.4 Daily Rainfall variation

Daily Rainfall is highly variable in both stations and it varies from 0 – 192mm in Anuradhapura and 0 – 255mm in Mahailluppalama weather stations. Fig 6 shows an increase of frequency and intensity of extreme Rainfall with time. Most important fact to note in extreme rainfall is that in certain months the total monthly Rainfall has been delivered from one or two extreme daily Rainfall events. This variability makes the reservoirs and soils in the district highly vulnerable to water stress.

![Diagram](image)

**Fig. 6. Dot Plot of Daily Rainfall, (a): Anuradhapura (b): Mahailluppallama (the dot denotes the intensity of Rainfall event)**

3.5 Extreme Rainfall analysis

From the analysis of data it is apparent that Rainfall in the Anuradhapura area is strongly influenced by extreme events. Therefore, analysis of extreme Rainfall events was carried out. The 95th or 99th percentiles were used to delineate the extreme Rainfall events (Nowbuth, 2010). The results in Fig 7 show that during past years, 99th percentile and maximum Rainfall values are on the rise suggesting future risk of
intense extremes events. Further, Fig 8 indicates that more than 50% of Rainfall from the total annual Rainfall have been delivered from extreme Rainfall events. The increasing trend in extreme Rainfall events without considerable change in the total annual Rainfall is highly unfavorable for water security in the district. Under such circumstances, many impacts associated with droughts and related water stresses will be inevitable.

Fig. 7. 95th & 99th Rainfall percentiles and maximum Rainfall during past years

Fig. 8. Percentage Rainfall obtained from Rainfall events ≥95th percentile

4. Conclusion

The analysis of Rainfall for past years in the Anuradhapura district shows that even though there is no notable variability in the annual Rainfall, the seasonal, monthly and daily Rainfall variabilities are substantial. The critical fact that needs attention is the extreme Rainfall events. They have contributed to a larger fraction of annual Rainfall causing a greater variability in the Rainfall distribution (Frequent dry spells and extreme wet events). Increasing trend of extreme events with frequent long dry spells could be a recurring phenomenon in the district as a consequence of anthropogenic climate change. Although, drought severity and water stress would be relatively less felt due to additional water supplemented to major tanks by the Mahaweli augmentation, as this water is not equally distributed throughout the district over the hydrological year quite a large area in the district suffers from water stresses in domestic, agricultural and ecosystem sectors. Further, potential future risk of water stress could be high in the district as predicted by IPCC report (Bates, B.C et al 2008).

The outcome of this research provides a solid scientific basis for decision makers in the water and disaster management sectors to consider long-term investments on a wide range water harvesting options to capture Rainfall, secure storages and water conservation strategies to satisfy all sectoral water needs in order to ensure water sustainability in the district.
References


Comparison of Water Quality Parameters in Karst Terrain; A Water Quality Analysis from Rotupihilla Limestone Cave in Poramadulla Area

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Abstract

The unique characteristics of karst environments may dominate to the water sources within the area which are using for the human day-to-day activities. Such water resources exist in the karst terrain are dynamic in nature and are affected by factors of irrigation activities, industrialization, urbanization and geological processes occurring within them and reactions with aquifer minerals. It may also having direct influence of rainfall patterns, infiltration rate, and leaching of pollutants from the landfill. Poor quality of water adversely affects plant growth and human health.

Water quality of underground water table may affect the bedrock strata which exists below the water table and area around the water springs. Due to the presence of limestone bedrock in the studied Rotupihilla limestone cave area, soluble cations and anions can dissolve in the groundwater table which may affect the water quality within the area. The study revealed that due to the erosional and depositional activities in the underground cave environment, dissolution rate of the underground cave may be high and therefore the cave environment present in the study area showing diverse geochemistry due to the differences in water quality parameters of the spring water and the ground water within the area.

Keywords: Karst environment, Carbonate rocks, ground water, water quality parameters

1. Introduction

Limestone cave is natural cavity that is formed underneath the Earth’s surface and those cavities may range from a few meters to many kilometres in length and depth. It has been recorded that most of the world’s caves are formed in porous limestone (1). Over millions of years, the process of forming such cavities leading to formation of caves in limestone is continued with the acidic ground water and/or underground rivers by which limestone are dissolved away. Weak carbonic acid in rainwater reacts with carbonate minerals of limestone dissolving and eroding away the rock as the water filters into the soils and sedimentary profiles in such areas. Upward extension of such cavities results for sudden collapse and subsidence forming
karst features and karst environment. Not only that, horizontal expansion of such cavities by continuous dissolution, connects with each cavities and adjacent fractures and joints increasing underground hydraulic continuity. Water moving through such terrains collects inheritance chemical characters of the adjacent rocks. Hence water in limestone terrains represent chemical nature of carbonates to particular extent.

People in karst environments use this unique water resources mainly for their household use and agricultural activities, though there are some issues and some deviations from fresh water (Jayasingha et al., 2012; 2013b). The suitability of the available water sources for drinking purpose can be measured by checking the water quality parameters.

Water quality index is the most effective tool to express complex water quality data into a single number as an index (Shanker and Latha, 2008; Chaturvedi and Bassin 2010; Saeedi et al., 2010, Sharma and Chipa, 2013) and it depends upon normalizing the data parameter according to expected concentrations and interpretation of good versus bad concentrations.

Correlation coefficients of water quality parameters not only help to evaluate the overall water quality but also to quantify relative concentration of various impurities in water and provide necessary information for implementation of rapid water quality management programs (Jothivenkatachalam et al., 2010; Karbassi and Pazoki 2015).

Depending on the topographical conditions, rainfall pattern, agricultural pattern and many other reasons, geochemistry of water can be varying from time to time within the area. Mainly surface water can be polluted due to various factors. Most recently it can be due to agro chemicals (Jayasingha et al., 2013b) using in agricultural environments. It is no doubt that ground water in such areas are highly affected.

Rotupihilla village in Poramadulla area is a mountainous agricultural environment where paddy and vegetables are cultivated. The underlying geology of the area is characterized with impure marble which is a carbonate rock in metamorphic terrain of Sri Lanka.

The main objectives of the present study is to determine the water quality in the study area by measuring various parameters to assess the groundwater quality for drinking purpose and agricultural activities.

2. Location

The study area covers about 1.5 km² at Grama Niladari (GN) division of Poramadulla village within the Hanguranketha Divisional Secretarial Division (DSD) in Nuwara Eliya district. It lies within the northing coordinates of 7°06′41.15″ and easting coordinates of 80°45′59.11″ which is located at Rotupihilla village in Poramadulla area. A famous limestone cave called ‘Rotupihilla Hirigal Guhawa’ is located in this area.

The area can be reached by Nuwara Eliya – Walapane main road (B 492) from Nuwara Eliya town, and then turn right to the Rotupihilla village from the Poramadulla junction or coming through Liyanwala – Brookside road (B 413) from Nuwara Eliya town, and reach Rikillagaskada town, and then turn right to the Rotupihilla village from the Poramadulla junction.

The study area belongs to highland wet zone where average annual rainfall is about 2,300 mm and the rainfall is greatly influenced by monsoons and inter monsoons. Average annual temperature of the area is 22.5°C.
The land use pattern is characterized specially by farmlands and paddy fields and in addition shrub lands and small forest patches which are basically secondary in formation. Farm lands are mostly vegetable cultigations and Chena cultivations.

Morphology of the study area where the elevation is about 900 m MSL distinguishes gentle slopes mostly and steep slopes specially at valleys. It seems that morphology is highly controlled by lithology and geological structures.

According to the 1:100,000 scale geology map published by Geological Survey and Mines Bureau, general geology various from Calc-gneiss to impure quartzite with varying mineral composition. Minor scale fold is associated with the study area and contact of marble-quartzite also identified.

![Fig. 1. (a) Topo map of the study area; (b) Geology map of the study area](image)

3. Methodology

In this study nine groundwater samples were collected in nine locations (Fig. 2) including the water flowing from the underground limestone cave (Fig. 3a), open stream (Fig. 3b), and a natural water spring (Fig. 3c) of the study area during January, 2017 which may not having the precipitation to the area and hence in a dry period. Standard methods has been adopted in groundwater sampling which are prescribed by the American Public Health Association (APHA, 1995).

Thirteen water quality parameters have been considered to ascertained water quality index such as pH, Electrical Conductivity (EC), Oxidation Reduction Potential (ORP), Temperature, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Ca\textsuperscript{2+} hardness, Mg\textsuperscript{2+} Hardness, Total Hardness, Alkalinity, Nitrate, Nitrite and Sulphate were measured. pH, EC, ORP, Temperature, TDS and DO were measured in the field
where the water samples were collected and by using the Hana pH, EC, DO multi water quality checker (model – HI 98194) and the EUTECH DO meter portable instruments.

Finally the water samples were analysed by using laboratory techniques to identify the Ca$^{2+}$ hardness, Mg$^{2+}$ Hardness, Total Hardness, Alkalinity, Nitrate, Nitrite and Sulfate concentrations. The Central Environmental Authority (CEA) of Sri Lanka has been considered to assess the suitability of groundwater for drinking purposes and other human activities.

Fig. 2. Satellite image of the water sampling locations

Fig. 3. (a) inside the limestone cave; (b) water sampling stream; (c) water spring in the area
4. Results and discussion

Due to the underground erosion and dissolution, there were high ion content in the water samples within the study area. Other measured values are varying within the stream and the spring water. All the values were compared with the standards given by Central Environmental Authority of Sri Lanka. Water quality of samples collected from the stream, which is flowing through the limestone cavity is not much varying and the water sample collected from the spring is totally different from the other samples (Table 1).

Table 1. Water quality parameters measured in the study area

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
</tr>
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<tbody>
<tr>
<td>pH</td>
<td>7.42</td>
<td>7.07</td>
<td>7.2</td>
<td>7.5</td>
<td>7.36</td>
<td>8.04</td>
<td>7.59</td>
<td>8.12</td>
<td>7.11</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>278</td>
<td>271</td>
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<td>239</td>
<td>261.8</td>
<td>175.7</td>
<td>197.8</td>
<td>196.5</td>
<td>241.8</td>
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<tr>
<td>EC (µ/cm)</td>
<td>589</td>
<td>612</td>
<td>584</td>
<td>590</td>
<td>603</td>
<td>611</td>
<td>642</td>
<td>608</td>
<td>1128</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>24.5</td>
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<td>23.8</td>
<td>23.8</td>
<td>23.4</td>
<td>25.96</td>
<td>25.32</td>
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<td>TDS (ppm)</td>
<td>294</td>
<td>306</td>
<td>292</td>
<td>295</td>
<td>301</td>
<td>305</td>
<td>321</td>
<td>304</td>
<td>562</td>
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<td>DO (mg/l)</td>
<td>6.04</td>
<td>5.25</td>
<td>6.05</td>
<td>5.86</td>
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<td>6.12</td>
<td>5.02</td>
<td>5.64</td>
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<tr>
<td>Ca(^2) Hardness (mg/l)</td>
<td>134</td>
<td>136</td>
<td>140</td>
<td>128</td>
<td>142</td>
<td>142</td>
<td>128</td>
<td>130</td>
<td>222</td>
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<tr>
<td>Mg(^2) Hardness (mg/l)</td>
<td>4.37</td>
<td>7.29</td>
<td>9.23</td>
<td>9.23</td>
<td>4.46</td>
<td>3.40</td>
<td>10.20</td>
<td>9.23</td>
<td>19.92</td>
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<tr>
<td>Total Hardness (mg/l)</td>
<td>152</td>
<td>166</td>
<td>178</td>
<td>166</td>
<td>162</td>
<td>156</td>
<td>170</td>
<td>168</td>
<td>304</td>
</tr>
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<td>Alkalinity (mg/l)</td>
<td>144.5</td>
<td>143.5</td>
<td>142.5</td>
<td>142.5</td>
<td>148</td>
<td>146.5</td>
<td>155</td>
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<tr>
<td>Nitrate (mg/l)</td>
<td>0.611</td>
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<td>0.642</td>
<td>0.523</td>
<td>0.872</td>
<td>0.735</td>
<td>0.725</td>
<td>0.830</td>
<td>0.854</td>
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<tr>
<td>Nitrite (mg/l)</td>
<td>0.162</td>
<td>0.100</td>
<td>0.032</td>
<td>0.017</td>
<td>0.117</td>
<td>0.081</td>
<td>0.072</td>
<td>0.125</td>
<td>0.101</td>
</tr>
<tr>
<td>Sulphate (mg/l)</td>
<td>4.5</td>
<td>6.2</td>
<td>5.1</td>
<td>4.9</td>
<td>6.6</td>
<td>9.1</td>
<td>6.1</td>
<td>7.5</td>
<td>6.3</td>
</tr>
</tbody>
</table>

pH is the measure of hydrogen ion concentration value in water which indicates whether a solution is acidic, neutral or basic. The pH required has to be in the range of 6.5–8.5 for the drinking purpose according to the CEA standards. In present study pH concentration is ranges from 7.07 to 8.12 which shows that it is within the permissible limit as prescribed by CEA.
ORP (Oxidation Reduction Potential) sensors work by measuring the dissolved oxygen. More contaminants in the water result in less dissolved oxygen because the organics are consuming the oxygen and therefore, the lower the ORP level. The ORP levels in the spring water and stream coming from inside the limestone cave is not much vary in all the water samples.

The electrical conductivity of the water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. Higher electrical conductivity value is showing in the spring water sample thus the water spring is exposed to direct sunlight and the temperature of the water increase. However the stream coming from inside the cave is having low EC because the cave environment does not having direct contact with the sunlight though the water is having low temperature values.

Total Dissolved Solids (TDS) are inorganic compounds that are found in water such as salts, heavy metals and some traces of organic compounds that are dissolved in water. Excluding the organic matters that are sometimes naturally present in water and the environment, some of these compounds or substances can be essential in life. The total dissolved solids present in water are one of the leading causes of turbidity and sediments in drinking water. According to the CEA standards, TDS<300 mg/l is good for drinking purposes. In here the stream water is showing that it is good for drinking purpose but the spring water may having higher TDS which is not much condign for drinking purpose.

Dissolved oxygen (DO) refers to the level of free, non-compound oxygen present in water. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality. According to the CEA standards, DO level of drinking water should be 6 mg/l. In the stream water samples from the limestone cave may showing the water under the standards thus the water samples outside the cave may decreasing the DO levels and hence the spring water is having very low DO levels which is not suitable for drinking purposes.

When water passes through or over deposits such as limestone, the levels of Ca$^{2+}$, Mg$^{2+}$, and HCO$^-$ ions present in the water can greatly increase and cause the water to be classified as hard water. This term results from the fact that calcium and magnesium ions in water combine with soap molecules, making it hardness in the water. Here the spring (located above the limestone cave) water sample which may having direct contact with calcite country rock which having the ability of dissolve the Ca$^{2+}$ and Mg$^{2+}$ ions. But the stream which was coming inside the cave is not always contact with the country rock thus the stream is having rapid water flow.

The alkalinity of natural water is determined by the soil and bedrock through which it passes. The main sources for natural alkalinity are rocks which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates also may contribute to alkalinity. From the collected water samples, alkalinity of spring water is much higher than the stream water thus the spring is always contact with calcite country rock.

According to the CEA standards, Nitrate level of the water should be 5 mg/l. But all the samples does not fulfil this requirement and hence the water is not suitable for drinking purpose from the Nitrate levels.
Nitrites are a salt or ester anion of nitrous acid, which can be naturally or artificially occurring in groundwater. Nitrites come from fertilizers through run-off water, sewage, and mineral deposits. It can also stimulate the growth of bacteria when introduced in high levels into a body of water. All the collected water samples are having same Nitrite concentrations which may not varying with the collected location.

Sulfates are a combination of sulfur and oxygen and are a part of naturally occurring minerals in some soil and rock formations that contain groundwater. The mineral dissolves over time and is released into groundwater. The collected water samples having the range of 4.5 – 9.1 mg/l sulfate concentration. The recommended sulfate concentration of CEA for drinking water is below 250 mg/l and hence all the water samples are fulfil this requirement.

5. Conclusions

The water quality of the spring water is differ from that of stream water and values of each parameter in spring water is higher than that of stream water. The difference in concentrations may be caused by nature of karstic environment where carbonate rocks is underlain. Mixing of anions and cations collected by dissolution process can be the process by which the chemical nature of spring water is altered.

The stream water which is coming inside the limestone cave can be used for domestic activities with simple treatments and it is noted that the spring water is not much suitable for drinking purpose where the advanced treatment methods are required.

Acknowledgements

Assistance by the Landslide Research and Risk Management Division and Environmental Division of National Building Research Organisation for conducting fieldwork and laboratory work is thankfully acknowledged.

References


Potential Evapotranspiration and Water Deficit Conditions in Anuradhapura District

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Abstract

Contribution of Evapotranspiration (ET) water losses to drought severity is a growing concern because ET is expected to increase as a consequence of global warming. The paper analyses the effect of Rainfall and ET on water stress conditions in the Anuradhapura district over a period of 9 years. Temperature variability in two weather stations located in two land use types (rural and urban) were also analysed to study the influence of Temperature on ET.

Daily Rainfall, Evaporation and Temperature in Anuradhapura and Mahailuppallama weather stations in Anuradhapura district were analysed to depict annual and monthly Rainfall distribution from 2008-2017. Potential Evapotranspiration (PET), calculated using Thornthwaite method, was compared with monthly cumulative Rainfall to study the water deficit conditions in the area. Annual and monthly Temperature variation in two different land types (Urban and Rural) were also analysed to study the land use induced Temperature impact on the ET potential.

The results suggest that the area was water stressed, where PET has exceeded the Rainfall in several years. Comparatively high Temperature in Anuradhapura station than that of Mahailuppallama suggests Urban Heat Island Effect that makes urban areas prone to more moisture loss through ET.

The study emphasises on strategies to control moisture losses from ET while appreciating the unique hydro-ecological architecture in ancient tank ecosystems; its unique capability to store water; shadow from evaporative forces, and release water from multiple storages to compensate ET losses from critical water storages (soil, water bodies and plants) at times of water deficit.

Keywords: Drought; Rainfall; Temperature; Potential Evapotranspiration; Water stress
1. Introduction

Droughts occur as a result of water deficit in an area. Severity of drought hazard can change over time and may cause a wide range of cumulative impacts on both natural and human environment. Drought begins with variability of Rainfall falling below normal and may continue for an unknown period of time. Wilhite and Glantz, (1987) categorize drought into 4 main phases, meteorological, agricultural, hydrological and socio economic, depending on the nature of stresses it cause on human and natural environment.

The paper analyses effect of meteorological (Rainfall, Evapotranspiration and Temperature) & environmental factors (Landscape: urban and rural) on evapotranspiration (ET) loss of water in the Anuradhapura District during 2008-2017. The paper recommends strategic water conservation approaches while appreciating unique hydro-ecology in ancient tank systems with a special reference to its salient features to minimise moisture losses through evapotranspiration.

Depletion of moisture in soil (agricultural drought) and loss of water from surface water bodies (hydrologic drought) are considered as the most critical consequences of drought as both have significant impacts on food security and domestic water availability. Apart from Rainfall variability and deficit, ET losses from storages (water bodies, soil and plants) are a significant component responsible for drought severity and consequent water deficit in an area.

All drought management plans focus on conservation of water resources which accounts mainly inputs from Rainfall and other sources (Trans-basin inputs) and water losses from withdrawals such as ET and groundwater infiltration. However, strategies to reduce ET losses are poorly addressed in many plant despite substantial contribution of ET water losses.

Contribution of ET losses to drought severity is important to study, because Temperature rise as a consequence of global warming and human induced land use changes can increase the severity of drought by depleting available water resources through Temperature induced ET.

The Dry zone of Sri Lanka receives an annual Rainfall less than 1250mm. October to January are considered as rainy months, and from May to September the dry zone falls in the shadow of the Southwest monsoon, a period of low Rainfall with high winds. The ET is higher (average Evaporation in the dry zone is between 1,700 mm and 1,900 mm) in the dry months. During which high solar insolation, prevalent dry winds and high air Temperatures cause more water losses through ET (Panabokke et al, 2002).
1.1 Environmental and climatological features in the Anuradhapura district

Anuradhapura district (the largest dry zone district) is located in the North Central Province of Sri Lanka covering a land extent of 7212 Km² (11% of total land in the country). The district alone has 4,180 tanks, out of which only 2645 are functional (NDMP: 2019-2030). The main water inputs to the area are from Rainfall and from Mahaweli river trans-basin diversion. Mahaweli river water feeds main tanks and irrigation canals. Yet a large area of the district depends purely on Rainfall and limited groundwater sources.

Majority of land in the district is rural. Paddy cultivation, village home gardens, forests, scrublands, Chena cultivation, tank-based wetland ecosystems and urban areas are the main landuses in the district. The urban landuses are confined only to Anuradhapura town area, which is expanding due to religious and tourism-based economy.

