A Comparative Study of Wind Standards for Tall Buildings

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ABSTRACT: The design manual "Design building for high winds – Sri Lanka" is the only mandatory document available for wind load design in Sri Lanka. This document extensively covers the design and construction of low rise buildings. However, the evolution of tall building construction requires advances for Sri Lankan wind loading standards, which cannot be prepared yet due to lack of available data and technology. Therefore, designers have used different international standards for wind design for medium and high rise buildings without understanding the impact of many different standards in a particular design fully. Hence, some of these common international wind standards such as CP 3 Chapter V – Part 2:1972, BS 6399.2:1997, AS 1170.2:1989, AS/NZS 1170.2:2002 and EN 1991-1-4:2005 are evaluated in this study by considering loads exerted at ultimate limit state on the structural members such as beam and column members, shells such as shear walls and supports of a building by wind loads to understand the suitability of these codes for Sri Lankan context. The serviceability limit state behavior of a building is also evaluated according to the methods given in wind loading standards. Finally made conclusions have been drawn about the selected wind loading standards, which can be used with Sri Lankan context until country could produce its own wind code.

Key words: Design manual, Wind loading standards, Return period

1 INTRODUCTION

The major building codes and wind loading standards around the world have begun to develop empirical relationships to produce an estimation procedure to evaluate the dynamic wind response (Kijewski and Kareem, 2001). According to the definition provided by Kulousky (1984), wind loading standard is a document, which enables estimating safety and serviceability of a structure with information supplied by meteorology and aerodynamics together with basics of structural theory. Due to the extreme wind conditions together with across