1.2 Evapotranspiration (ET) and Potential Evapotranspiration (PET)

ET is the total moisture loss to the atmosphere from plants, soil and from open water bodies. Moisture loss from plants through stomata is called transpiration while that from other sources are called Evaporation. The PET is the environmental demand for moisture through Evaporation and it is equal to moisture loss when adequate water sources are available for Evaporation. ET is lower than PET when there is not enough water to evaporate or when plants are unable to transpire readily.
1.3 Factors affecting Evapotranspiration (ET) and Potential Evapotranspiration (PET)

ET depends on several factors such as soil type, cover vegetation, solar radiation, relative humidity, air temperature, wind velocity and etc. When favorable heat sources are present (solar radiation and high air Temperatures) the atmospheric water holding capacity is increased. This causes pumping more moisture from the available water storages soils, plants, open water bodies and to a certain extent groundwater through soil matrix under capillary action. Dry winds play a major role on evapotranspiration by taking away the moisture from the atmosphere. Further, dark surfaces and additional heat sources usually prevalent in urban built landscapes tend to have higher Temperatures supplying more energy for moisture losses through ET.

When PET is greater than the Rainfall for a long period, the system undergo water stress conditions resulting drying up of soil, open water bodies and plant wilting when additional water supply from Rainfall or irrigation is not available. Although ET is largely ignored in drought management plans, it accounts to a major fraction of water loss in a system (from plants, open waters and soils).

Effect of Temperature variability on ET is important to study because high Temperatures can result more moisture losses by Evaporation and Transpiration. Landuse has a strong influence on the Temperature variability and consequently ET. Urban landuses generally have higher Temperatures due to a phenomenon called “Urban Heat Island Effect (UHE)”. In UHE the air in urban built environments become hotter than its cooler rural surroundings, Akbari et al 2008. This is largely due to heat absorbing materials present in urban environment, lack of vegetation cover and the geometry of urban landscapes, Akbari et al 2008.

2. Materials and Methods

2.1 Data sources

Daily Rainfall, Daily Minimum and Maximum Temperature data of Anuradhapura and Mahailuppallama weather stations were obtained for the period, 2008 to 2017 from the Department of Meteorology. As ET data were available only at Mahailuppallaama weather station, PET was estimated only for Mahailuppallama area.

2.2 Data analysis technique

2.2.1 Rainfall and Evaporation trend analysis

Annual Rainfall distribution for a period of 9 years in two weather stations; Anuradhapura and Mahailuppallama, were analysed to study temporal trends. The mean Rainfall and Evaporation of the Mahailuppallama weather station were analysed to portray general water stress conditions in the area.

2.2.2 Water balance calculation

Water balance was depicted by plotting cumulative Rainfall (RF) against cumulative PET. The difference tells whether the area is under water stress or water surplus. If
the RF = PET the water resources are marginally sustainable, and if the PET < RF there is a water surplus and no water stress. However, when there is a deficit of water for a relatively long period, the district is at water stress, during which PET > RF. The interpretation of annual water balance did not consider the water inputs and losses in the previous years, the losses from groundwater infiltration, inputs from trans-basin diversions and those from other sources.

2.2.3 Calculation of Potential Evapotranspiration (PET)

Monthly PET was estimated using the Thornthwaite method, well-known and widely used methods for estimating PET based on Temperature. Calculation procedure is as Upcommons.upc.edu, 2018, where monthly Thornthwaite Heat Index (i) is calculated using the following formula:

\[ i = \left( \frac{t}{5} \right)^{1.514} \]

Where \( t \) is the mean monthly Temperature. Then the Annual Heat Index (I) is calculated, as the sum of the Monthly Heat Indices (i):

\[ I = \sum_{i=1}^{12} i \]

The Potential Evapotranspiration (PET) was obtained for each month using the following formula considering a month of 30 days and 12 theoretical sunshine hours per day:

\[ PET_{\text{non corrected}} = 16. \left( \frac{10. t}{I} \right)^{\alpha} \]

Where \( \alpha \) is,

\[ \alpha = 675.10^{-9}. I^3 - 771.10^{-7}. I^2 + 1792.10^{-5}. I + 0.49239 \]

\[ PET = PET_{\text{non corrected}} \frac{N}{12} \frac{d}{30} \]

Where N = Theoretical sunshine hours for each month & d = number of days for each month.

2.2.4 Temperature variability of different landuses

Temperature data of the two stations in urban and rural landuses were analysed to depict the influence of landuse type on annual and monthly variation of Temperature and consequent PET. The two stations represent different land use features; Anuradhapura station is an urban built area whereas Mahailuppallama station represents mostly rural agricultural climatic conditions (Fig 2).
3. Results and Discussion

3.1 Rainfall and Evaporation distribution

The annual Rainfall in two weather stations has been fluctuating between 1000mm-2500mm (Fig 3) during the period. Both stations show similar pattern of variation. Rainfall is slightly high in Anuradhapura in many years (Fig 4). The monthly Rainfall and Evaporation of Mahailluppallama weather stations show that in all months except October, November and December, the Evaporation is on the higher side suggesting dry weather with possible water stress conditions in the area.

![Mean annual Rainfall distribution (2008-2017)](image1)

![Mean monthly Rainfall and Evaporation (2008-2017) at Mahailluppallama](image2)

3.2 Water balance, availability and deficit conditions

The cumulative Rainfall, PET and water deficit for 9 hydrological years are depicted in Fig 5 and 6. The results show that except years 2012/13 and 2014/15, in all other years the PET is higher than the Rainfall emphasizing general water deficit conditions during the decade. This is somewhat evident by the Figures on government’s expenditure for drinking water. LKR 2.1m and 5.9m were spent on drinking water alone for financial years 2016 and 2017 respectively(NDM:2019-2030). When groundwater infiltration is also accounted in the water balance, the water deficit in the surface water storages (soil and water bodies) will be much high. However, the areas with major irrigation canals and reservoirs receive augmented water from river Mahaweli. These irrigation inputs partly harness the water demand in Mahaweli system areas in the district.
Fig 5: Cumulative Rainfall (RF) and PET distribution during 2008-2017: Mahailuppallama
3.3 Temperature variability and PET

The annual Temperature variability shows no notable Temporal trends in both stations (Fig7). But, the Temperatures in Anuradhapura weather station is somewhat higher than that of Mahailluppallama in all years (Fig 1 and 2). Anuradhapura area is an urban landscape where as Mahailluppallama is very much a rural setting. The results suggest influence of UHE in Anuradhapura station where Temperature is about 2 degrees Celsius higher than that of neighbouring rural landscapes. When the Temperature is high, the demand for ET is increased resulting more moisture losses from available storages (soil, plants and water bodies) in urban landscapes.
Monthly variation of Temperature shows that during April to September the Temperatures are comparatively high (Fig 8). Therefore, moisture loss by ET is high during these months. As these are dry months with low Rainfall the water deficit conditions are expected to be high during this period.

![Graph showing monthly variation of temperature](image)

**Fig 8: Monthly variation of Temperature (2008-2017): Anuradhapura and Mahailluppallama (refer Fig 7 for explanation for box plots)**

3.4 The strategic water conservation approach in the ancient tank based hydro-ecological system to reduce evapotranspiration losses

The study emphasises need for promising drought management strategies which maximize Rainfall interception and minimize losses, and recommends integrated water conservation strategies with a special reference to reduce ET losses which is considered to be a significant fraction in the water budget.

The paper appreciate hydro-ecological micro catchment management existed in the ancient tank ecosystems in the dry zone of Sri Lanka and values its unique capability to compensate ET losses. The tank ecosystems have several Hydro-ecological zones (HEZ) for water conservation. These HEZs are articulated in such a manner to maximize rain water interception from the wet season and to store. Some HEZs act as sponges to hold water and capable of reducing infiltration and ET water losses.

Fig 9 portrays different HEZs in a tank ecosystem and its multiple water storage functions: a) Free standing water in storages and the hydroscopic low permeable thick clay-silty layer beneath the free standing water, b) peripheral reed bed with thick spongy silt-root zone and c) grassy fallow areas in the head waters d) Wet paddy fields in the tank command area with low permeable clay liner. The Evaporation losses are greatly reduced when water is stored in these zones (except the free standing water body). The water is held in highly hydroscopic matrixes which shadow moisture from surface heat sources and dry winds (equivalent to mulching). During the dry period, retained water in these HEZs is released under varying hydraulic velocities to compensate losses from withdrawals and evapotranspiration. Moreover, the soil moisture in the tank command area, the paddy fields, and the fallow areas which are wet most of the year, contribute to balance atmospheric moisture deficit while
reducing the Evaporation demand on free standing water in storages (canals, streams and tanks).

4. Conclusion

Fig 9: Hydro-ecological zoning architecture in ancient tank ecosystems in the dry zone of Sri Lanka

The analysis of Rainfall, PET and Temperature show that the Anuradhapura district was under water deficit conditions most of the time during past 9 years. The study highlights influence of UHE; high Temperatures in Anuradhapura weather station (urban) which is about 2 degrees Celsius higher than that of neighbouring rural landscapes. Therefore, the PET in urban areas can expected be high. This draws attention of urban planners towards sustainable landscape designs to reduce ET. The paper emphasises on hydro-ecological micro catchment management existed in ancient tank eco systems in the dry zone of Sri Lanka with a special reference to its unique capability to reduce/compensate ET losses, and recommends strongly on rejuvenation of tank ecosystems in the district as a priority water conservation strategy to combat drought severity.

References


Analysis on Sustainable Community Resettlement Sites for Disaster Risk Communities in Hali_Ela DSD in Badulla District

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Abstract

Landslide hazard makes huge impact on settlement planning in hilly areas in Sri Lanka. The resettlement process is conceptualized as a disaster recovery and preventive strategy for disaster risk communities. There is a global attempt on sustainable community resettlement practice focusing on disaster risk communities in safer areas. The UNs, Seventeen revised sustainable development goals also make a platform for sustainable community resettlement practice by making cities and human settlement inclusive, safe, resilient and sustainable.

The NBRO has engaged to develop Hazard maps on landslides prone areas and identified exposures in Badulla district. Based on that there is a developed ‘Land Bank’ which indicates developable areas for resettlement practice in Badula. To face the global challenge of ‘Sustainable community resettlement practice this research study was carried out to identify the factors affecting community sustainability in resettlement practice and to identify whether the available lands, which are identified from the Land Bank, are suitable for development as sustainable community resettlement sites.

This study has focused on the factors of physical infrastructure, Social Infrastructure, policies and regulations and Livelihood restoration. The study was carried out by using suitability model in the analysis. The identified were the most Suitable lands, Suitable lands, moderately suitable lands, Lowly suitable lands, Poorly Suitable lands and Unsuitable lands from the identified 2550 acres of lands. The study evolves to identification of providing better place to live within their locality while improving better living condition of the people. The study will be supportive to develop sustainable resettlement planning for disaster risk communities while providing solutions to certain global undesirable development trends leading to land use conflicts, increased vulnerabilities and disaster risks.

Keywords: Sustainable community resettlement practice, Land bank, Suitability Model, Livelihood restoration
1. Introduction

Many countries are facing landslide as a disaster due to natural phenomenon as well as man-made activities. The impact of disasters make huge losses on natural environment as well as man-made environment while it causes huge impact on settlement planning in hilly areas in Sri Lanka.

In Sri Lanka, 10 districts are prone to landslide hazard; it covers 30% of the total land extent. Landslide hazard is increasing year by year and it leads to risky environment for communities to live in hilly areas. The resettlement process is conceptualized as a disaster recovery and preventive strategy for disaster risk communities. In the process of resettlement, there are many challenges and barriers faced by the relevant stakeholders. The relocated communities have to face challenges, particularly with regard to adopting to a given environment either willingly or unwillingly. The decision makers also have the challenge with regard to the selection of sites in ideal locations to make communities sustainable.

Though the resettlement site selection mainly focuses on finding hazard free area, there should be much attention paid to ensure these sites create sustainable community resettlement environment. The NBRO has been engaged to develop hazard map on landslide-prone areas and identify exposure on it. Based on that, the ‘Land Bank’ was developed which indicated developable areas for resettlement practice.

The UNs, seventeen revised sustainable development goals also make a platform for sustainable community resettlement practice by making cities and human settlements inclusive, safe, resilient and sustainable.

A sustainable community can be referred to as one that is economically, environmentally, and socially healthy and resilient (sustainable communities, 2018). The resettlement projects can be successful not only by providing safer environment to community, but also by ensuring a combination of social wellbeing as well as economic security.

In Sri Lanka, NBRO has largely been engaged in landslide risk community resettlement projects. There is a need on identification of resettlement sites in 10 districts of the country. As such, the land bank map has been developed to identify developable lands in Badulla district and the land verification has been completed therein. There should be a proper evaluation to identify whether such lands have the capacity to achieve the sustainable community resettlements. Therefore, this study has focused on the identification of factors for sustainable community resettlement and the analysis on whether the available lands which are identified from land bank suitable for develop as sustainable community resettlement sites to overcome the challenges of identified factors.

2. Factor Identification

Elements of community’s Infrastructure such as transportation, healthcare, water and sanitation, schools, the generation and transmission of power, food production and food security, safety and the places to worship should be considered as significant in resettlement practices. As stated by Cernia (1988), combination of these elements should be included in the new sites or at least similar conditions to previous locations must be provided with regard to social infrastructure. The socio economic factors focus on the impacts that tend to decrease the income of displaced people. Kinsey and Binswanger (1993) discuss that resettlement of people into a new area without
recognizing their original settlement characteristics may lead to the failure of the program.

According to the Asian Development Bank (1990), the location and quality of a new resettlement site are the most critical factors that should be considered during the resettlement planning process because it determines access to social, cultural and economic opportunities that can restore the livelihoods of the affected communities. The spatial location of the resettlement site rises the difficulties connected with the provision of basic fundamental infrastructure by the government in resettlement areas (Kinsey & Binswanger, 1993).

Types of critical infrastructure include: information and communications networks; government services; banking and finance; water supply; electrical power, oil and gas production and storage; transport networks; emergency services; and public health services (Lee Bosher, 2007). A deep knowledge of socio-economic characteristics and conditions of the households that need to be resettled is a fundamental pillar for appropriate resettlement planning (Alice N., 2016). Based on the above literature, the following factors are identified as analytical categories in this research.

Table 1: Factors of Community Resettlement Model

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>Location of Educational land use in relation with environmental suitability will lead to physical and mental health, time and resources wasting, tiredness and boredom of students.</td>
</tr>
<tr>
<td>Health</td>
<td>Hospitals and medical centres are important concern on avoid illnesses</td>
</tr>
<tr>
<td>Recreation</td>
<td>Vicinity of educational and cultural institutes such as library, cinema, theatre, museum, gallery, Cultural centres, permanent exhibitions and recreational centres and sports complexes</td>
</tr>
<tr>
<td>Livelyhood restoration</td>
<td>Location of ther resettlement sites close to Urban centers or prvious locations reduce the phisical and economic displacement and it affected to make livelihood restoration</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Proximity to roads, bus routes, access to othor facilities</td>
</tr>
<tr>
<td>Water/ electricity</td>
<td>Availability of Power transmission lines/Pipeline reduce the cost of providing infrastructure</td>
</tr>
<tr>
<td>Religious &amp; Culture</td>
<td>social and cultural compatibility</td>
</tr>
</tbody>
</table>

3. Methodology

There are 12 Divisional Secretariat Divisions identified as landslide hazard areas in Badulla district and Land Bank Field Verification has been carried out therein. Out of that, Hali_Ela Divisional secretariat Division has been selected as the case study site to carry out the analysis.
In order to facilitate multiple dimension of sustainable community resettlement site analysis, this study has adapted physical, Social and economic factors to achieve the research objective.

**Figure 2: Methodology**

The land bank map is a base of developable lands analysing the hydrology, Human Settlement, Environment sensitive areas, Slope and flow path of landslides and Accessibility. 2550 numbers of land plots were identified which are more than one acre in extent as developable sites through the land bank maps.

3.1 Suitability Model

The suitability model can be used to calculate optimal site locations by identifying possible influential factors. The following factors were identified that can influence sustainable community resettlement site development.
As primary data collection methods used field observations and surveys. Secondary data collection has been carried out from the related sources on the data types.

### Table 2: Secondary datasets for analysis

<table>
<thead>
<tr>
<th>Goal</th>
<th>Preferred criteria</th>
<th>Datasets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suitable land</td>
<td>Developable land</td>
<td>Land bank</td>
</tr>
<tr>
<td>Water</td>
<td>Access to water</td>
<td>Land bank</td>
</tr>
<tr>
<td>Electricity</td>
<td>Access to electricity</td>
<td>Land bank</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Proximity to roads, bus routes</td>
<td>Roads</td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>Availability of school facilities</td>
<td>Schools</td>
</tr>
<tr>
<td>Health</td>
<td>Availability of Hospitals</td>
<td>Hospitals</td>
</tr>
<tr>
<td>Livelihood Restoration</td>
<td>Minimum distance to Town centre / locality</td>
<td>Town centres/DSD boundary</td>
</tr>
<tr>
<td>Recreation</td>
<td>Access to town centres (Sinema/Public park)</td>
<td>Town centres</td>
</tr>
<tr>
<td>Social and cultural compatibility</td>
<td>Resettle within locality</td>
<td>Local boundary</td>
</tr>
</tbody>
</table>

## 4. Analysis and Results

The analysis was carried out using the Arc GIS 10.2. The following process has been followed in the analysis. As the first step, field verification and observation of identified lands from Land Bank map were carried out. Then it could filter the potential lands which are in consist with suitability criteria such access to water, electricity, host community and excluded the lands with unsuitability such as land consists with natural springs, boulders etc. Then applied the identified factors on sustainable community resettlement for the filtered potential lands. The suitability model was used to determine the minimum distance to schools, hospitals, urban centres and bus routes. Through the process of suitability model, weighted the locations and it could filter the suitable community resettlement sites under five categories. Most suitable sites, suitable sites, Moderately suitable sites, poorly suitable sites and unsuitable sites which can utilize in site section for community resettlement planning.

![Figure 3: Outcomes of each steps in methodology](image)

Out of the suitability analysis model, the following results were obtained. From the land bank map there were identified around 2550 acres lands.
Table 3: Results from land bank map

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Land Extent</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most suitable lands</td>
<td>1981.27</td>
<td>77.68</td>
</tr>
<tr>
<td>Suitable lands</td>
<td>270.38</td>
<td>10.58</td>
</tr>
<tr>
<td>Moderately suitable lands</td>
<td>141.44</td>
<td>5.54</td>
</tr>
<tr>
<td>Poorly suitable lands</td>
<td>149.82</td>
<td>5.87</td>
</tr>
<tr>
<td>Unsuitable lands</td>
<td>8.96</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure 4: Findings of suitability analysis

The result of the analysis allowed identifying the resettlement requirements in connection to land area, type of activities required to re-establish the income, the access to basic public services and rebuilding the social economic networks.

5. Conclusion

Based on the analysis the examined and through the Land Bank were identified as developable lands fulfilling the major factors of sustainable community resettlement process. From the study, the following recommendations could be made. It could determine the importance of social physical and economic factors in sustainable community resettlement planning. The identified land most suitable for sustainable community resettlement sites can be used for further resettlement activities in the
case study area. Identification of sites around with town areas may use to Satellite
township development in urban planning while reserving the natural areas. Selection
of sites for resettlement practice should consider not only physical suitability but also
social, cultural and environmental factors, since they lead to make communities
sustainable. Suitability model can be used as a tool for site selection in resettlement
planning. The results of the study provide valuable information for the urban planning
for policy and decision makers. In order to overcome the challenges of site selection in
resettlement planning, a methodology can be developed to identify sustainable
community resettlement sites for disaster risk communities.

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Analysis of a Slope Triggered by Rainfall Infiltration: A Case Study on Ihalakotte Earthslip

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Abstract

Slope failures triggered by rainfall are a frequent geotechnical hazard in Sri Lanka and have grown into an issue of national concern. The slopes formed of in-situ weathering of metamorphic parent rocks possess significant matric suctions and thus higher safety margins during dry seasons. Infiltration of rainwater destroys the matric suction, develop perch water tables and triggers failures. Some failures may end up as flows, but some may be subjected to only limited deformations and can be restored by appropriate remedial measures. Special care should be exercised when investigations are conducted to identify special features related to the highly variable initial sub soil conditions and the slip surfaces corresponding to the movement. This will be essential in the design of rectification measures. In this paper an attempt has been made to examine and compare field investigation results obtained from a site in the up-country railway track where an earth slip has occurred. A numerical simulation of the infiltration process was done using SEEP/W software incorporating the soil characteristics obtained from the field investigations. The study has shown that the slip was initiated by the formation of a perched water table condition closer to the boundary of sub soil layers with contrasting characteristics.

Keywords: Slope stability; pore water pressure; rainfall infiltration; matric suction

1. Introduction

Rain induced slope failures have become recurrent events in Sri Lanka over the last few decades. The growth of infrastructure at a rapid rate, failure to address all critical aspects in designs, poor constructions, not adhering to necessary construction details, neglect of regular monitoring and maintenance, adverse changes in climatic conditions are the main causative factors leading to catastrophic slope failures. Most of the times, the failure surface in these instances would not be very deep below water surface but would remain at shallow levels.

The high matric suctions that prevails during the dry period increases the slope's safety margin. Prolonged heavy rainfalls infiltrating into the slope will reduces or completely eliminate the matric suction straight from the surface level. The wetting front progresses further down with the time. Perched water table condition could
develop with rainfalls of greater intensity (Sujeevan & Kulathilaka, 2011). Presence of relict joints in the residual soil formation enhances the infiltration process further. The rainfall that would have contributed to run off could infiltrate into the soil when relict joints or surface roughness features are present. (Idirimanna, 2017).

Highly variable sub soil conditions prevailing in residual soil formations formed by weathering of metamorphic rocks will lead to very complex patterns of infiltration. Downward movement of infiltrated water will be restrained at the boundaries of highly weathered and less weathered formations due to their contrasting permeability and zones of high pore water pressure may be formed at such boundaries. As such, these boundaries would be potential failure surfaces. In many slope failures caused by prolonged extensive rainfall, flow of the soil layer down to the boundary of rock could be seen. A comprehensive study of infiltration in to slope of composed of highly variable soils is quite complex, but some meaningful findings can be obtained through a combination of numerical studies and detailed field investigation and monitoring.

This paper presents a comparative analysis of the results obtained from a field investigation programme conducted at the earth slip occurred in the up-country railway track of Sri Lanka in between Ihalakotte and Balana and the numerical studies conducted on the same.

2. Description of the Studied Site

2.1 Location and site conditions

The site location is at 59¾ milepost on the Main Railway Line in between Ihalakotte and Balana railway stations. The specific site area is slopping towards the South-Western Direction with an average slope of 30° to 42°. The upper part of the land is composed of exposed highly fractured rock (Figure 1(a)). The area lies in the central highlands of Sri Lanka. A subsidence had been observed in the railway track in between Ihalakotte and Balana on May 17th, 2016 after two days of heavy rainfall and rail services were disrupted.

![Fig. 1 (a) Exposed rock with fractures; (b) Soil slope below the railway track](image-url)
2.2 General observations

The sliding has been triggered by the built up of pore water pressures, caused by heavy infiltration of rainwater. There were no proper arrangements to drain out rainwater flowing down through fractured rock above the railway track. The flow of this water and the impact of water falling directly on to the slope below the railway track has led to its saturation and triggering of the failure. This movement has led to a subsidence in the railway track.

2.3 Establishment of the ground profile

To establish the sub soil profile and to understand the mode of failure and to design rectification measures, it was decided to conduct a Borehole (BH) investigation programme covering two critical cross sections of the slope. Consequently, four numbers of boreholes were drilled, two boreholes representing each cross section (Figure 2). These investigations were done in a relatively dry period after the main rainy season.

![Figure 2. Locations of the boreholes along the two selected cross sections](image)

3. Sub Soil Information and Interpretation

A comparative analysis was conducted using the data collected from general observations made during the preliminary stage and results obtained from the field tests. Subsurface data from BH 01 indicates lower SPT “N” values at the depth of 4.70 m to 6.00 m level. In addition, loss of drilling fluid (water) has been recorded in the same depth range as per the borehole log. Similar response has been shown at the BH 02 at the depth of 5.00 m – 6.00 m. Field SPT “N” values corresponding to the boreholes drilled along section 01 indicate relatively low values at the depth of 2.5 m and 7.00 m levels at the location BH 03 and 4.0 m level at BH 04. The field observations on patterns of crack propagation, water losses recorded at certain depths while boring and the subsurface data obtained from SPT tests conducted show a close resemblance confirming a development of a potential slip surface. Based on this collective
information acquired, the potential slip surfaces, through the Section 1 and Section 2 were predicted as shown in the Figure 3(a) and 3(b).

![Fig. 3. (a) Predicted failure surface along section 01; (b) Predicted failure surfaces along section02.](image)

4. Assessment of the Stability of the Slope

4.1 Transient Seepage Analysis of the Slope

From the field investigation data, it was obvious that the presence of natural phreatic surface had encountered almost at the level of rock – soil interface, as indicated in borehole logs. Whereas the predicted failure planes were encountered at shallower depths. Hence, to understand the changes of saturation zone/ formation of perched water table conditions, need to be addressed through a transient seepage analysis. Accordingly, a transient seepage analysis was conducted using the SEEP/W 2012 software. The cross section shown in Figure 4 assumed to be reasonably representing the ground profile with the properties shown in the Table 1. The soil hydraulic parameters normally appropriate for residual soils were taken from the available literature and as well as from the laboratory tests results conducted on similar soils in Sri Lanka (Sujeewan & Kulathilaka, 2011).

![Fig. 4. Assumed subsurface profile with different soil formation](image)

Table 1. Hydraulic properties used in the transient analysis
A boundary flux, q, which was equal to the rainfall intensity was applied along the surface of the slope. No flow boundary conditions were assumed at the sides of the slope. The applied boundary conditions are as shown in the Table 2 below:

**Table 2. Applied boundary conditions**

<table>
<thead>
<tr>
<th>Slope Geometry</th>
<th>Boundary Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB, FG, CD</td>
<td>No flow boundary (Q= 0 m$^3$/s)</td>
</tr>
<tr>
<td>DE, EF</td>
<td>Rainfall intensity</td>
</tr>
<tr>
<td>AG, BC</td>
<td>Total heads at sides (Pressure head=0)</td>
</tr>
</tbody>
</table>

The idealized rainfall intensity 50 mm/day was applied for a duration of two days. The values were chosen based on the antecedent rainfall conditions that the slope experienced before the moment occurred. This rainfall was simulated in the SEEP/W module for durations of a period of two days as a step data point function. The depletion of the matric suction, development of positive pore water pressures – a perched water table condition near surface and the rise of the ground water table was studied for the period of two days long rainfall and for four days of no rain thereafter. The initial phreatic surface assumed to be present at a depth of around 9.0 m from the existing ground level, which is almost the soil – bed rock interface.

This assumption was made observing the variation of water table in the boreholes after period of dry weather. An upper limit for matric suction profile was not defined owing to unavailability of actually measured data pertaining to suction profiles. The pore water pressure distributions were obtained along section 1-1, section 2-2 and section 3-3 and are presented in Figure 5.
Fig. 5. Pore water pressure variations along the considered cross sections

From the results obtained it was evident that the wetting front progresses the slope with depleting the initial matric suction. During the prolong rainfall (2-day, 2.9 day wetting front reaches positive pore water pressures as indicated in the Figure 5 above. This is more distinct along the sections 2-2 and 3-3. However, once the rainfall stops the pore water pressure profile again tends to gain its initial state. Formation of near surface saturation zones were visible as indicated by isolines corresponding to each time step, shown in the Figure 6. These perched water table conditions move along the slope as the time progresses rather than infiltrating further deep into the slope. This is a manifestation of forming near surface flow paths within the saturation zone. However, the response of the slope to infiltration depends on the initial matric suction profile and the path which the soil is following (either wetting or drying) at the time of the infiltration. Therefore, it is prudent that the initial conditions need to be predicted with a higher accuracy in order to make the model more reliable. Moreover, it was evident the beyond the point of saturation of the upper soil layers, the excessive water will runoff as indicated by surface ponding effect in the analysis.
Fig. 6. Variation of the phreatic surface and formation of perched conditions over 6 days

4.2 Stability analysis of the slope

Slope stability analysis was performed using limit equilibrium analysis method. The results of the transient seepage analysis conducted with SEEP/W software were exported to SLOPE/W in order to carry out the limit equilibrium analysis. The properties shown in the Table 3 below were assigned to represent respective soil layers.

Table 3. Properties of the subsurface assumed for stability assessment

<table>
<thead>
<tr>
<th>Layer description</th>
<th>Notation</th>
<th>Effective stress parameters</th>
<th>$\phi_b$ (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\phi'$ (deg)</td>
<td>C'(kPa)</td>
</tr>
<tr>
<td>Loose silty sand</td>
<td></td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>Medium dense to very dense silty sand</td>
<td></td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Bed Rock</td>
<td></td>
<td>45</td>
<td>100</td>
</tr>
</tbody>
</table>

An average value of $\phi_b$ was assumed for angle “Phi b” in order to account for the additional shear strength of the soil skeleton within the unsaturated zone (Gan et al. 1988). Effective stress parameters again taken from similar studies conducted in past. The results obtained from the SLOPE/W analysis are presented in the Figure 7 below.
The Figure 7 above shows a decrease in factor of safety as the wetting front progresses into the slope. After the period of two days, factor of safety value decreases to a value less than one, which indicates the instability of the slope. This could be the point of initiation of the slope moment. This is confirmed by the close coincidence of the predicted failure surfaces obtained from the analysis offield investigation data and the numerical methods, along the section 01.

5. Concluding Remarks

It is vital to understand the infiltration process into residual soil slopes resulting from rainfalls and the response of the slope for the same when studying the stability criteria and as well as in designing slope protection measures. This paper examines a case study of a recent earth slip occurred in the high lands of Sri Lanka, with available field investigation data and numerical simulation methods. The following conclusions can be drawn from the study:
• Filed investigation data along with the data absorbed from field instrumentation could effectively be used to predict the slip surface of a shallow earth slip.
• The wetting front of the slope tends to progress along the slope creating near surface saturation zones, rather than infiltrating deeper into the slope as indicated by infiltration analysis.
• The angle phi 'b' shows zero values at the critical failure surface, which is a clear indication of the existence of additional shear strength due to matric suction and governance of shallow slope failures by the formation of near surface saturation zones.

Acknowledgement

The authors are grateful to National Building Research Organization (NBRO) for permitting the use of data pertaining the project “Geotechnical investigation for the slope movements in the railway track at Ihalakotte” conducted by NBRO in 2016.

References

Effect of Land Use Pattern on Land Instability and Slope Failures in Tea Cultivated Terrain in the Central Highlands of Sri Lanka: A Case Study from Nuwara Eliya District

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Abstract

Natural hazards associated with intense rainfall during monsoon and inter-monsoon seasons are causative factors of the most pressing natural disasters in Sri Lanka such as landslides, flood, and land subsidence. Such types of disasters are becoming a frequent occurrence in central highlands of Sri Lanka in the recent past. Presence of intense rainfall throughout the year causes the increase of natural disasters. Out of them, landslides are the most common hazardous phenomenon. Therefore, expansion of human settlement is more popular in flat areas than in sloping areas in the central highland region. Land use pattern of the land area plays major role in case of landslide susceptibility. Central highlands of Sri Lanka is famous for the tea cultivation as well as vegetable cultivation. The area covered with tea plants are observed as safe slopes and however the vegetable cultivation within the tea lands are with having poor surface drainage system may cause land instabilities and slope failures. The study revealed that impact of land instability and slope failures are due to improper vegetable cultivation pattern within the hilly areas in tea cultivated hilly terrain in Nuwara Eliya district.

Keywords: land instability, tea estates, human settlement, vegetable cultivation

1. Introduction

Sri Lanka is generously covered with water resources, having a large number of rivers most of which originate from the central highlands. The main source of water is direct rainfall, as high annual precipitation is experienced in the Central Highlands. According to historical records, the Central Highlands were covered with natural vegetation before large scale deforestation took place for the agricultural activities. In the 19th century, tea cultivation was introduced by the British and at present it is still continuing. Besides the tea cultivation, vegetable gardens play major role in the agricultural industry in the central highlands of the country. It was recorded that severe erosion takes place in the hill country due to under market gardens (vegetables and potatoes), tobacco and poorly managed chena cultivation. With population growth in the hill country, settlements and farming have rapidly expanded even to the steep
slopes, which may cause severe erosional activities due to the high precipitation. As a result, water reservoirs within the region are under high risk of sedimentation and the agriculturally utilized lands have been loosing their productivity. Tea estates which may be having proper surface drainage system with step drains and line drains showing minimum soil erosional features within the region.

Vegetable cultivation in Nuwara Eliya is practiced on hilly areas due to the limited land area and cultivation is done with high valued crops. Farmers expect high return on investment as such cultivation is done two or three times per year without giving any resting period for lands. Since land is exposed to continuous precipitation for many months per year, it is vulnerable to severe erosion. The fast growth in the agricultural sector in Sri Lanka has led to resource degradation, with adverse impact on sustainability. The major source of environmental damage associated with agriculture is land degradation, particularly soil erosion on the steeply sloping lands of central highlands. Soil erosion is concentrated in hill country where watersheds of major rivers are located. According to the agricultural records obtained from the Department of Agriculture, Nuwara Eliya district shows the highest amount of soil erosion, as about 58% of the potato-cultivated land found to be prone to severe soil erosion (Abeygunasekara, 2004).

Due to the comparative income advantage of potato cultivation, farmers tend to use steeply sloping lands, which are not recommended for seasonal crops, which may increase the soil erosion. Both the climate and terrain are prone to soil erosion, and serious damage to land and water resources are experienced in the cultivation of vegetables mainly potato. Damage is mostly due to inappropriate soil conservation measures. Owing to the high cost in soil conservation farmers do not adopt proper soil conservation measures which lead to land degradation in areas cultivated with vegetables. Some farmers adopt soil conservation measures, which are inadequate to arrest soil erosion problem satisfactorily. The impact of these improper cultivation practices has caused soil erosion and other environmental problems.

It has been found that the soil erosion rate in Nuwara Eliya agricultural lands can be as high as 15 t/ha/year (Samarakoon, 2004). As a root crop, vegetable cultivation causes acceleration of soil erosion due to the ground being loosened in several cultivation practices such as land preparation, weeding, fertilizer application, earthing up and even harvesting. But the tea plants which exist within the hilly areas were planted more than 50 years ago and almost the tea plants are fully covered the earth surface which may not subjected to direct precipitation.

2. Location

The study area is located within the Nuwara Eliya district in the Central Province of Sri Lanka. Four study locations were selected from the tea estates within the hilly terrain named Ragala estate, Alnwick estate, Mahacooodagala estate and Concordia estate. GPS coordinates of the study locations are as follows.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>North</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Ragala estate</td>
<td>7.00733300</td>
<td>80.8699363</td>
</tr>
<tr>
<td>02</td>
<td>Alnwick estate</td>
<td>6.99621400</td>
<td>80.8976060</td>
</tr>
<tr>
<td>03</td>
<td>Mahacooodagala estate</td>
<td>7.02883873</td>
<td>80.8420640</td>
</tr>
<tr>
<td>04</td>
<td>Concordia estate</td>
<td>6.99684400</td>
<td>80.8287250</td>
</tr>
</tbody>
</table>
3. Methodology

Initial field survey was done due to the land instabilities recorded and the information received to the Nuwara Eliya district office of National Building Research Organisation. Field data were collected in the study area such as land use pattern, building type, crack details within the walls and floors of the building, topographical conditions (location of valleys, ridges, and steep slope areas), rock type, geological and hydrological data. All these data were collected from Ragala estate, Alnwick estate, Mahacoodagala estate and Concordia estate which are the prominent tea cultivated areas in the hilly terrain.

4. Results and Observations

Selected locations of Ragala estate, Alnwick estate, Mahacoodagala estate and Concordia estate are having the similar land use pattern and topographical conditions. Most of the natural valleys located near the estate line rooms were obstructed by vegetable cultivation due to the human activities. Severe erosion takes place from the direct precipitation due to this improper cultivation methods in the valley banks and nearest tea fields. According to the data gathered from the Department of Meteorology, central highlands of Sri Lanka obtaining rainfall from North-East monsoon, South-West monsoon and Inter-monsoon rains throughout the year. Therefore these hilly
trains are faced to huge amount of precipitation than other part parts of the country. And hence the activities like soil erosion, land instability and slope failures are triggered from the rainfall events occurring throughout the year.

5. Discussion and conclusions

Soil erosion occurs where both natural and human activities cause the soil to become less vigorous or less healthy. The ultimate erosion of the soil is the removal or loss of its physical components. Whilst many forms of soil erosion exists such as acidification, salinity, organic depletion, soil structure decline or nutrient depletion, which may specifically deals with slope failures (in its many forms) and landslides. Erosion and landslides cause a reduction in the mass and volume of a soil and ultimately lead to modification and/or reduction in the physical extent of the soil ecosystem.

All the studied four tea estate locations were found to be affected by land instability. Most of the valleys within the line rooms are obstructed by vegetable cultivation through which the rainwater could not freely flow down in to the lower slope area. People tend to cultivate vegetables within the valley area which were water logging and much more fertile due to the deposition of fertilizers which were washed away from the tea plants.

Most of the walls and floors of line rooms were cracked which were located near the valleys and steep slope areas. Poor drainage pattern is one of the major problem within these estate line rooms and the vegetable cultivated areas may be subject to continuous soil erosion due to the surface runoff from the rain water. And the absence of well managed erosion control system in the vegetable cultivated areas with line drains, surface drains, and step drains within the valleys and the toe walls into the unstable cut slopes are the major issues for the reported land instabilities within the tea cultivated hilly terrain.

Fig. 2. (a) Slope failure occurred in Ragala estate; (b) Vegetable cultivation within natural valley in Alnwick estate
But the tea fields within the observed tea estate area are well maintained from the soil erosion by using step drains, line drains, stone walls for the earth cuts and all the drains are reinforced with stone layer. Therefore, this type of land instabilities and slope failures are not observed within the lands which are having tea plants in hilly terrain.

Acknowledgement

Assistance by the Nuwara Eliya district office of Landslide Research and Risk Management Division of National Building Research Organisation for conducting fieldwork and data collection is thankfully acknowledged.

References

[13] But the tea fields within the observed tea estate area are well maintained from the soil erosion by using step drains, line drains, stone walls for the earth cuts and all the drains are reinforced with stone layer. Therefore, this type of land instabilities and slope failures are not observed within the lands which are having tea plants in hilly terrain.
Trial MSW Fill at Meethotamulla Abandoned Dump Site
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Abstract

The waste mound located at Pothuwilkumbura, Meethotamulla, Kolonnawa collapsed on 14th April 2017, claiming a total of 32 lives of people, destroying houses and infrastructure situated at the toe region towards the south-western side of the waste mound. Records revealed that the area before 1990 had been a low-lying marshy area consisting of a thick peat layer. With the urban growth and rapid development, the location has been received waste in increasing amounts in the subsequent years. This area is a prime land situated very close to the city of Colombo, and therefore, conversion of the abandoned waste mound and surrounding into a mix development region with landscaped landfill has become a contemporary need. National Building Research Organization (NBRO) has been requested to propose a complete design for Meethotamulla Closure and Reclamation Project. It is understood that geotechnical parameters required for a design is not available in Sri Lanka since there are no similar type of researches undertaken previously. A trial fill of 50 × 30 m² is compacted up to 5 m height using municipal solid waste (MSW) on a platform built at the site with distinct monitoring such as settlement, leachate and gas to study the performance of the trial over a period of few months. The objective of the trial was to facilitate the findings appropriately for the design requirement overall reclamation plan. This paper describes the studies conducted in the laboratory and field to investigate the properties of MSW.

Keywords: Meethotamulla waste fill failure; Municipal Solid Waste; Properties of waste materials; Closure & Reclamation;

1. Introduction

An unprecedented disaster was taken place followed by the collapse of infamous uncontrolled and unregulated waste fill at Meethotamulla. This is one of the tragic accidents which could have prevented since the pres-signs leading for a failure were exposed. The closure and reclamation of Meethotamulla waste fill appears to be the most effective waste management option after analyzing several possibilities which can produce a viable solution to the current state of the site. The increase in urban
population and the scarcity of land have urged the degree of importance with mix development in Meethotamulla, which is a prime land very close to the city of Colombo.

Closure and Reclamation and Mix Development of Meethotamulla waste fill is a recently started project under Urban Development Authority (UDA). The project will be implemented in different phases, converting the ex-waste fill into a landscaped park will be executed as the first phase of the project. The significance of redeveloping ex-waste fills into a landscape/public park can be further justified by the inadequacy of urban green space in Colombo city. National Building Research Organisation (NBRO) was requested to propose a complete design for the proposed development works. Major concerns in the process of developing a landscaped landfill include slope stability, leachate management, landfill gas management and instrumentation and monitoring.

Since there are no previous experiences in similar type of works in Sri Lanka, it was decided to make a trial embankment using MSW at site. The main objective of the study is to determine the physical and engineering characteristics of MSW which are necessities for designing of transformation of ex-waste fill into a landscaped park. This paper describes the approach adopted in carrying out the trial embankment.

2. Subsurface Investigation

The proposed location for the trial embankment is at the waste slide as shown in Fig. 1. A borehole investigation was conducted to identify the subsurface condition after the failure. According to the results (Fig. 2) of the borehole investigation, the study area consists of waste up to about 18 m from top of the surface where the trial fill was planned. Clay is found underneath by the waste cover and it is extended up to about 8 m depth.

![Fig. 1: Proposed location for trial embankment](image-url)
Rainfall and drainage patterns may change the ground water regime. Also the leachate and recirculation of fluid in the landfill can affect the pore pressure if landfill is not properly controlled. As a result, the weight of materials in the slope is increased and thereby causes an increase in the pore water pressure which leads to a decrease in effective stress which eventually leads to a shear strength reduction (Omari & Boddula, 2012). For this reason, a decrease in pore water pressure makes the landfill more stable while soil water pore pressure developed along interfaces reduces the stability of the landfill. Therefore, studying pore water pressure and understanding the water level inside the landfill are vital factors in this task. A piezometer together with a standpipe water level meter was installed in the borehole to obtain the variation of pore water pressure and fluctuations of ground water level.

3. Trial Compaction

Unit weight of MSW, waste compaction characteristics and prediction of settlement behaviour can be identified as one set of major input parameters required for a safe design. It should be noted that the composition of MSW varies from region to region and country to country. These variations produce fundamental and significant differences in engineering behavior of waste. As with soils, the unit weight is affected by compaction effort and layer thickness, the depth of burial (i.e. overburden stress) and moisture content (Dixon, Russell, & Jones, 2005). Unlike soils, the unit weight also varies significantly because of large variations in the waste constituents (e.g. size and density), state of decomposition and degree of control during placement (such as thickness of daily cover or its absence). Since MSW is a particulate material and a large proportion of the components have a high void ratio and a high compressibility, compaction processes will reduce the voids within an individual component as well as voids between various components. The unit weight of compacted waste will depend upon the waste components, thickness of layer, weight and type of compaction plant and the number of times equipment passes over the waste.
In order to identify the variation between in-situ density of waste and compacted density, waste compaction and settlement behavior, it was decided to carry out a trial compaction selecting an area of 50 × 30 m². In this pilot study a 10 ton vibratory sheepsfoot roller is used. After conducting several sample tests in different layer thickness and different roller passes, the MSW layer of 0.5 m is spread out and that layer is compacted with 10 number of roller passes. 

Fig. 3(a) shows the plan view and
Fig. 3(b) shows the cross sectional view of the trial area to highlight the instruments installed for monitoring work.
(a)
(b)

Fig. 3: (a) Plan view of trial area (b) Cross section of trial area

4. Density and Material Composition

In-situ soil/waste density was measured by using a water replacement method in compacted area as well as in random locations within the waste fill in different heights. Some selected results given in Table 1 clearly shows that there is a significant difference between the compacted fill and random fill where there was very minor compaction or no compaction applied while dumping.

Table 1: Moisture content and wet density of waste

<table>
<thead>
<tr>
<th></th>
<th>No compaction</th>
<th>After compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Location 4</td>
<td>Location 3</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>95.32</td>
<td>100.28</td>
</tr>
</tbody>
</table>
The composition of the waste material in Meethotamulla waste fill site was also measured. As indicated in the following Table 2 it should be noted that it has a high proportion of plastic and polythene materials whereas soil content is very low. In addition, a comparison with material distribution pattern between Sri Lankan and Japanese (Miyamato, et al., 2012) scenario was made. Accordingly, it is revealed that properties of MSW of other countries obtain from similar type of research work cannot be directly used in the designing work in local context.

<table>
<thead>
<tr>
<th>Table 2: Waste composition in Meethotamulla and Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Weight</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>kg</td>
</tr>
<tr>
<td>Location 4</td>
</tr>
<tr>
<td>Location 3</td>
</tr>
<tr>
<td>Location 2</td>
</tr>
<tr>
<td>Location 1</td>
</tr>
<tr>
<td>Japan</td>
</tr>
</tbody>
</table>

5. Hydrogeological Connectivity

Piezometric heads and ground water level fluctuations were recorded before and after a waste layer of 1 m was completed. The results are provided in the Table 3. According to the readings of piezometer, it may in connection with a deep rock aquifer which is under high phreatic pressure or confinement of possible hydrogeological connectivity with water bearing formation. This will be further monitored properly in order to determine its possible influence on long term stability of proposed landscaped fill.

<table>
<thead>
<tr>
<th>Table 3: Fluctuation of ground water level and piezometric head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standpipe (water level below platform)</td>
</tr>
<tr>
<td>platform</td>
</tr>
<tr>
<td>layer 01</td>
</tr>
<tr>
<td>layer 02</td>
</tr>
</tbody>
</table>

6. Waste Settlement

Waste Settlement is a major geotechnical aspect of the restoration and development of closed landfill sites. The mechanism of MSW settlement is complex, and the settlement can be attributed mainly to short-term deformation followed by long-term biodegradation of MSW (Wong, Leung, Wong, & Tang, 2013) and possible consolidation if soft soil present. Both total and differential settlements of the waste mass are of engineering concern. In the absence of a predictive model for waste settlement, it is essential to make field observations of waste settlement before construction. Therefore, in this study settlement plates and displacement stakes were installed in the trial area. It was observed that after compacting up to 2 m height, MSW fill experienced a settlement about 10% of the fill height. This settlement may be due
to waste compression from overburden effects. However, there was no movement recorded in the displacement stakes indicating no lateral movement.

7. Conclusion and Way Forward

Conceptual plan of the trial fill is designed as a trial with number of monitoring observations. Settlement of MSW due to compaction and overburden is measured with settlement plates while lateral movements are measured from displacement stakes. Further, pore water pressure and ground water table fluctuations are measured from piezometer and stand pipe respectively. Ongoing observations are providing encouraging results.

When the trial fill is completed and the settlement observations provide minimum variations, the final design will be implemented. In addition, to facilitate the design and optimize the landfill geometry the shear strength parameters of MSW will be incorporated. Inclusion of leachate and gas collection system in existing MSW is a great challenge. However, these are to be properly installed in the overall design and a cover soil will be placed to allow for vegetation to grow. NBRO will finalize these details after finalizing the analysis obtained from the ongoing monitoring system.

8. Acknowledgement

The authors acknowledge officers of National Building Research Organisation and the staff of University of Moratuwa who involve in this study and officials of the Urban Development Authority, Sri Lanka for their support on this study.

References

Analysis of Road Cutting Failures and Designing of Countermeasures - A Case Study along the Bulathsinhala - Horana Road, Kalutara District, Sri Lanka
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1Scientist, National Building Research Organisation, Sri Lanka

Abstract

Road cutting failures are identified as one of the widespread man-made disasters causing damage to lives, properties, and disruption of traffic in Kalutara district. The case study was focused on a 10.5 km long road segment between Punchimiriskanda and Kobowakakanda along the Bulathsinhala – Horana (285) route where several major and minor roads cutting failures have been reported. The present study aims to introduce proactive countermeasures for road cutting failures through a detailed investigation and stability evaluation with an understanding of the regional geological setting. Topographical maps, Google maps and Landslide Hazard Zonation maps published by the National Building Research Organization (NBRO), were studied together with drainage patterns, climate pattern and land-use patterns in the study area. Field analysis coupled with laboratory tests revealed that low permeable 1m thick clayey soil layer in subsurface lead to the creation of perched water table within the soil mass causing minor road cutting failures in extreme weather conditions. They can eventually develop into slope failures in Punchimiriskanda area. However, infiltration of excess waters by a high content of gravel and sand in Kobowakakanda caused limitation on this scenario. However, the surcharge load of the massive boulders in Kobowakakanda area affects the stability of the slope. Loss of metric suction during the intense rain causes road cutting failures of both sites. It was revealed that escarpment and intermediate slopes containing breaking steps result in failures with the greater width. This case study further identifies mitigation measures and conceivable approaches for the development of stability of road cut failures.

Keywords: Road cutting failure; mitigation; boulders; slope stability;

1. Introduction

Road cutting failures have been identified as one of the widespread hazards caused mainly by man-made activities; causing damages to lives, properties, and disruption of traffic in Kalutara district. Such cutting failures mainly originate during the widening of existing road networks without applying proper mitigation measures.
These failures have mainly been reported during the south-west monsoon period that lasts from May to September.

This case study was carried out on Bulathsinhala – Horana road (285 routs), along a 10.5 km long road segment. The slope failures were reported close to two hillock areas, Punchimiriskanda and Kobawakakanda. This road segment is aligned in parallel to the escarpment slope of the hillocks and runs across the toe of the hillocks. Therefore, cutting failures with 3.6 m – 34.6 m in height with large unstable boulders resting on the slope is a common feature which can be observed when travelling along the road.

According to Weerasingha (2015), road cutting failures are more common on dip slopes rather than on escarpment slopes and they are rare in intermediate slopes. Slope angle ranging from 21° - 30° have a higher susceptibility to failure than the slopes with a range greater than 40 in dip slopes and less than 11° in escarpment slopes Weerasinghe, (2015). Geological setting, slope height, slope angle, seepage, overburden thickness and geometry of cut slopes are the factors affecting the stability of cut slopes (Hearth et al., 2014). Safety margins of residual soil slopes are high during the periods of dry weather due to prevailing metric suctions (Kulathilaka et al., 2015). When the road cuts are subjected to continuous wetting and drying over a period of time, shear strength parameters may change and metric suction will be extinct resulting cutting failures (Kulathilaka and Sujeewan, 2011).

1.1. Problem statement and Objectives of the study

Selected areas for the case study were severely affected by the monsoon rain in June 2014. Consequently, several small cutting failures along the route at Punchimiriskanda area, and one major adjacent with a few minor cutting failures at Kobawakakanda area had been developed. At the time of field of this research, another catastrophic event such as Landslide took place on 25th May 2017. Due to this event, all the minor scale cutting failures were developed into slope failures in Punchimiriskanda area. Old cutting failures in Kobawakakanda area were found to be unaffected with compared to the situation at Punchimiriskanda.

The problem has been progressively developing during each torrential rain periods. In some events, the road has been completely blocked by debris. However, the removal of unstable debris was not allowed by the NBRO for weeks until the bad weather condition ceased. Due to slope geometry, with incoming monsoons, some of the cutting failures can further be developed into major landslides. Therefore, having a clear understanding of the engineering soil properties of these soil slopes will aid in performing immediate, cost effective and sustainable rectification measures to protect public property and lives.

2. Study Area

The study area is located in Kalutara District in Western Province of Sri Lanka. Geographically, the study area belongs to lower country peneplane (Cooray, 1984). Problematic hillocks along Bulathsinhala – Horana, 285 road located in Bulathsinhala Secretariat division. According to the geology map published by Geological Survey and Mines Bureau, Punchimiriskanda area contains Garnetiferous Quartzofeldspathic Gneiss whereas Kobawakakanda area lies within Charnokitic Gneiss (Figure 1).
Fig. 1. Geology map of the study area (source: 1:100,000 scale maps, sheet No: 16, Geological Survey and Mines Bureau)

3. Methodology

3.1. Preliminary Study

Desk study, field reconnaissance, and geotechnical investigation were carried out to obtain necessary information and data for this study. Rainfall data were collected from Meteorological Department of Sri Lanka on the months of June 2014 and May 2017 (Figure 2 and Figure 3).

Fig. 2. Rainfall data from 01.06.2014 to 30.06.30

Fig. 3. Rainfall data from 01.05.2017 to 30.05.2017
3.2. Collection of soil sample

Seven undisturbed soil samples (UD Samples) were collected from the remaining visible vertical soil profile of the cutting failure at both Punchimiriskanda and Kobawakanda site into 6-inch diameter PVC pipes and seven disturbed soil samples were also collected from the same location. All samples were collected on dry sunny days. The depth of the collected soil samples was noted down in meters from ground level.

![Existing Soil Profile of a). Punchimiriskanda, b). Kobawakanda](image)

3.3. Surveying

Two separate contour maps were generated using a total station with Nikon Nivo 3.M+ brand. Heights were based on an arbitrary datum. Contour intervals were drawn with 1 m intervals and across section were generated more than 50 m in lengths using Civil 3- D 2016 version.

Additionally, Mackintosh probe survey was conducted to characterise subsurface geology of the both areas.

3.4. Laboratory Testing

3.4.1. Tri-axial Test

3.4.1.1. Consolidated Undrained (CU) tri-axial test

The test was conducted for 4 samples where large – scale cutting failures were Kobawakakanda area in order to find effective soil parameters. The test was done according to BS 1377 method, under consolidation phase and shear phase.

3.4.1.2. Unconsolidated Undrained (UU) tri-axial test

Initial dimensions of the sample and thickness of the rubber membrane were measured. Then soil specimen collected from both areas were placed in a tri-axial chamber. The shell pressure was increased to a desired value of 50 kPa for the first case and 100kPa in the second case. Shear the specimen at the rate of 1% min or 1.25 mm/min for 70 mm sample height. Then, the test was continued according to BS 1377 standards. The test was carried out in order to determine undrained cohesion of clay layer present in Punchimiriskanda area.
3.4.2. Other Laboratory Tests

Falling head permeability test was done for clay samples extracted from 1 m – 2 m thick clay layers found in Punchimiriskanda area. Falling head permeability test method was carried out for 3 cylindrical soil samples which prepared 98.7 mm in diameter and 129.5 mm in length. Sand pipe dimensions use for the test were 5 mm in diameter and 19.64 mm² in area. Direct Shear test was done for four samples which were selected in the field. The proctor compaction test was done for two disturbed soil samples found in both areas to find maximum unit weight of the different soil types found in two locations. And, also sieve analysis test was done for two soil samples to obtain particle size distribution of both soil types.

The circular mode and non-circular mode of failure were observed using Bishop’s simplified method and Spencer’s method (Kulathilaka and Sujeewan, 2011). Geo-Studio 2004: SLOPE/W software was used for stability analysis based on Spencer’s method.

4. Results and Discussion

According to 1:50,000 scale landslide hazard zonation map prepared by mapping unit of the NBRO, Kobawakakanda area belongs to High-hazard zone. Therefore, the cutting failures can be developed into huge slope failures if the area is not mitigated. But, Punchimiriskanda area belongs to medium hazard zone and eventually, it can be converted into high hazard zone due to improper land-use practices (figure 5). Not only the slope failures but also unexpected rock falling incidents would be occurred especially in Kobowakakanda area. Even though the area is not highly populated, this road is the one and only access to the Horana town from Bulathsinhala.

Measured average slope angle at Kobowakakanda area is greater compared to Punchimiriskanda area and land form is deviated from uniform to convex in both sites. Geologically, the rock type underlying the overburden is Quartzofeldspathic Gneiss with the mineralogical composition of Quartz (25%), Potassium Feldspar (20%), Garnet (5%), Biotite (5%), Muscovite and trace amounts of Graphite in Punchimiriskanda area. In Kobawakakanda area, the rock type underlying the overburden is Charnokitic Gneiss with the mineralogical composition of Quartz (30%), Feldspar (20%), and Biotite (20%) Garnet (5%). Biotite content of the rock was higher compared to other minerals. A highly weathered form of parent rock was found only in the toe of the slope.
According to the orientation of the bed rock, all the cutting failures in Punchimiriskanda area are located on the bottom part of the escarpment slope (table 1). In Kobawakakanda area, all the cutting failures are located on the bottom part of the intermediate slope. Dip slopes have a higher tendency to failure than scarp slopes whereas those in intermediate slopes are moderately safe (Weerasinghe, 2014).

### Table 1. The orientations of foliations and joints of rocks at two sites

<table>
<thead>
<tr>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Punchimiriskanda</td>
</tr>
<tr>
<td>Structural plane</td>
<td>Strike direction</td>
</tr>
<tr>
<td>Foliation</td>
<td>N 78 W</td>
</tr>
<tr>
<td>Joint set 1</td>
<td>N 20 E</td>
</tr>
<tr>
<td>Joint set 2</td>
<td>N 80 E</td>
</tr>
</tbody>
</table>

There are a lot of huge unstable boulders and thin colluvial soil layer near the unstable vertical road cuts in Kobowakakanda area. Weight of the unstable boulders especially near to the head of the cutting failures, act as a surcharge load which affect the stability of the cut. In heavy rainy days, the shear strength of the soil decreases gradually due to loss of metric suction and also additional load exerted by heavy boulders causes expedition of the failure in Kobowakakanda.

In addition to that, Mackintosh results and laboratory tests such as permeability and UU tests confirms that the presence of weak soil layer in vertical soil profiles in Punchimiriskanda area. Therefore, observed vertical soil profile in figure 4 and its
layering near the road cutting failures is proven through the Mackintosh results. Presence of weak soil layer at the middle part of the soil profile is confirmed at the Punchimiriskanda area. It is observed gravel and cobble rich soil at Kobawakakanda area and Mackintosh test results also confirmed this observation.

These cutting failures were initiated on 01.06.2014 due to heavy rainfall more than 180 mm per 24 hours. Four minor road cutting failures were reported in Punchimiriskanda area. One major and five minor cutting failures were recorded Kobowakakanda area. There were a lot of unstable boulders near the cut slopes in Kobowakakanda area. Cutting failures were activated again on 26.05.2017 due to heavy rainfall more than 375 mm per 24 hours. Then previous cutting failures in Punchimiriskanda developed into slope failures while no substantial failures in Kobowakakanda area. Falling head permeability test and UU tri-axial test revealed that the presence of semi-permeable clay layer in Punchimiriskanda area while there are no such weak soil layers in Kobowakakanda area. Yellowish brown clay coatings are common within B-horizon of the Red-Yellow Podzolic soils types found in Kalutara District, according to Moorman and Panabokke (1961), which creates perch water table within the soil mass. Overburden in Kobowakakanda mainly composed of sand, gravel, and cobble mixed soil layers which facilitate draining activity through the soil profile. And also, small cutting failure developments occur due to the presence of solitary unstable boulders scattered very near to the crown region of the vertical road cuts in between 49/3 to 49/5 culverts in Kobowakakanda area. And also rain water stagnation due to pits created by the uprooting process of rubber trees, facilitates the creation of slip surface on highly weathered slippery bedrock surface in Kobowakakanda.

4.1. Stability Analysis

Fully specified slip surface option was used as it contains the knowledge of the failure history and accurate survey details. “Fully Specified” option was used to obtain the minimum Factor of Safety (FOS) for the possible slip surfaces going along the weak clay layer. Soil parameters, which were obtained from laboratory tests were used for the analysis.

4.1.1. Punchimiriskanda Area

Presence of the clay layer significantly alters its shear strength parameters in rainy seasons. This is proven by changing the shear strength parameters ($C=45$, $\phi=0$) in the dry season to drain parameters in the rainy season. Here the cohesion ($C$) is changed from 45 kPa to 3-4 kPa while the internal friction angle ($\phi$) changes from 0 degrees to 15 degrees. Whatever the mechanism of failure, possible proactive countermeasures need to be placed to stabilize the existing slopes before next monsoon rain.

**Table 2: Material properties of the critical section and the design CS-C section**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Notation</th>
<th>$\tau$ (kN/m$^2$)</th>
<th>$\phi$ (degree)</th>
<th>$c'$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual soil</td>
<td></td>
<td>17</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>Clay layer</td>
<td></td>
<td>18</td>
<td>15</td>
<td>4</td>
</tr>
</tbody>
</table>
When mitigating the slope, engineered crown drains should be constructed as the first step. Surface water flowing through the crown drain should be converted into cascade drain and it can be directed to the main drainage system which runs parallel to the main road. Considering the flexibility and water table continuation gabion wall should be constructed with 3 m effective height with suitable geotextile filter (Figure 6) and inserting long and short horizontal drains by 100-150 descending angle to the horizontal decrease the subsurface water table by 3 m. Reshaping the ground slope into steps increases the stability up to FOS of 1.653.

![Graph](image)

Fig. 6. Stability and design stability under extreme weather conditions on 26.05.2017
4.1.2. Kobawakakanda Area

Large-scale failure was taken place during heavy rainfall on 01.06.2014. Debris, especially with heavy boulders, moved to the downslope and the road was entirely blocked. A few amounts of debris were removed to facilitate the transportation, but other debris were kept on the toe of the failed cut slope. Stability analysis proves that the slope was stabilized under extreme rainfall conditions.

However, another extreme rainfall event took place on 26.05.2017 the slope was not stabilized as expected. Therefore, the effect of the boulders was considered in the analysis. It is proved that boulders mixed with the debris act as a toe support and water can be drained out easily due colluvium nature of the debris.

It is shown in the table that FOS value is significantly drawn down when removing the boulders resting on the debris during the raining. Removing all the boulders still resting on the slope may not affect to the stability significantly except removing toe the support. But heavy boulders very near to the crown of the cut effect to the stability in heavy rainy period.

\[
\begin{align*}
\text{Fig. 7. Stability and design stability under extreme weather conditions on 26.05.2017} \\
\text{The minor cutting failures can be mitigated through the soil nailing which is better for controlling surface erosion through the shot creating. The stability analysis confirms the effect of metric suction in both locations. Due to the presence of fine grain soil layer in Punchimiriskanda, negative porewater pressure is higher than coarser}
\end{align*}
\]
grain soil types found in Kobowakakanda area. Therefore, vertical soil cuts show unexpected stability at Punchimiriskanda in dry periods. However, in rainy days negative porewater pressure decreases drastically within short period of time. Then total cohesion also decreases around 45 kPa to 4 kPa. Loss of metric suction reduces the shear strength and also weight of the pore water increases the shear stress within the soil mass which will be end up with a failure if there is no adequate toe support.

5. Conclusion

Presence of clay layer in Punchimiriskanda hillock area may activate the failure which has a permeability of $8.69 \times 10^{-3}$ m/s. Even though clay layer has undrained shear strength parameters in the dry period those values change into drain shear parameters in rainy periods. Therefore, effective cohesion changes from 45 kPa to 34 kPa and effective internal friction angle changes from zero to 15 degrees during extreme rainy conditions resulting failures. In extreme weather conditions, low permeable subsurface strata such as clay layers lead to the creation of perched water table within soil mass which will cause the minor road cutting failures that can eventually develop into slope failures. The high content of gravel and sand infiltrates the excess water easily in Kobowakakanda area while Punchimiriskanda area creates local perched water tables due to the presence of clay layers. Therefore, on 26.05.2017 minor cutting failures were developed into small slope failures in Punchimiriskanda area and cutting failures were not developed into slope failures as expected in Kobawakakanda area. Heavy boulders near the cutting failures, affect the slope stability during heavy rainy seasons in Kobowakakanda due to its surcharge load. In the dry season, the factor of safety values of the cut slopes of Puchimiriskanda was greater than factor safety values in Kobowakakanda which confirmed that the presence of fine grain soil increases the effect of matric suction.

Acknowledgement

The authors thanks Dr. H.A.G Jayathissa for his valuable assistance and specially acknowledge Mr. Reshan Champika, Mr. E.A.S.N. Wimalawardhana, Mr. Aruna. Mr. H.M.D. Madushan and Mr. Udayanga Jayasundara for their grateful support to conduct Mackintosh test and other laboratory tests.

References

Cost-Benefit Analysis for the Mitigation Measures of Landslide Vulnerability Reduction

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⁴Director, Landslide Research & Risk Management Division, National Building Research Organisation, Sri Lanka

Abstract

Occurrence of landslides, slope failures and rock falls and their reactivation have become a frequent natural phenomenon in Sri Lanka attracting more and more attention due to its impact on human and economic loss. Many of the natural hill slopes that are considered as safe in the past are now recording landslides due to human interventions. According to the available records, nearly 1000 human lives were lost and over 300,000 people were made homeless in the period of past 25 years. Many infrastructure facilities including highways, dams, railway tracks, hospitals, schools and other public & private buildings were damaged. In May 2017, 35 major landslides occurred causing the major number of deaths from the disaster events, 176 out of 219. In this background, National Building Research Organisation has signed an agreement with the Asian Infrastructure Investment Bank to obtain funding assistance for mitigating/rectifying unstable slopes in high risk areas in 11 districts of 06 provinces of Sri Lanka. The project will execute mitigation measures to protect the key infrastructures, such as the railway network, highways, roads, water supply and electricity network and communication system. Intention of these mitigation measures is to ensure the safety of communities from frequent catastrophes caused by landslides. NBRO conducted a detail cost-benefit analysis to identify the need of this landslide mitigation project to Sri Lanka. It resulted in a net benefit of 22% to the country by implementing this project.

Keywords: Cost-benefit analysis, Landslide mitigation
1. Introduction

It is the responsibility of the project implementing agency to assess costs and benefits associated with each stage of the landslide mitigation project financed by the Asian Infrastructure Investment Bank (AIIB). The purpose of cost-benefit analysis (CBA) in the project is to have a systemic approach to figure out the pluses and minuses of various paths through a project, including transactions, tasks, and investments. Government of Sri Lanka (GoSL) planned for an estimated total investment of USD 104 million in three years (January 1, 2019 - December 31, 2022) and has dispensed a budget for USD 97 Mn for Civil works and associated designs and construction supervision/management for landslide mitigation with the financial support by the Asian Infrastructure Investment Bank (AIIB). Project objective is to improve the landslide risk management effort of the country by introducing required mitigation measures and thereby, redress the present situation of high risk imposed on vulnerable communities and infrastructure. The project will benefit more than 12,000 population vulnerable to landslides in identified project locations.

The project would be implemented into 2 phases:

**Phase I will include 27 landslide sites in critical conditions,** which will be designed and prepared for bidding by NBRO in-house staff, with some externally recruited specialists, for which procurement process must start immediately. The Mission was informed that out of these 27 sites, the detailed designs for 4 sites have been already completed and the Detailed Project Reports (DPR) have been ready to be incorporated into related Bidding Documents. As soon as the environmental and social aspects (site-specific Environmental and Social Management Plans) have been prepared and incorporated, it is expected that the Bids for these 4 sites will be called within 2 months from to date.

Phase II will include:

I. Preparation of detailed designs and bidding documents and assistance to procurement of contractors for the remaining 120 landslides, and

II. Supervision on construction.

This consulting assignment will be carried out by a qualified consulting firm/s, based on Quality and Cost procurement selection procedures, for which NBRO has started to prepare a draft TOR.

2. Aims and of Objectives of the Project

The main objective of the project is to improve the landslide risk management effort of the country by introducing required mitigation measures and thereby, redressing the present situation of high risks imposed on vulnerable communities and infrastructure.

This project is targeting at:

I. Mitigating selected landslides and unstable slopes

II. Enhancing capacity of NBRO to effectively deal with landslide mitigation efforts,

III. Introducing and regularize the best land use practices and construction/development guidelines for landslide prone areas, and

IV. Enhancing public awareness on landslide mitigation.
3. **CBA for the Project**

CBA is a systematic approach to estimate the strengths and weaknesses of alternatives (for example in transactions, activities, functional business requirements or projects investments); it is used to determine options that provide the best approach to achieve benefits while preserving savings. The CBA is also defined as a systematic process for calculating and comparing benefits and costs of a decision, policy (with particular regard to government policy) or (in general) project.

Broadly, CBA has two main purposes:
- To determine if an investment/decision is sound (justification/feasibility) - verifying whether its benefits outweigh the costs, and by how much;
- To provide a basis for comparing projects - which involves comparing the total expected cost of each option against its total expected benefits.

CBA is related to (but distinct from) cost-effectiveness analysis. In CBA, benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their net present value. (Wikipedia, 2018)

![Figure 1: Schematic representation of damage categories](image)

Cost-benefit and related project appraisal approaches are applied in seeking to secure the highest return to investment. CBA is an appropriate method for the assessment of the economic efficiency of the Disaster Risk Reduction measures. CBA is methodologically complex and should be seen as a decision facilitator rather than the sole criterion for decision making. Costs and benefits associated with a project are estimated by comparing the situations that would hold with and without the project and then expressed in monetary terms. It provides a decision-making tool for comparing scenarios with or without landslide mitigation in place. (David Hugenbusch, 2016)
4. Methodology

Integrating risk-based methods into cost-benefit approaches makes it possible to consider the impacts of landslide mitigation by quantifying their likely economic consequences. CBA consists of following steps;

<table>
<thead>
<tr>
<th>Steps</th>
<th>Activity</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Initial data collection in 147 landslide mitigation project sites</td>
<td>Initial data collection includes; District, Divisional Secretariat Division, location, potential damages, potential damages, approximate area liberated by landslide mitigation, type of landslide, status of landslides and proposed landslide mitigation measures</td>
</tr>
<tr>
<td>02</td>
<td>Drone survey and detail data collection in 50 sites</td>
<td>Drone survey provides a quick, safe and potentially superior means of inspecting large scale, remote and difficult to reach landforms with significant cost benefits compared to traditional inspection methods. Simple applications of UAV involve real time or post viewing of footage and still photographs of the study area. Primary data was collected at the site using an online application.</td>
</tr>
<tr>
<td>03</td>
<td>Detailed benefit calculation of 50 sites</td>
<td>Benefit analysis calculated in 50 sites includes; costing for human lives, cost of using alternation roads, costing for building replacement, costing for road debris clearance, costing for road repairing, possible costing saved by the project on infrastructure such as electricity, water supply provisions.</td>
</tr>
<tr>
<td>04</td>
<td>Benefit value calculation for 97 sites</td>
<td>Benefit value calculation for 97 sites includes other sites (28-117), sites proposed by Road Development Authority and sites proposed by Sri Lanka Railways. Benefit value calculation for these sites were calculated from the experience acquired from 27 critical sites and additional 23 additional sites (50 sites). Assumptions on benefits were made including; houses protected,</td>
</tr>
</tbody>
</table>
CBA is presented by dividing the landslide mitigation project costs through the landslide mitigation project benefits. In this step, project benefit value was calculated for 147 sites includes; 27 critical sites, additional 23 sites, other sites (76), sites proposed by Road Development Authority (7) site and sites proposed by Sri Lanka Railways (14).

**Figure 2: Methodology adopted for CBA of 147 landslide mitigation sites**
5. Data Collection Method

Drone survey and data collection were done for the 50 sites to detail the landslide mitigation sites. Drone survey was proceeded to develop Orthomosaic images, Keyhole Markup Language (kml) and Digital Surface Model (DSM) of the location. With these outputs, it will help develop mosaic image, 3D model, contours and cross sections to demarcate the clear representation of the site.

Data were collected by using online application “AppSheet”. “AppSheet” is an app maker that makes it easier for everyone to develop custom Android and iOS apps even without any coding experience. It allows developing apps directly from the data and makes it possible for beginners to create and deploy apps in less time. (FinancesOnline, 2018)

This online database helps to:
- Monitor the progress online and on time
- Ability to data collection on site
- Data storing and store in supportive platform

6. Assumptions & Limitations of CBA

CBA was carried out for the project; to reduce the landslide vulnerability by mitigation measures, based on following assumptions and limitations,

<table>
<thead>
<tr>
<th>Table 2: Assumptions &amp; limitations of CBA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>El no.</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td><strong>Human lives</strong></td>
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<td>2</td>
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<tr>
<td><strong>Buildings</strong></td>
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<tr>
<td>3</td>
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<tr>
<td><strong>Roads</strong></td>
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<td>5</td>
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<td>6</td>
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<td>10</td>
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<td>11</td>
</tr>
</tbody>
</table>

**Road debris clearance**
innovation for build back better

7. Benefit Analysis

Detailed benefits are calculated for the initial 50 sites where drone surveys were conducted and detailed data collection, based on above mentioned assumptions & limitations. Total benefit for detailed 50 sites is USD 74.24 Mn. Detailed 50 sites benefit distribution (%) among each main element as follows;

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saved forest area</td>
<td>35%</td>
</tr>
<tr>
<td>Saved exposed commercial activities</td>
<td>10%</td>
</tr>
<tr>
<td>Saved exposed commercial activities</td>
<td>5%</td>
</tr>
<tr>
<td>Rail passenger income loss saving</td>
<td>15%</td>
</tr>
<tr>
<td>Saved railway network</td>
<td>10%</td>
</tr>
<tr>
<td>Saved drainage network</td>
<td>5%</td>
</tr>
<tr>
<td>Saved water supply network</td>
<td>5%</td>
</tr>
<tr>
<td>Saved electricity network</td>
<td>5%</td>
</tr>
<tr>
<td>Saved road repair cost</td>
<td>5%</td>
</tr>
<tr>
<td>Saved cost for use of alternation road</td>
<td>5%</td>
</tr>
<tr>
<td>Saved cost for road debris clearance</td>
<td>5%</td>
</tr>
<tr>
<td>Saved landslide impact area</td>
<td>5%</td>
</tr>
<tr>
<td>Saved buildings</td>
<td>10%</td>
</tr>
<tr>
<td>Saved human lives</td>
<td>5%</td>
</tr>
</tbody>
</table>

Figure 4: Benefit distribution (%) based on detailed 50 sites
Benefit value calculation for the remaining 97 sites were calculated from the experience acquired from detailed 50 sites. Benefits had been predicted based on the experienced on 50 sites and considered the behavior of the elements for the prediction and analysis. Total benefit for 97 sites is USD 52.58 Mn. For 97 sites, benefit distribution (%) among each main element is as follows;

![Benefit distribution (%) based on 97 sites](image)

**Figure 5: Benefit distribution (%) based on 97 sites**

8. **CBA Results**

A favorable CBA result for a landslide mitigation measures can be a strong argument for investment. There are some notable flaws with CBA, in particular that results of the analysis will depend on how one defines and values different benefits and costs and on the level of discount rates used.

The cost-benefit-ratio is determined by dividing the landslide mitigation project costs through the landslide mitigation project benefits. The result is presented as ratio. The result is also stated as benefit-cost-ratio for which the benefits are divided through the costs. In this way of representing the results, a project is categorized as efficient when the result is above unity (one).

Net Benefit Analysis: \[
\text{Net Benefit} = \frac{\text{Estimated Benefit - Cost for Landslide Mitigation}}{\text{Cost for Landslide Mitigation}} \times 100\%
\]

Then,

- If, result > 0%  Project is financially feasible
- If result = 0%  Project is financially neutral
- If result < 0%  Project is financially unfeasible
Calculation in USD

USD conversion rate: LKR 162.00 (Central Bank of Sri Lanka - October 2018)
Estimated Benefit (USD): 126,830,441.59 (126.83 Mn)
Cost of the Project (USD): 104,000,000.00 (104 Mn)

Net benefit analysis = \[
\frac{\text{USD 126.83 Mn} - \text{USD 104 Mn}}{\text{USD 104 Mn}} \times 100\%
\]

= 22%

9. Conclusion

The above CBA was carried out by NBRO to assess the need of the project to reduce the landslide vulnerability by mitigation measures. In the period of CBA, following recommendations were drawn to develop the CBA technique for the given project.

9.1. Maintenance cost of the mitigation sites:

After the completion of construction landslide mitigation measures, it is required to calculate maintenance cost of each landslide mitigation site. This maintenance can be identified as turf cleaning of the site, surface drain cleaning, subsurface drain cleaning and rock fragment removal/cleaning. The cost for above mentioned maintenance activities had been calculated for a period of 15 years. These sites can be mainly categorized as cutting failure (13), rockfall (18), debris flow (02), landslide (43) and slope failure (71).

In the landslide mitigation sites, the following mitigation activities will be carried out in the next 15 years;

Table 3: Maintenance activities in the landslide mitigation sites

<table>
<thead>
<tr>
<th>Maintenance Activity</th>
<th>No. of sites</th>
<th>Cutting failure</th>
<th>Rockfall</th>
<th>Debris flow</th>
<th>Landslide</th>
<th>Slope failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turf cleaning</td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Surface drain cleaning</td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Subsurface drain cleaning</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Rock fragment removal/cleaning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total maintenance cost for 147 landslides mitigation sites per year is USD 0.16 Mn. It is proposed that, a mitigation site should be maintained for a period of 15 years and its cost will be USD 2.35 Mn. Average cost per year per site is USD 1,064.44.
Figure 6: Total maintenance cost for 15 years (%)

This maintenance cost should be considered when conducting the CBA. This maintenance cost was not assessed at the beginning of the CBA. As well as, it is required to predict the other factors for the period of 15 years. It may emerge as conflicts and difficulties of the benefit analysis. Therefore, maintenance cost was not considered for the analysis.

9.2. Integrating development activities with mitigation sites.

Detailed CBA was carried out for the 50 sites with drone surveys. Benefits had been analyzed based on the initial measurable criteria which will be generally applied with the human activities. It is realized that, spatial planning development integrated with the mitigation site will be added as additional benefit to the site.

Example:

Site No. 139
Location: Ohiya station, Welimada, Badulla
Potentials: Railway station, Road connected to Horton plains, Milk farms, Higher altitude
Development identification: Tourism integrated transport hub development

References

Livelihoods in Post-Disaster Resettlement Planning: The Case of Wasanthagama, Kegalle District, Sri Lanka

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Abstract

Post-disaster resettlement programmes are generally aimed at providing adequate housing for the affected population. Relocation to safer areas is sometimes considered necessary, as disasters reveal the hazards present in certain areas. However, moving people away from their previous homes can have an effect on their sources of income and their sense of community. This paper will briefly study the livelihoods component within the government’s resettlement programme following the landslides of May 2017 in Sri Lanka. It will specifically look at the case of the resettlement site at Wasanthagama, in Kegalle District. The paper will argue that livelihoods and non-tangible assets - such as training and social bonds - are important elements that need to be considered in post-disaster programmes. Further, it will suggest that strategies for long-term means of support ought to be planned jointly with the communities themselves, allowing the affected population to be key actors in the implementation and success of the programme.

Keywords: Livelihoods; Resettlement; Post-disaster Programmes

1. Introduction

Post-disaster reconstruction is a complex and challenging process for all those involved. When relocation is deemed necessary, a number of important criteria must be considered; for example, safety from hazards, available land, current infrastructure, etc. However, the chances for a successful programme become difficult when access to livelihoods and income generation are not fully included in these criteria (Boano, 2012).

In May 2016, and then one year later, in May 2017, the central and southwestern areas of Sri Lanka faced extremely heavy rainfalls, which resulted in severe floods and landslides. Hundreds of people lost their lives and many more saw their homes and livelihoods destroyed. As a response, the government of Sri Lanka, with the support from NBRO and other organisations, has been implementing a reconstruction programme that aims at providing not only housing for the affected population but also relocation for the people living in ‘high risk’ areas.

Different entities are involved in the process. International and national non-government organisations have assisted with emergency shelter and settlement
response to the people affected by the disaster— including, where necessary, temporary accommodation, such as tents, non-food items, transitional shelter, and cash transfers. Divisional Secretaries identify suitable land for the new permanent housing and develops the designs for the road layouts and the infrastructure. NBRO provides the designs for the new housing typologies, establishes construction parameters, and approves and supervises the overall implementation. Beneficiaries, on the other hand, are able to choose from an owner-driven approach— where they can build their own houses— or a donor-driven approach— where government or donors will build the houses for them.

Simultaneously, the National Building Research Organisation has been developing a series of hazard maps— showing areas prone to landslides or other events— and then risk maps, classifying zones depending on their risk. The organisation uses various tools for this purpose, such as drone technology, aerial photographs, geological surveys, hydrological studies, among others. The idea is that risk maps allow NBRO and the government to identify settlements and communities living in high and medium risk zones, who may potentially need to be relocated into safer settlements.

2. Wasanthagama

A large number of settlements are being planned, and some of them have already been completed. In Kegalle, a new settlement near Aranayake now provides permanent housing to the families affected by the 2016 landslide. These families were previously in temporary tents or transitional shelters. The site at Wasanthagama comprises about 56 houses and a new evacuation centre.

The houses are a joint effort between private donors and the government, whereby the former provided the material for the construction, and the latter assisted with labour from the armed forces. The evacuation centre was built by the Ministry of Disaster Management, with technical support from NBRO, and financial assistance from the Asian Development Bank (ADB).

The area is primarily rural; therefore, many people rely on agricultural activities for a living, including rubber, tea, cinnamon and pepper farming. From the families who have moved into the new settlement, many have lost their sources of income due to the landslide, but also some lost their livelihoods as a result of the relocation. NBRO, however, has been monitoring the implementation of the programme, and collecting regular data from the beneficiaries. This has permitted to evaluate the socio-economic conditions of the people over time.

A number of unstructured interviews were carried out among beneficiaries in mid-2017, when some had already moved into the new houses. One of the interviewees explained that she used to work in a garment factory prior to be resettled. It would take her about 1.5 hours to reach work from her previous home; although, she would use government buses. Now that they have moved to Wasanthagama, she cannot work at the factory because it would require to take 3 buses and to spend about 6,000 rupees a month in transport, almost half of the usual salary. Now her family is trying to find daily petty work. Another interviewee, who used to live at the top of the landslide but her plantation was not destroyed, mentioned that her husband still goes to the plantation every day by public transport, even though it takes a long time to get there. Nevertheless, she is grateful that the school is closer to her new house, so her children can go more easily. Others, whose house and plantation were totally destroyed, and did not have any other sources of income, were solely relying on subsidies from the local...
government –an allowance of 1,300 rupees a week- and from non-government organisations.

In general, the people affected by the disaster were receiving financial assistance. Such assistance was, however, temporary, intended to support households to recover from the adversity. As a result, families needed to find more sustainable livelihoods. A few households started to collect and trade spices, and were growing vegetables in their yards. Others started small businesses, such as carpentry, etc.

NBRO has also started a training programme to masons and local contractors to enhance their knowledge on hazard resilient housing construction techniques (NBRO, 2018). Training sessions have taken place across different districts and tool kits are distributed among participants. These sessions have been particularly useful to build the skills of the people involved in home-owner driven approaches.

3. Discussion

Academics and practitioners have acknowledged the importance of livelihoods in creating successful reconstruction projects. A strategy to enable sustainable means of support is suggested because it can provide a holistic approach to the programme, moving actions from relief to development. At the same time, it permits an understanding of vulnerability in relation to capacity, placing vulnerable people at the centre of the issue. Different organisations have used the concept of ‘sustainable livelihoods’ as a framework for the implementation of reconstruction programmes. This seems a viable approach because it is people-centred and it is founded on the creation of robust assets to reduce vulnerability in the long term. For example, the government of Ethiopia uses a sustainable livelihoods approach to map the effects of hazards in vulnerable people (Sanderson, 2012).

Whilst many agendas dedicate greater attention to the provision of tangible assets (such as housing, money, land, and natural resources), it has been demonstrated that non-tangible assets (such as human capital, social networks and political opportunity) are equally important to enable sustainable livelihoods. An evaluation of a reconstruction programme in post-earthquake Kashmir in 2005 revealed that initiatives to build non-tangible –or soft- assets were repeatedly more effective than those targeted at the provision of tangible assets -or hard- assets even if the former were cheaper in comparison to the latter (Sanderson, 2012). Soft assets can include skills training and the strengthening of community networks, necessary for the development of livelihoods.

For this reason, it is vital to provide the opportunities for people to build strong assets. Some people may need to develop skills through training. Others have the skills, but lack the physical or economic resources to generate income (for example, several people lost their land, implements, and other assets in the disaster). From the outset, a meaningful participation of those affected is crucial.

The training programme implemented by NBRO has proven to be an important starting point to develop the skills of local masons in disaster-resilience housing construction. Such training could also be extended to self-recovery processes, strengthening the capacity of people to rebuild or repair their own houses after disaster. Furthermore, skills programmes can be expanded to other areas, such as carpentry, plumbing, etc.

In Kegalle, the Vidatha Resource Centre –located on the Mawanella-Ambadeniya Road, near Wasanthagama- provides opportunities for locally based training. This
centre is part of a nation-wide scheme for skills development in rural areas, which can help to improve the capacities of the affected population.

Additionally, the new evacuation centre at Wasanthagama presents an unequalled opportunity for the creation of a communal space that people can use to receive training and to develop their skills. This space can help to strengthen social networks and a sense of community.

Thus, the resettlement programme could enact a community-centered participatory approach, strengthening people’s self-initiatives, alternative livelihood means, and a sense of ownership. In Sri Lanka, previous examples, such as the ‘Creating Opportunities for Economic Revival and Development’ (CORD) Project, implemented in Nuwara Eliya in 2007, can bring some important lessons (Ganepola, 2009).

4. Conclusions

The resettlement programme has been an important action to provide safe housing to a large number of people in Sri Lanka. However, when families are displaced from their original place, livelihoods and social bonds are also compromised. Their relation to context is also disturbed. Although new and safer accommodation is well commended, livelihoods, and other ‘non-tangible’ aspects should be considered.

It is important to plan livelihood strategies at the beginning of each resettlement programme, together with the affected people, so that they do not become more vulnerable. Needs assessments and workshops with the community will be necessary for this purpose. The affected people should also be fully engaged in the relocation process, including the selection of the site, the settlement planning, etc., in order to achieve long-term sustainable outcomes.

Alternatives to relocation could also be explored, especially in areas of middle and low risk. Capacity building, training to people and mitigation strategies are important elements of a successful programme. The idea is to make people less vulnerable by providing the appropriate assets to deal with situations of risk. The provision of tangible and non-tangible assets can help to reduce vulnerability. Community action, training, and support are crucial for this. In the end, the suggestion is to shift the approach from a housing reconstruction programme to a sustainable livelihoods plan that enables people’s empowerment by understanding their needs and capacities.

Acknowledgement

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References


An Assessment on Knowledge Transfer in Post Disaster Housing Construction

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¹Scientist, National Building Research Organisation, Sri Lanka

Abstract

Between 2014 and 2017, Sri Lanka was struck by several major disaster events affecting thousands of houses which had to be rebuilt and relocated in safer places. Government of Sri Lanka has initiated a disaster resettlement programme to resettle those affected people in many districts during last few years with the technical guidance of National Building Research Organisation (NBRO). The disaster resilient housing concept was the theme and the main housing construction concept which was introduced by NBRO for new houses was to reduce the impact of potential hazardous events. Before started constructions, there were number of knowledge transferring program on this new concept of resilient housing construction to officers in Divisional Secretariats, Technical Officers, Masons and Beneficiaries who are implementing the program in ground level. This study examines the effectiveness of the knowledge transferring programmes for Masons, in terms of understanding of the concepts and application of disaster resilient housing construction in ground works. Semi structured interviews were conducted with randomly selected masons who attended to awareness program in Agalawatta DS Division in Kaluthara District. The result indicate that masons are ready to absorb and implement the new knowledge on resilient construction. However, findings of this research also suggest there are problems in implementation of the new knowledge. Lack of awareness among beneficiaries on the importance resilient house is a key problem in implementing the new knowledge.

Keywords: Hazard Resilient Housing, Knowledge Transferring, Resettlement and Construction

1. Introduction

With the increasing of natural disaster events in Sri Lanka, it was observed that considerable number of houses in the island has been affected from those events (Figure 1). In fact, the government has to spent large amount of money to either rebuild or resettle those houses in safe areas.
Fig. 1. Houses damaged and destroyed


However, NBRO has identified that, main contributing factor for losses and damages of houses in the natural disaster events, is the poor building construction and not because of the intensity of the events (NBRO, 2017). Most of these damaged houses may be classified as engineered buildings that have been constructed without a proper architectural and structural design from qualified professionals.

The house builders or the masons who are building the houses in the remote areas of the country, mostly use their traditional transferred knowledge from one generation of masons to next generation. The junior masons usually have apprenticeship to build their knowledge and skills under the senior masons. After junior masons felt that they have gained enough knowledge, then they start performing as masons.

Masons have important role in housing construction (Especially in the disaster prone areas), since the quality of the constructed houses is mainly dependent on experience and skills of the masons.

After 2016 and 2017 flood and landslide disaster events in Sri Lanka, the government had decided to rebuild the affected and at-risk houses in safer locations as a long term recovery initiative. The post disaster reconstruction program was initiated as a “disaster resilient housing construction” where disaster resilient constructions were promoted. According to NBRO, 1980 houses in 2016 and 3600 houses in 2017 were to be constructed as a disaster resilient houses and the government assisted the housing programme with additional 30% funding for the resilient features of the houses.

However, the concept of “Disaster Resilience House Construction” was relatively new to island’s construction industry. Both the masons and technical officers were not aware about the new concept of construction. Therefore, it was a challenge to the implementing authorities to achieve the disaster resilient concept within the programme. NBRO, as the main technical service provider for the reconstruction programme, designed a comprehensive training and awareness programme on disaster resilient housing construction for transferring the knowledge to masons and technical officers. However, two questions have emerged about the effectiveness of the trainings: to what extent the trainees understand about disaster resilient housing and how is the gained knowledge being applied on the ground?
With this background, this paper examines the effectiveness of knowledge transferring programme conducted for masons. The effectiveness in this paper is constituted with the understanding of the training participants and implementation of knowledge about disaster resilient house.

2. Literature Review

2.1 Disaster and Post Disaster Recovery in Sri Lanka

The NBRO has identified 15,025 houses which are mostly vulnerable to the landslide disaster and located in Badulla, Nuwara Eliya, Matale, Kandy, Kegalle, Ratnapura, Kalutara, Galle, Matara and Hambantota districts (NDRSC, 2018). Following table shows the disaster damages and losses from 2004 to 2017.

<table>
<thead>
<tr>
<th>#</th>
<th>Event</th>
<th>Damage and Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2004 Tsunami</td>
<td>217.5 billion</td>
</tr>
<tr>
<td>2</td>
<td>2005 flood and landslide</td>
<td>5.0 billion</td>
</tr>
<tr>
<td>3</td>
<td>2011 flood and landslide</td>
<td>77.0 billion</td>
</tr>
<tr>
<td>4</td>
<td>2016 flood and landslide</td>
<td>99.0 billion</td>
</tr>
<tr>
<td>5</td>
<td>2016 flood and landslide</td>
<td>70.0 billion</td>
</tr>
<tr>
<td>6</td>
<td>Total</td>
<td>251.0 billion</td>
</tr>
</tbody>
</table>

As shown above table, government of Sri Lanka has spent billions of Rupees for recovering above losses during last decade. However, as stated by (Vithanagama, 2015), (Keraminiyage, 2008), (Ratnayake, 2008) most of post disaster government recovery endeavours have not gained positive returns due to poor planning. As stated in Sendai Framework\(^1\), recovery project should incorporate building back principles and resilient concept. It further elaborates that investing 1 dollar in resilience saves 4 – 7 dollars.

2.2 Disaster Resilient Housing

Resiliency is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (UNISDR, 2018). NBRO designed the house plans (See the figure 01 & 02) resilient to known hazards such as landslides, high wind and flood, and those were used to construct the houses under the resilient housing construction programme.

\(^1\) The Sendai Framework for Disaster Risk Reduction is an international document which was adopted by UN member states between 14th and 18th of March 2015 at the World Conference on Disaster Risk Reduction held in Sendai, Japan and endorsed by the UN General Assembly in June 2015.
The Sendai Framework for Disaster Risk Reduction is an international document which was adopted by UN member states between 14th and 18th of March 2015 at the World Conference on Disaster Risk Reduction held in Sendai, Japan and endorsed by the UN General Assembly in June 2015.

2.3 Knowledge Transfer

Knowledge may be defined as the mental state of ideas, facts, concepts, data and techniques which build on received information that is enriched by personal experience, belief, and values (Benny Hidayat, 2017); (S. Bender, 2000).

Benny Hidayat, (2017) describe the knowledge transfer model which proposed by (Champika Liyanage, 2009).

Benny Hidayat, (2017) further stated that, among those processes, Liyanage et al. (2009) have stressed on the importance of knowledge application, all other processes of knowledge transfer will be in vain if the transferred knowledge is not implemented. Also in the model proposed by (Champika Liyanage, 2009) there are prerequisite factors to ensure the success of knowledge transfer. Those factors are willingness to share knowledge from the source of knowledge’s side and absorptive capacity and willingness to acquire knowledge from receiver’s side (Benny Hidayat, 2017); (S. Bender, 2000).
3. Methodology

Series of knowledge transferring programs was conducted by NBRO for masons in landslide impacted DS Divisions in Kaluthara, Ratnapura, Galle, Matara and Hambantota Districts on landslide resilient housing constructions. This research was based on the responses for semi structured questionnaire taken from randomly selected 20 professional of masonry who have participated for knowledge transferring program in Agalawatta DS Division in Kaluthara District. Sample size is around 20% out of total participants in particular DS Division. Since the Agalawatta DS Division perform highest construction progress of landslide resettlement program has been taken for this study. The interview was mainly focused on syllabus of the training, methods of delivery in the training, barriers for the builders in understanding the training contents, and barriers in implementing knowledge from the training.

4. Analysis

The primary aim of this research is to identify that examine the knowledge transferring programs in terms of understanding of the concepts and application of disaster resilient housing construction in ground works and this analysis was based on the responses taken from masons for semi-structured questionnaire.

As per the results, majority of masons (Around 70%) have more than 20 years of experience in construction works especially in housing construction. The rest of masons have various working experience range from ten to twenty years. Though they have pleasures of experience in housing construction, around 90% of masons have developed their professional skill from informal methods. Most of the masons were previously working as helper under a senior masons and after acquired sufficient knowledge on construction (as per they think) they have become a masonry profession. Another 20% of masons have developed their professional skills from the generation. Only two masons(10%) had followed professional/ technical cause on construction out of twenty masons who have been interviewed.

Though most of interviewees had have experience in housing construction more than 20 of years prior to the training, 90% of masons have not been aware of disaster resilient construction. Only 10% of masons who had followed technical cause were aware on resilient construction, but it has not been practiced in ground level. Hence, as they mentioned, the knowledge transferring programs on resilient construction was very obliging to masons to improve their professional knowledge on resilient constructions. The training and awareness programs were consist of how to construct a resilient house including resilient features such as foundation, plinth beam, columns, reinforce bar, joints, lintel etc. and selecting quality construction materials. These techniques were further illustrated in a guidebook and distributed among masons for easy understanding the concepts during workshops.
Fig. 4. Professional development of masons

It was significantly observed that the knowledge transferring programs was very obliging to participants and all the interviewed masons mentioned that it was useful to,

- Upgrading the professional skills
- Alignment with current level of skills and knowledge
- Relevance to the profession
- Improvement of the knowledge on profession

Further, it was discovered that this was the first time ever participation in such technical workshops of disaster resilient construction techniques, and around 10% of participants have participated to other masonry workshops but haven’t discuss on disaster resilient constructions. It was conspicuously noted that the interest among the participants towards the knowledge shared regarding the disaster resilient construction techniques and they were highly satisfied with the responses received from the program conductors. Thus, this factors altogether perform to well transferring of knowledge and the received output of the responses exhibits that the level of success in knowledge transferring is in satisfiable rate.

Knowledge transfer often associated with acquire the knowledge and transfer the gained knowledge. Hence, the masons gained new knowledge or improved their knowledge in terms of disaster resilient constructions and this knowledge need to be implemented in the ground level when they constructing a new houses. Thus, this research have been examined the success and barriers in implementing or transferring the knowledge on disaster resilient construction.

After the 2017 natural disaster event, National Landslide Resettlement Program was started by Government of Sri Lanka to resettle the directly affected and high risk families in landslide prone areas. Ministry of Disaster Management published a set of guidelines to be followed in constructing houses under the resettlement programme.

This guidelines were included minimum standards to be included in constructing a resilient house. It was mandatory to include these feature house and it was evaluated before releasing financial assistance in each stage of the house construction. The
beneficiaries were aware and trained on these guidelines by NBRO, highlighting the
disaster resilient techniques and importance of having resilient features in houses.

All the interviewees stated that after the training program, they have engaged with
housing construction for landslide victims as well as for other people. They have
offered to both parties to build their houses with resilient features. Among them, only
landslide victims have agreed to construct their houses with disaster resilient features
and others were not interested to incorporate resilient features. Mostly, following
conditions have been mentioned by people who were not interest to build their houses
with additional reinforcement.

- High cost for additional reinforcements
- Consuming time to build house with resilient features
- Owners think that it is an over design for single story houses
- Owners haven’t proper awareness on disaster resilient construction

Further, interviewees mentioned that general public also should have a proper
idea and awareness on disaster resilient construction for successful implementation
of this in ground level. The people who have proper understanding on this methods
was interested to construct their houses with resilient features. This situation shows
that house owners also play an important role in implementing disaster resilient
construction in hazard prone areas. Hence, it is important to conduct various
campaign, advertisements, and training programs and distribute books, broachers,
film talks on disaster resilient construction among house owners to mainstream this
concept.

Following pictures shows that the houses constructed with resilient features and
without resilient features.

Fig. 5. House constructed without resilient feature in flood prone area by non-trained masons

Fig. 6. House constructed with resilient feature in flood prone area by trained masons
5. Conclusion

As the main technical consultant of resettlement housing construction under the national resettlement programme, in disaster prone district, it is needed to ensure the safety of resettled families in new locations and ensure disaster resilient houses are constructed. In this regard, NBRO has conducted a series of knowledge transferring program for Masons in such areas on disaster resilient construction. It focuses on reducing the damage to lives, residential houses and vulnerable communities by ensuring enhanced planning, siting, design and construction of houses by building housing units that are more resilient to the impact of natural disasters. This study examines the effectiveness of those knowledge transferring programmes in terms of understanding of the concepts and application of disaster resilient housing construction in ground works. This research has identified that the stakeholders had good motivation to attend the training and since they have building construction experience and they can absorb and modify the new knowledge on disaster resilient construction technologies. But, masons have faced difficulties in transferring/implementing the knowledge in ground level due to less awareness of house owners. It means, by strengthening knowledge of masons itself cannot implement the concept of resilient house in ground level. It is far needed the contribution of house owners, to reach it to a successful end. Hence, in terms of resilient disaster resettlement programme, training of both the masons and beneficiaries are equally important to achieve resilient house concept.

References


An Evaluation of Locational Distribution of Individually Resettled Sites (IRS); Case Study of Ayagama & Kalawana DS Divisions

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Abstract

Government of Sri Lanka has planned to resettle families who have been identified by National Building Research Organization (NBRO) as directly affected by recent severe disaster events and families living in hazard prone areas in central and southern half of Sri Lanka. Than going for a single option resettlement programme, the government offered three resettlement options to be selected by beneficiaries in resettlement program; which consists of 1) constructing houses in government resettlement site 2) buy a land where beneficiaries prefer to live and construct house, and 3) buy pre-constructed house. The main objective of the introduction of diversified resettlement options was to minimize the negative impacts of mass resettlement and to pulling-out the victims from high hazard, high altitude areas to non-hazard prone district or locate them in to urban areas. As NBRO statistics shows, 46% of victims have selected option 2 and 3 as their resettlement option. The paper mainly focused on to identify whether the objectives of government has been achieved in terms of their movement from original location to new location. It was selected Ratnapura district as the study areas while semi structured interview were conducted with randomly selected beneficiaries, to understand the beneficiary opinion on selecting resettlement option. Remote Sensing and Geographical Information System (GIS) was used to analysis the locational distribution of sites. The result of the research revealed that, it has been able achieved the expected objectives of the alternative resettlement options.

Keywords: Resettlement, Individually Resettled Sites, Locational Distribution

1. Introduction

The occurrence and effects of disasters worldwide since the beginning of the 20th century is available in the global Emergency Events Database (EM-DAT) and it shows that the number of disasters triggered by the occurrence of natural hazards – has accelerated sharply worldwide (Correa E., 2011). Sri Lanka is also prone to many disasters including landslide, flood, lightning strikes, coastal erosion and effects of environmental pollution. Based on the information available on the people affected by natural disasters during the last few years, it could be clearly identified that landslide
and floods are the most common disasters in Sri Lanka. The most severe impact on floods and landslide was occurred in May, 2017 due to heavy rain and strong winds from south western monsoon affecting around half a million of people living in Ratnapura, Kaluthara, Galle, Matara and Hambantota Districts.

Subsequently, the government of Sri Lanka (GoSL) planned to resettle families living in hazard prone areas of Ratnapura, Kaluthara, Galle and Matara with the financial assistance from government. The main objectives of this resettlement program were,

1. To provide guidance and government financial assistance to complete the “core-house” for the beneficiaries selected from the National Building Research Organisation with the concept of “House to House”.
2. To complete the “Core House” with the concept of “Build Back Better”.
3. To ensure a disaster resilient core house is constructed.

Source: Implementation framework for the resettlement of landslide and flood victims by Ministry of Disaster Management

The diversified rehabilitation options were introduced to beneficiaries to minimize the negative impact of mass resettlement and let them to select one of the following options as they prefer to resettle; 1). Construct the house in government owned land plot, 2). Land purchase by beneficiary and construct the house; (hereby referred as Individually Resettled Sites – IRS) and 3). Buy pre-constructed house (hereby referred as Individually Resettled in Pre-exist Houses – IRH). These options were introduced with the purpose of pulling-out the victims from high hazard, high altitude areas to non-hazard prone district or locate them in to urban areas and to minimize the negative impacts of mass resettlement.

After the disaster situation occurred in 2017, 3600 households have to be resettled in safer locations in affected district. It is accounted 35% of beneficiaries have selected option 02 while 11% has selected the 03rd options as their resettlement alternative. With this background, this paper is intended to examine 1) the locational distribution of Individually Resettled Sites (IRS) and Individually Resettled in Pre-exist Houses (IRH), 2) whether the objectives of introducing such options are achieved or not.

1.1 Objectives of the research

The main objectives of this research are,

I. To identify the spatial distribution of Individually Resettled Sites (IRS) and Individually Resettled in Pre-exist Houses (IRH)
II. To compare locations of IRS with original sites and identify their movements with hazard prone locations
III. To examine whether objectives of introducing IRS and IRH option is achieved or not
IV. To give directions to policy makers to improve or alter rehabilitation options in future programs.

2. Literature Review

Since 1980’s due to the increase in number of landslide events and higher number of victims, landslide is considered as a serious threat to human settlement.

Out of 25 administrative districts in Sri Lanka ten (10) districts are prone to landslides namely NuwaraEliya, Badulla, Kegalle, Kalutara, Kandy, Matale and recent time of Matara, Galle and Hambantota. The above-mentioned landslide prone area covers approximately 30% of the total land area of the island, and it is occupied by about 35% of the population of Sri Lanka. Density of occurring landslides in these districts are at 1-2 per sq.km. Trend analysis by NBRO researchers reveal an acceleration of landslide occurring in Sri Lanka (Jayaweera, 2009). As stated by Jayaweera, the above acceleration of landslide are mainly due to the spread of human settlement throughout the hill country including fragile areas as identified by National Physical Planning Department (NPPD).

NPPD released and gazetted the National Physical Planning Policy of Sri Lanka. It has identified hilly areas as fragile and further settlements are not recommended. This is one of the win – win situations that the resettlement project has achieved.

NBRO which is the focal point for national landslide related studies, has found that 14,680 houses located in the hill country are prone to high landslide risk and are recommended to be resettled in safer locations. However, as stated by the Smith (1991), the whole process of resettlement is much more complex than is seen in the approach employed by many reconstruction authorities after disasters. Further he stated that, in general, it is fair to say that far more sensitivity to the complexities of the resettlement process is needed in post disaster resettlement. It is not, for example, generally recognized by reconstruction authorities that the consequences of resettlement itself may even be more grievous than the impact of the disaster.

As stated by Perera et al, (2012) and Smith (2001), resettlement is a multisided opportunity for the reconstruction systems of production and human settlements that represent a development in the standard of life of those affected, as well as in the regional economy of which they are a part. According to Correa, (2011), apart from reducing the risk reduction, resettlement is an opportunity to improve the standard of living of vulnerable group in high-risk areas. At the same time, resettlement may be a land use planning strategy, where communities living at high risk and environmentally sensitive areas may negatively affect the sensitive ecosystems and may be a triggering factor for new natural hazards.

Argument of these scholars are, “resettlement”, must also be development oriented and planning must take into account that the social and physical infrastructure, school and health services, access to employment opportunities, housing plot allotments and dwellings meet expanded needs.

As stated by Vijekumara (2016), having several resettlement options within a resettlement programme is one of the key factors for its success. According to Vijekumara, “Nueva Esperanza Resettlement” programme is one of the successfully implemented resettlement programs in Bogota of the Columbia, which has used several resettlement options within the programme to resettle 1074 families who were living in landslide high hazard areas.
Landslide resettlement programme which had taken place after the 2016/2017 disaster situation, was introduced with several resettlement options. The resettlement program was lead more towards development oriented and meet the objective of National Physical Plan of NPDD which is to directing the residential population from central fragile area to non-hazardous prone areas and urban centers.

3. Methodology and Study Locations

Case study approach was selected as the method of study for the research. Kalawana and Ayagama divisional secretariat divisions of Rathnapura district, were selected as the location of study, as it has higher contribution (Ayagama – 54, Kalawana – 46) to the above discussed options. 20% of randomly selected beneficiaries were interviewed using semi-structured interview method. Global positioning locations of old and current places were obtained from the field surveys. The collected remote sensing data were analysis using the Geographical Information System (GIS) applications. The previous location and resettled location of the selected beneficiaries were mapped spatially. Both of those location maps were used to analysis the spatial movement of the families with selected criteria.

![Figure 01: Location of study area](image)

4. Analysis & Discussion

The primary aim of this research is to identify the spatial distribution of IRS/IRH sites and based on it to evaluate whether the objectives of introducing IRS option to reselling have been achieved or not. All of these IRS/IRH locations were evaluated by NBRO as a mandatory requirement before proceeding with resettlement process. NBRO evaluated these lands with set of established criteria. Free from natural hazards, accessibility to infrastructure (Physical and social), and accessibility to livelihood are some of the criteria used in land evaluation. When considering about spatial distribution of Individually Resettled Locations, majority of beneficiaries had selected their locations within the same DS Divisions. Selecting IRS locations within
the same DS Division in Ayagama as a percentage was 71% and quite high in Kalawana which is 90%. As a total, it was recorded more than 80% victims prefer to select their resettlement location within the same DS Divisions. It was observed that there is an outward movement of IRS/IRH (from other Rathnapura district to other district). It accounts 19% and 07% in Ayagama and Kalawana DSDs respectively. Considerable number of beneficiaries of Ayagama DSD have moved to Horana and Bulathsinhala DSDs in Kaluthara District which is located very closer to Ayagama. Further, it could be identified that some beneficiaries who selected IRS/IRH locations in another DSDs in same District; it accounts 7% from the total.

As per the implementation guideline for the resettlement of landslide and flood victims; it has been recommended to consider major two standards in selecting mass resettlement sites, such as resettlement site should be located

- Less than 2.5km distance from nearest town centre
- Less than 0.5km distance from main access road

Source: Implementation framework for the resettlement of landslide and flood victims by Ministry of Disaster Management

![Figure 02: IRS location Selection](image)

Further in this research, it has been observed whether there is a trend to select IRS/IRH sites closer to town centres and main access roads from hilly areas in terms of standards indicated in implementation guideline. As per the result, around 50% of beneficiaries have selected their resettlement sites in areas which are in compliance with both standards. Another 25% beneficiaries have selected their sites either within 2.5km distance from town centres or 500m distance from main access roads (Figure 03).
**Figure. 03: IRS location Selection**

In this context, it has been found that majority of people (nearly 75%) have moved closer to town centres or main access roads. Figure 05 shows that the spatial distribution of IRS/IRH sites and the existing locations of victims. As per the map, it can be clearly identified that most of people have been moved to town centres and closer to main access roads from hilly areas.

**Figure. 04: Spatial Distribution Map of IRS/IRH site – Ayagama DSD**
Figure. 05: Spatial Distribution Map of IRS/IRH site – Kalawana DSD

Figure. 06: Spatial Distribution Map of IRS/IRH site and existing locations
Further, open ended interviews were conducted from 20% of people who have selected for analysis to identify reasons behind selecting IRS/IRH locations within same DS Division. Majority of people said that they wanted to resettle closer to their previous locations since availability and easy access to their livelihood options. Most of them were not prefer to take a risk on finding livelihood options by resettling in less familiar areas or districts. Apart from that, following socio-economic factors were affected for not moving non-hazardous district including;

- Most of beneficiaries owned small holder tea or spicy cultivation in or closer to their previous locations.
- They were not intended to move away from origin community and relatives
- Sometimes, financial assistance is not adequate to purchase lands from other areas etc.

Interviewees mentioned that, in addition to livelihood options, they have considered availability and easy access to electricity, water and access road in selecting IRS/IRH locations for them.

As NBRO specified, site development (Site excavation, road development, electricity and water supply, ground improvement, drainage improvement and livelihood development) cost per housing unit is 75% from the total investment per housing unit. As an example, if the cost per house is Rs. 1.2Mn, another Rs. 0.9Mn will be incurred for site development, if it is implemented as a mass resettlement. Therefore, site development including providing of infrastructure for mass resettlement sites is a major crucial factor in mass resettlement programs. It is observed that more than a year has elapsed since construction commenced in mass resettlement sites in Ratnapura District, but still no water and electricity have been provided for resettlement sites. The provision of large-scale infrastructure is additional cost and burden to the government as well. As per the District Secretary of Ratnapura District, unavailability of required amount of government lands, unsuitability of available lands in the district is main issue for mass resettlement. Although, there are some lands which meets suitability criteria for resettlement, it takes more than three months to acquisition. However, it is clearly show that, government burden of site development and infrastructure provision has become zero for all the IRS/IRH selected houses. Apart from that, beneficiaries have paid their attention on livelihood option attached to the new places. As described in literature, lack of access to livelihood means is a major factor failure in mass resettlement programmes. With the option of IRS/IRH, it can be clearly observed that, livelihood problem has automatically solved. Finally, this researched proved that, introduction of diversified resettlement programme with the IRS and IRH option, has contributed positive outcomes to the programme and it has been able to achieve the expected outcomes. In other words, it has helped to minimize the negative impacts of mass resettlements, pull-out the victims from high hazard to non-hazard prone district or locate them in to urban areas.

5. Conclusion

In a summery, this research tried to identify impact of introduced resettlement alternative options of IRS and IRH. Two divisional secretariat divisions from the Rathnapura district was selected to study. Open ended interviews and spatial analysis were performed to identify the pros and cons of the resettlement options.
The analysis show that, location of IRS/IRS lands are moved towards more accessible infrastructure available locations and those areas are disaster free. So, the objective of pulling out from hazard prone to hazard free developed area, is achieved. Further, it has saved site development and infrastructure development cost of 46% of houses which is huge saving for the government.

Finally, these options have helped to solve the famous resettlement failure factor of livelihood access. Thus, it can conclude that, the resettlement programme has able achieve the expected outcomes from the IRS/IRH options.

References


An Evaluation of Socio-Economic Sustainability of the Disaster Resettlement Housing Projects in Sri Lanka
- Special reference to Kegalle District Resettlement Programme 2016

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Abstract

Recently in Sri Lanka, occurrences of natural disasters especially, landslides and floods were getting increased and the requirement of recovery and relief had to be carefully managed. It would be more appropriate if the Ministry of Disaster Management as the main planning and implementation authority in Disaster Management could perform precautional strategies before the disaster affects, since they were not striking unexpectedly. After identifying the risk level of a house or after the disaster strikes, the government stands with a high responsibility of resettling the community and achieve disaster resilience at once. In this context, Resettling the community in larger scaled schemes seemed as an appropriate strategy where Sri Lankan government has implemented three resettlement programmes in 2014, 2016, 2017/18 covering seven districts.

As the resettlement projects had many stakeholders collaborating together, it should be examined in many perspectives. This study attempts to evaluate the sustainability of prevailing resettlement practice in terms of social and economic aspects, facilitating multi-stakeholders. Similarly, and adopted a Multi-Criteria Cost Benefit Approach referencing Kegalle district resettlement programme (2016).

Result indicates positive Benefit-Cost Ratio in empirical application, defines more benefits to the stakeholders. However, the actual situations appeared more doubtful, indirect indicators were developed on ‘Social’ – ‘Economic’ and ‘Physical’ attributes to evaluate in-depth. This evaluation exposed positive ‘Social’ well-being but not ‘Economic’ or ‘Physical’. Locational in-efficiencies, difficulties in livelihood restoration and behaviours of the community towards the resettlement practice were the main drawbacks of achieving the ‘Socio-Economic Sustainability’ at the end.

Keywords: Disaster Resettlement; Public Finance; Socio-Economic Sustainability; CBA; Hidden Indicators; Resettlement perceptions
1. Introduction

1.1. Background

Growing trend of natural disaster situations in past few decades are alarming Sri Lanka to adopt more appropriate physical plans in order to minimize the hazardous after effects (Ballingar & De Silva, 2017). At the same time, it is required to re-settle the affected communities in a safer and resilient manner. From that base Sri Lankan government strategically formed into constructing larger scaled resettlement housing schemes with the technical support from National Building Research Organisation (NBRO) – in relation with Ministry of Disaster Management (MDM).

Disaster is not only a damage, but also and opportunity where the government could drive towards a resilient and urban-friendly settlement structure by regularizing the irregular and vulnerable hill-country housing settlements. Exclusively to reduce the physical & social negative consequences on these communities’ displacements government is allocating approximately 500millions annually for disaster recovery and relief (Annual Performance Report, 2016). Where the implementation agencies should optimize this allocation and the resettlement (investment) with the external accomplishments as achieving disaster resilience by the end.

1.2. Overview of Disaster Resettlement Practice

Every year millions of people are being displaced or relocated due to two main reasons, either as development induced or as disaster induced. For the past twenty years more than 20 million people around the world have been forced move their homes in order to make space for massive development projects. Conversely after the natural disasters such as La-Nina 2010, Tsunami 2004 and 2011 millions of people lost their habitats in and around countries like Australia, Pakistan, Brazil, Japan, Indonesia including Sri Lanka (Perera, Weerasoori, & Karunarathne, 2012). A disaster is a phenomenon that can cause damage not only to life and property, but also can destroy the economic, social and cultural wellbeing of a community.

Within the last two decades the effect of natural disasters on Sri Lankan community increased substantially and resulted in creating new requirement to the country; resettling the affected communities in a safer manner and restore their lives. 14 years ago, after the great Tsunami affects, more than 98,000 houses had to be rebuilt (Keraminiyage & Dias, 2016) in order to restore the earlier equilibrium of the vulnerable coastal communities.

And more recently community requirement of disaster induced resettlement was called for landslide and flood disasters which began to occur regularly with the climatic and monsoonal fluctuations. Currently MDM is taking the authority of Disaster Relief & Recovery (DRR), ensure the disaster resilience of the community and the Disaster Resettlement (DRS) programmes. Recently there were main three resettlement projects implemented in Badulla 2014 (75 houses), Kegalle 2016 (1980 houses) and around five districts namely Rathnapura, Kalutara, Galle, Matara & Hambantota 2017/18 (3600 houses).
For these programmes, the government has followed three different implementation procedures. But in general, all the projects should be implemented in a way to its effectiveness and achieve a successful resettlement programme at the end.

With the development of the building technology many countries have achieved the building resilience and reduced the losses and damages from disaster strikes, where a substantial attention is required perseverance and persistence with a clearer focus on People and their Health and Livelihoods and a Regular follow-up -16th sentence; section III, Sendai Framework for Disaster Risk & Reduction (DRR) 2015-2030 (UN, 2015). Resettlement is a practice of introducing the new built environment to the society which could regularize the irregular, vulnerable human settlements constructed with building resilience. And there are certain conditions community requires when making a fundamental change in the system and restoring their earlier equilibrium, which seems to be lacking in many resettlement practices in Sri Lanka. Resettlement fails if the built environment is not providing the community’s basic requirements. Failure, has been more focused on inappropriate house designs, insufficient infrastructure, inappropriate hosting environments alike. (Sridarann, Keraminiyage, & Amaratunga, 2017).

In the other terms, resettlement projects are implemented under the government expenditure category of ‘Welfare’. And all the regular welfare services are (Education, Health) provided to the community expecting to achieve a longterm measure of sustainability. If the government is spending on DRS project that also should proceed with an acceptable social/ economic benefit to any stakeholder party. And the industrial argument is, if the government is spending billions from public money on resettling the disaster affected community - 500 billion annually for DRR and recovery without concerning about the returns to the society that indicates a huge loss/failure.

As the argument coming from the sociologist’s view of Michael M. Cernea, “Mutual reinforcement between the economic, financial and social analyses of resettlement components in projects is indispensable for avoiding their future” (Cernea M. M., 1999). With the background of calling a ‘Constructive alliance’ between economic and sociological knowledge, this study continues to apply in-depth economic knowledge to evaluate the fundamental goal of DRS practice in Sri Lanka - ‘Build Back Better’ (NBRO, MDM, & DMC, 2016)

2. Methodology

Since this study is to analyse the prevailing DRS Housing Projects in terms of social and economic sustainability and to propose suitable intervention to achieve it. To accomplish it, multi – criterial cost benefit approach will be used. As the data and information to be used on the analysis, may vary within both quantitative and qualitative approaches which would produce many complications in the conclusion stage.

A qualitative research can help to realize the complexities in the empirical situation and interpret better on the implications of quantitative data, and this research may use both approaches, Quantitative and Qualitative by the analysis variance.

In-depth literature survey will be used majorly and knowledge and experience of DRS industrial expertise may be used to establish a methodology to evaluate the current DRS programmes. And to examine the prevailing DRS projects implemented in Local context and determine the ‘Government Investment’ on DRS in terms of Socio
– Economic aspects, an empirical application was required. In this study, considering all the possibilities and limitations, 05 DRS projects from the Kegalle District resettlement programme 2016 will be applied to the evaluation.

Table 1 - Details of the Selected DRS Projects

<table>
<thead>
<tr>
<th>#</th>
<th>Resettlement Project (Kegalle District)</th>
<th>Number of Families resettled</th>
<th>Type of the resettled community</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Wasanthagama</td>
<td>56 units</td>
<td>Directly affected from the disaster</td>
</tr>
<tr>
<td>02</td>
<td>Ruwandeniya (China Housing Project)</td>
<td>60 units</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>Kalugala</td>
<td>82 units</td>
<td>Mixed community</td>
</tr>
<tr>
<td>04</td>
<td>Karandawatta</td>
<td>56 units</td>
<td>High risked zone community (NBRO declared)</td>
</tr>
<tr>
<td>05</td>
<td>Parambewatta– Bossalla Section</td>
<td>29 units</td>
<td></td>
</tr>
</tbody>
</table>

Data analysis on this study takes two paths as there are two main objectives to be achieved within. All the collected data and information should be analysed with justified techniques as,

- 1st Objective achieving by – ‘Establishing the Methodology to evaluate Socio-Economic sustainability of current DRS practice’ - Content analysis of Information gathered through literature and industrial expertise knowledge – Stakeholder Perception will be used to finalize the main indicators of evaluation.
- 2nd Objective achieving by – ‘Examining the prevailing DRS practices in terms of socio-economic sustainability’- Multi criterial CBA which was formulated by 1st objective will be applied into the empirical conditions. Correlation analysis and theories of behavioural economics will be used to conclude the results obtained.

2.1. Method of Evaluation

As it is required to establish an applicable methodology to evaluate the current DRS practice, intention is to declare the ‘Social’ & Economic’ sustainability by measuring the positive benefits and gratification levels of defined indicators. As identified through literature and empirical conditions, evaluation indicators should be two types.

- Direct Indicators
- Indirect Indicators

Since these two types are influencing on many stakeholder parties, analysis based for this study has to consider the indicator influence on those different participants. Direct indicators were evaluated by measuring direct costs and benefits on each stakeholder party. Since then, this study continues an extended version of CBA where it measured the direct costs and benefits influenced on main stakeholder parties.
And the Indirect indicators were evaluated comparing the successive levels of each attribute, ‘Social Well-being’, ‘Economic Restoration’ and ‘Physical Properties and Infrastructure System comparison’; literature based 24 measures were critically examined and evaluated within these three attributes.

3. Results and Discussions

Table 02 represents the total costs and benefits for general RS housing unit, as direct costs calculated during the field investigations and referring secondary information. Benefits were calculated following the Shadow Pricing* technique, measuring the non-physical properties.

Ex:

- Total cost of a house (including labour) = Rs. 1,200,000
- Total benefit of resettling the community = Rs.2,000,000 (for houses)
- than compensating them after the disaster* = Rs.2,500,000 (for businesses)

*If the resettlement was not implemented properly the house would be stoked where the government stands to pay the compensations/insurances granted through national Insurance Trust Fund (NITF).

Considering all the measurable costs endured by each stakeholder party as categorized in Table 02, an average cost of a RS unit recorded as ± 3 million rupees. Also considering all the benefits granted by re-settling the vulnerable community, same stakeholders could save the ± 3.5 million rupees from one unit. A common calculation was developed as Table 02 but, each project needs separate adjustments with the externalities they had to tolerate.

Table 2 - Direct Evaluation - General Result for single RS unit

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Participant Category</th>
<th>Direct Costs (LKR)</th>
<th>Direct (LKR)</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resettled Community</td>
<td>Directly affected &amp; High risked community</td>
<td>1,200,000</td>
<td></td>
<td>400,000</td>
</tr>
<tr>
<td></td>
<td>NDRSC</td>
<td>25,000</td>
<td></td>
<td>1,200,000</td>
</tr>
<tr>
<td>Government/Implementation Authorities</td>
<td>Divisional secretariat</td>
<td>1,900,000</td>
<td></td>
<td>2,000,000</td>
</tr>
<tr>
<td></td>
<td>NBRO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure Providers</td>
<td>NWSDB</td>
<td>100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CEB</td>
<td>22,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PRDA</td>
<td>Road Development done by DS office – (Included in the total cost)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hosting Community</td>
<td>Neighbourhood families</td>
<td>They do not bear any direct costs or benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3,247,000</td>
<td>3,600,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BCR</td>
<td></td>
<td>1.16</td>
<td></td>
</tr>
</tbody>
</table>
Using the information gathered through the project databases and field investigations, calculated Benefit Cost Ratio (BCR) for selected five DRS programmes were varying showing as table 05.

### Table 3 - Customized BCR values calculated for each DRS project

<table>
<thead>
<tr>
<th>#</th>
<th>Housing Project</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Kalugala Housing Project</td>
<td>1.24</td>
</tr>
<tr>
<td>02</td>
<td>Wasanthagama Housing Project</td>
<td>1.18</td>
</tr>
<tr>
<td>03</td>
<td>Karandawatta Housing Project</td>
<td>1.15</td>
</tr>
<tr>
<td>04</td>
<td>Ruwandeniya - <em>China Sri Lanka friendship</em> Housing Project</td>
<td>1.07</td>
</tr>
<tr>
<td>05</td>
<td>Parambewatta Housing Project – Bossalla Section</td>
<td>1.04</td>
</tr>
</tbody>
</table>

The BCR for all projects were valued more than 1, which indicates that project grants more benefits than its costs towards the society. Even though the five programmes contained different BCR values ranking Kalugala project at the top while Donor-driven projects below, actual situations were observed more inverse. As the projects needed more in-depth study, it extended to explore the sustainable measures of each indirect attributes and perform a critical evaluation.

Yet, each project has a combination of different social, economic and systematic issues which communities are facing through their day-to-day living and influencing on projects’ sustainability at the end and those issues were evaluated through the perception of the communities. For that, it needed a deep socio-economic exploration which was grown from the community surveys and interviews. Because of the number of indicators considered for analysis were many and their relationships of influencing each other were more frequent, the results derived from correlation analysis*, which made the decision-making more comprehensive and rational.

(*Correlations were calculated using Spearman Method.*) Finalized information, it was clear that the community type and the project location have a higher influence on its overall sustainability.

- With -0.721** correlation, it was having a strongly negative relationship between Participant category and overall wellbeing measures, assuming (as the values varying) affected communities are more satisfied with their overall RS project than the high risked communities.
- With +0.680** correlation, it was having a strong positive relationship between Project location and overall wellbeing measures, assuming Wasanthagama and Ruwandeniya communities are comparatively fulfilled with their initial sustainable requirements than the Karandawatta and Bossalla communities.

Their reactions, adaptation and their attitudes define them and each project in the DRS programme was treated unequally with given facilities as the donor’s choices and government’s grants were varying. Causing these limitations, final results were being rationale and accurate after clarified by comparing Locational and Participant categories with their well-being levels (Table 03 & 04).
Table 3 - Overall satisfaction levels as varied by community type

<table>
<thead>
<tr>
<th>Community Type</th>
<th>Social well-being</th>
<th>Economic restoration</th>
<th>Properties and Infrastructure System comparison</th>
<th>Overall Satisfaction of the Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected</td>
<td>94.7%</td>
<td>72.4%</td>
<td>89.4%</td>
<td>85.5%</td>
</tr>
<tr>
<td>High-Risk</td>
<td>75%</td>
<td>29.1%</td>
<td>50%</td>
<td>51.4%</td>
</tr>
</tbody>
</table>

As all the social indicators were found around 95% and 75% gratified within both the two communities, overall social well-being assessment of the Kegalle DRS practice can be concluded as a *Socially Sustainable* project.

Within the DRS projects of affected communities, capability in economic restoration recorded as 72.4% which is also a considerable level where the same projects were 89.4% adopted with given infrastructure system.

Same time, investigation conducted on high-risked community found that, more than 70.8% was unsatisfied in economic restoration and employment where only 50% of them recorded as satisfied upon infrastructure system.

The finalized DRS projects done for directly affected communities have recorded more than 85% and high-risked communities were only satisfied up to 51%.

Same technique was applied to check the results obtained, as the location of the project varied. And the resulted output is discussed in Table 04 below.

Table 4 - Overall satisfaction levels as varied by project Location

<table>
<thead>
<tr>
<th>Project Location</th>
<th>Overall social well-being</th>
<th>Overall economic restoration</th>
<th>Properties and Infrastructure System comparison</th>
<th>Overall Satisfaction of the Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wasanthagara</td>
<td>99%*</td>
<td>83.3%</td>
<td>99%*</td>
<td>94.4%</td>
</tr>
<tr>
<td>Ruwaneniya</td>
<td>83.3%</td>
<td>66.7%</td>
<td>99%*</td>
<td>83.3%</td>
</tr>
<tr>
<td>Kalugala</td>
<td>71.4%</td>
<td>7.1%</td>
<td>35.7%</td>
<td>38.1%</td>
</tr>
<tr>
<td>Parambewatta</td>
<td>83.3%</td>
<td>66.7%</td>
<td>33.3%</td>
<td>61.1%</td>
</tr>
<tr>
<td>Karandawatta</td>
<td>99%*</td>
<td>60.9%</td>
<td>45.5%</td>
<td>68.8%</td>
</tr>
<tr>
<td>Overall satisfaction of the Indicator</td>
<td>87.6%</td>
<td>56.9%</td>
<td>62.9%</td>
<td>69.14%</td>
</tr>
</tbody>
</table>

(* all the participants were recorded values more than 4 = satisfied/ extremely satisfied)

DRS projects selected for the empirical application have achieved more than 80% of the social sustainability except for the Kalugala project. Wasanthagara community was highly capable of restoring their economic requirements (83.3%). Both donor-driven projects achieved 99% of adopting into their infrastructure system, as these percentages showing that donor-driven RS projects for affected communities have recorded the highest gratification in terms of Social and Economic sustainability.

Kalugala, which is a mixed project of SL government and UN Habitat (also including both affected and high-risked communities) has recorded the lowest level of 38.1% which was significantly incapable of achieving the community’s social well-being at the end. As it recorded comparatively lower stages from all three attributes, the project needed further inspection to check the drawbacks.
Basically, its community is located far away from their original settlement as they were re-located from Bulathkohupitiya, Ganthuna, Elagipitiya GNs. From the data collected through the field investigations it was observed that more than 90% of the sample was unable to restore their livelihoods or either to recultivate their crops since their location is far away from their plantations, working places and the soil is not supporting for any crops to earn economic wealth as well. Since the most crucial downsides could be identified through these studies it would be more appropriate if the authorities can make arrangements in implementation where these issues being addressed. Simply, this research is focused on the recent DRS practice done, as these learnings might be useful to justify the essential requirements which are to be adjusted in the forthcoming human settlement planning process.

4. Conclusion and Recommendations

After the application, prevailing DRS practice of Sri Lanka was evaluated in two pathways. As all five projects recorded direct BCR values more than 1, it was considered as net-benefitted programme which are compromising more benefits to the society than its costs. Yet, the actual conditions of the projects seemed more pessimistic, indirect indicators were evaluated in-depth as the final results were obtained more generously. As they all were highly benefitted programmes to the community, they also achieved an acceptable level of restoring their ‘Social well-being’ measurements (more than 87%). But considering the recorded levels in their ability in ‘Economic Restoration’ recording is only 52% which has directly impacted to reduce the overall socio-economic sustainability of prevailing DRS practice in to 69.1% level.

This was due to certain reasons as discussed at the industrial experts’ surveys, the locational ineffectiveness (S.Sc. Rathnasiri, 2018), difficulties in livelihood restoration (Director (HSPTD/NBRO). Sugathapala, 2018) and behaviours of the community (Sc. Jayathilake, 2018) towards the DRS practice.

By following a scientific procedure on each crucial planning stages (Sc. Vijekumara, 2018) and introducing a livelihood development strategy from the implementation policy itself these drawbacks would eventually disappear.

There was a gap in evaluating the current DRS practice in Sri Lanka, hence this study provides a general methodology to the industry to evaluate current DRS practice, concerning all the possible social and economic indicators.

From the results and conclusions discussed it is very clear that almost every resettled family has a major issue on restoring their livelihoods. Although DRS practices conducted to achieve disaster resilience with the concept of ‘Build Back Better’ the vulnerable community and projects would no longer be sustainable if the government neglect their attention on it.

Therefore, it is recommended as outcome of this research to include appropriate planning strategies for restoring livelihoods of a resettled community in the implementation policies when it is difficult to locate a new settlement near to their original settlement. This can be highly beneficial on long-term socio-economic sustainability of the project and on the success of human settlement planning procedure for vulnerable communities towards the end.
References


Government Intervention for Adequate Housing: 
Comparative Study Between Sri Lanka and South Korea 
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Abstract

Housing is one of the key development sectors as a basic need of people. Thus, the government intervention to fulfil housing requirement by citizens shall be observable in many countries. However, inability to assure adequate housing causes to create several socioeconomic and environment related issues affecting the long-term development, vary from household to national level. Even with this background, implementation of housing programs; under a well-planned framework to provide adequate housing could achieve socioeconomic upliftment of people that shall contribute even for the national economic development as per the case of South Korea. Further, such planned attempt will preserve the natural environment minimising impacts of extreme weather events.

Keywords: adequate housing; long-term development; well-planned framework

1. Introduction

Housing is one of the basic needs of human beings despite the country, religion or any other factor. Without appropriate shelter, people cannot meet their basic needs and participate adequately in society. Therefore, housing is a fundamental component of quality of life that further contributes for the economic development. Housing was not an issue in the ancient society, where land resources were unlimited and economy was mainly based on agricultural activities with small population size. But, with the industrial revolution that were taken place in the latter stage of the 18th century the rate of urbanization is getting increased and the society has transformed to agricultural oriented society to industrial and service-oriented society (Levy 2013). At the same time, urban development has been a prime factor to increase the economic growth of a country perceiving that cities as engines of economic growth; in other hand, this transformation creating competition pressure on land resource and demand for urban services (Banister 2005). In that, housing has become such an important element as a basic need of people and expensive commodity to own by a family.

In this context, government interventions through appropriate policy directives are vital to ensure that every income group of the society get opportunity to own an adequate housing to ensure their wellbeing. However, as far as development of housing
sector in Sri Lanka is concern, it is questionable whether the government led housing programs could contribute in provision of adequate housing for people.

Thus, this paper discusses such vital policy directives taken by South Korea and Sri Lanka to ensure massive housing supply for people to meet their housing need in the context of providing adequate housing that lead for sustainable development. Thereby, conclude areas that have not addressed in Sri Lanka with reference to the case of South Korea, who has reached a rapid economic development within a limited period of time.

2. Method of Study

This study was conducted as a case study review of both Sri Lanka and South Korea on government intervention in supplying housing in massive scale, with especial reference to provision of adequate housing. The review was based on secondary data considering housing programs executed within similar period of time [1980’s and 1990’s] in both countries.

3. Adequate Housing

This section attempts to define what is adequate housing which will be applied to evaluate case studies of government intervention for housing in both South Korea and Sri Lanka.

The topic adequate housing has been discussed in the United Nations Conference on Housing and Sustainable Urban Development; Habitat III, conducted in May 2015, New York (UN Habitat 2015). Thereby, adequate housing has been recognized as part of the right to an adequate standard of living in international instruments including the 1948 Universal Declaration of Human Rights and in the 1966 International Covenant on Economic, Social and Cultural Rights. Accordingly, a particular form of shelter should meet seven number of elements, in order to consider as an “adequate housing” that listed below;

I. Security of tenure: housing is not adequate if its occupants do not have a degree of tenure security which guarantees legal protection against forced evictions, harassment and other threats.

II. Availability of services, materials, facilities and infrastructure: housing is not adequate if its occupants do not have safe drinking water, adequate sanitation, energy for cooking, heating, lighting, food storage or refuse disposal.

III. Affordability: housing is not adequate if its cost threatens or compromises the occupants’ enjoyment of other human rights.

IV. Habitability: housing is not adequate if it does not guarantee physical safety or provide adequate space, as well as protection against the cold, damp, heat, rain, wind, other threats to health and structural hazards.

V. Accessibility: housing is not adequate if the specific needs of disadvantaged and marginalized groups are not taken into account.

VI. Location: housing is not adequate if it is cut off from employment opportunities, health-care services, schools, childcare centres and other social facilities, or if located in polluted or dangerous areas.
VII. Cultural adequacy: housing is not adequate if it does not respect and take into account the expression of cultural identity.

Thus, this paper discusses about policy directives adopted by South Korea and Sri Lanka to supply housing in massive scale and thereby, comparative assessment will be done between approaches adopted by two countries and finally, it will be evaluated whether each country has been able to provide adequate housing.

4. Case of South Korea

It has been a real miracle for the world that South Korea to became a developed country from the bottom after a miserable period they faced due to colonisation by Japanese; during 1910 to 1945 and thereafter, the Korean War taken placed during 1950 to 1953. Currently, Korea is one of the leading countries in the world in terms of socio-economic development which is being driven by advanced technology, industrial development, efficient administration, land and housing development, agricultural development along with environment protection.

Housing was one of the key areas that South Korea had focused to be successes with the high demand created with the rapid economic growth. The policy decision taken was to create new towns in order to meet this huge housing demand. In this, it has planned to supply housing in massive scale with the development of new towns which was the new settlements development in planned manner (KRIHS 2012). Therefore, this paper will discuss mainly about the new towns development policy of South Korea to ensure housing supply in massive scale.

4.1 New Town Development Policy Adopted by South Korea

In order to cope with housing shortage and control the increasing housing price the new town development policy was adopted and first phase of new towns development has been implemented during 1980s and 1990s where second phase has been initiated after the year 2000 (KRIHS 2012). As further elaborated by the KRIHS (2012), the concept of a new town includes policy measures and planned and self-reliant functions. Specially, the Korea’s new town development has been carried out by a policy means of housing supply following the development norms that a new town should be equipped with self-reliance in terms of production, consumption and distribution. Key steps of the process were selections of the land, basic conceptions, development plans, land sale and completion per plan. Most importantly, the new town development has been carried out on the basis of separate laws.

Most importantly, the new town development has been carried out on the basis of separate laws. In this, first phase of the new towns’ development has been carried out under the law on housing promotion act where second phase of new towns development; that the new towns with multiple functions, has been carried out based on separate laws that had been enacted for specific projects such as Sejong City Special Law, Innovative City Development Act... etc. As well as, in the new towns development, it has focused on sustainability of the development rather than providing just housing for people. Therefore, sustainable urban development principles have been adopted in order to enhance the competitiveness of towns and provide high quality life for its citizens with ease access for socio-economic needs including livelihood options. The first phase of new town development that were built as large-scale residential districts
are; Gaepo (1981), Godeok (1981), Mokdong (1983), Sangye (1985) new towns and Dunsan (1988) and Kyeryung (1989). Those new towns were developed in order to move some administrative functions located in Seoul to local areas. Anyhow, in order to control the rapid increase of the housing price in the latter stage of 1980s the government made a decision to build five new cities Pyeongchon, Bundang, Ilsan, Sanbon, and Jungdong in the capital area. These new cities were called “the first-generation new city. The main target was to supply 2.0 million new houses within 7 years period of time; 1989-1996. The total development area of those five new cities was 50.1 km², and about 292,000 residential units for 1.17 million people have been accommodated. Under the second-generation new city’s development program, the government suggested 11 second generation new cities around the capital area and 2 cities in local areas. The total development area of those 13 cities is 164 km², and about 712,000 residential units have been planned to provide within the areas.

4.2 Key Achievements and Critics of the New Town Development Approach

This section discusses about the key achievements of the new town development approach adopted by South Korea to supply housing in massive scale.

According to KRIHS (2012), the first-generation new towns contributed to stabilizing the prices of real estate around the capital area by supplying a large number of residential units in 1990s. One of the significant features in the first phase of new towns development was the 67.5% of the total residential units had provided to low income families that did not have their own homes in the first generation of new town development. As well as, these new towns have supplied relatively more urban infrastructures and public facilities than traditional cities in Korea. Specially, transport service to access Seoul and provided more urban parks, roads, parking lots than other existing cities was important. The second-generation new towns in Korea had created a pleasant living environment through low-density development than first generation new towns. Specially, energy-efficient planning techniques through efficiency of urban spatial structure such as compact city and Transit Oriented Development (TOD) have been applied along with green network, ecology parks and adoption of waterways...etc.

Further, under the new town development program, it has been able to increase the supply of rental houses for low- and middle-income people in order to satisfy their housing requirements. Accordingly, rental housing supply rate has been increased up to 8.1 percent in 2011 where it was 1.2 percent in 1985. Most importantly, one of the key obvious achievements of the new town development approach is its overall contribution to the national economy of Korea as comprehensive planning approach had been followed in the implementation, rather than just providing a house for people.

5. Case of Sri Lanka

Likewise Korea, Sri Lanka also colonised by few colonial governments. But Sri Lanka was ruled by colonial governments for more than 400 years since 1505 to 1948. Similar to Korea, Sri Lanka also faced a war. But it was a civil war which was took placed for 30 years. Anyhow, Sri Lankan governments have been focused their attention to fulfil basic needs of people and housing was one of such aspects.
Housing policies of Sri Lanka can be divided into two major segments; urban housing policies and rural housing policies. Further, urban housing policies can be divided into three stages; prior to independence from British rule (before 1948), after political independence and during the civil war (1948-2008) and the contemporary situation after end of 30 years civil war (Samaratunga and Hare 2013). This paper discusses about policies adopted by the government in post-independence and during the period of civil war (1948 – 2008), as there is a considerable time period for study the intervention of Sri Lanka government for housing. Further, it focused on policies adopted to ensure housing supply in massive scale.

There had been several policy interventions for housing in Sri Lanka right after the independence in 1948; such as, enactment of housing loan act and establishment of housing loan board in 1949, establishment of Department of National Housing in 1953, establishment of national housing fund in 1954 and Aided SelfHelp Housing program introduced in 1972 to assist middle class income group...etc. The aided self-help housing program had been a quite attractive scheme at that time where government had born the cost of the land, building materials and certain necessary services required for a low-cost house while the buyer provided the labour. An interest free 20 to 25-year loan covered the cost of building materials, while a normal ground rent was charged for the land. But, foundation for government intervention to supply housing in massive scale was laid in 1978 with the establishment of Urban Development Authority (UDA) and National Housing Development Authority (NHDA) in 1978 and 1979 respectively. The key objectives of this program were to eliminate slum and shanty dwelling and provide standard houses for low- and middle-income class people. Thereafter, three major programs were implemented by the government; first, hundred thousand houses program during 1978-1983, second, the one million houses program during 1984-1989 and third, the 1.5 million houses program during 1989-1994 (Samaratunga and Hare 2013).

Although, there were several programs implemented to supply houses in Sri Lanka after 1994, this paper will only have considered above mentioned three programs as largest programs that have been implemented in Sri Lanka to supply houses in massive scale.

5.1 The Hundred Thousand Houses Program (1977–1983)

The first program was the hundred thousand houses program that had been implemented during 1978 to 1983 under the lead role of newly established NHDA by constructing 50,000 houses in rural areas through aided self-help method, another 30,000 houses in urban areas through direct private constructions and remaining houses had been constructed by the UDA as slums and shanty upgrading program in Colombo which is the capital city of the country. The main funding mechanism for these programs was treasury grants, foreign aid and Housing Lottery income which were run by the Ministry of Housing at that time.

5.2 One Million Houses Program (1984-1989)

The one million housing program had been implemented under the leadership of NHDA from 1984 to 1989. The program was consisted of six sub-programs covering rural and urban areas, the private sector, plantation housing and major resettlement projects. The main feature of the one million housing program was the minimum
intervention and maximum support provided by the government and maximum involvement of the builder families. It had been considered as an important initiative as community centred participatory housing program administrated by local government and supported by national institutions.

5.3 The 1.5 Million Houses Program (1990-1995)

Although, there were several criticisms about the number of houses constructed under the one million houses program and the standard of the houses, government introduced 1.5 million houses program and implemented during 1990 to 1995. But, main key feature of this program was, it attempted to address the housing requirements of all the income groups. The program was implemented under eleven sub programs and aided self-help method and private direct construction methods were adopted.

5.4 Key Achievements and Critics of Three Major Housing Supply Programs in Sri Lanka Implemented During 1977 –1995

It has been significant period for housing development in Sri Lanka as large number of houses had been constructed during the period of 1977 to 1995. Most importantly, through this program, number of owner-occupied housing units had been increased considerably in Sri Lanka. In terms of the tenure type, in 1981, 69.5% of the total housing stock of the country were owned by the occupant where it had been increased up to 83% in 1990 (Ministry of Housing, Construction and Public Utilities 1996).

Despite such achievement of the above mentioned three housing programs, there were several critics and most of them are based on facts and figures, which will be vital to consider in future housing development programs in Sri Lanka. Mainly, those three programs had been criticised due to very poor quality of houses. According to a report published by the Ministry of Housing, Construction and Public Utilities in 1996 revealed that approximately, 50 percent of the total housing stock of the country had been constructed with semi-permanent materials as per the year 1996. Also, another study revealed that according to housing standards, middle income homes should be at least 1000 square feet, 36% of the houses of Sri Lanka is consisted of a small floor area which is less than 527 square feet (National Housing Symposium, Sri Lanka 2011). This situation could be mainly due to following aided self-help method where beneficiary family themselves managed the construction of their house.

Also, another key criticism was that those housing programs were just considered construction of a house per household without considering their livelihood development, socio-economic up liftman or provision of other important social and physical infrastructures and this situation have been negatively impacted on the whole economy of the country.

6. Evaluation

This section evaluates the approaches adopted by both South Korea and Sri Lanka to supply housing in massive scale, with special reference to their intervention to supply “adequate housing” as defined at the United Nations Conference on Housing and Sustainable Urban Development (UN Habitat 2015) based on seven elements:
security of tenure; Availability of services, materials, facilities and infrastructure; Affordability; Habitability; Accessibility; and Location.

**Security of Tenure:** Comparative to the new town development approach of South Korean and three housing programs adopted by Sri Lanka to supply housing in massive scale, the security of tenure is high in Sri Lankan approach. This is mainly due to approach of Sri Lankan government was to supply a house for each homeless family and there were no any profit oriented approach. Further, in case of low and middle income groups; Aided Self-Help Housing methods were adopted by Sri Lankan government where land and materials provided by the government and household themselves needed to construct the house employing labours. Further, they were provided a loan to borne the cost of labour and ownership for the land had been granted by the government.

**Availability of services, materials, facilities and infrastructure:** the new town development approach of Korea to provide houses in massive scale had been implemented under a comprehensive plan considering physical, social, economic and environmental aspects of development; specially focusing on sustainability of the development. Therefore, people have been received different options for their livelihood and social services under well-developed physical infrastructures. But, in Sri Lankan case, the government had only focus to provide a house for a family without considering their socio-economic requirements or sustainability of such settlements in long run.

**Affordability:** the affordability for housing in Sri Lankan case is higher than Korean case due to Sri Lankan approach was to provide low cost housing unit for low and middle class income group. Most importantly, the only cost had to borne by a household was the labour cost that needed to construct the particular house. But, in Korean case affordability had been high as the entire investment for development were supposed to recover from selling houses with a profit margin by private companies. Indeed, the completion of second-generation new town development program of Korea has been delayed in completion and one of the major reasons was the lack of affordability by majority.

**Habitability:** Habitability is certainly high in houses that were constructed under the Korean new town development approach where in Sri Lankan context it has been recorded that around 50 percent of houses are semi-permanent structures and did not consisted of standard floor area for most cases as well.

**Accessibility:** There are several options for transportation had been provided under the Korean approach specially, latest technologies of Korea transportation had been provided in those new towns. But, in Sri Lankan case there had not made any plan to provide quality services and for several cases marginalised lands had been provided for housing which were not even accessible.

**Location:** the new town development program of Korea had been implemented under the concept of self-sustain cities. Therefore, new towns were facilitated with most of the community requirements within the city itself in order to be competitive.
in the market. In Sri Lankan case, although most of the houses were constructed in city limi
t, it was criticized that the people did not get enough access for at least basic services.

7. Conclusion

This paper discussed about government lead policies for massive housing supply with special reference to cases from South Korea and Sri Lanka and two cases were evaluated based on seven elements that are needed to fulfill in supplying adequate houses as discussed in the United Nations Conference on Housing and Sustainable Urban Development (UN Habitat 2015).

As per the discussion and evaluation, the case of South Korea had adopted comprehensive approach considering the long-term sustainability of the investment providing adequate housing under the new town development policy with the involvement of private sector. Specially, the comprehensive and sustainable approach adopted in new town development approach of South Korea have had certain impact on rapid development boosting their economic growth. However, in Sri Lankan case, consideration to provide adequate housing has paid inadequate attention.

References
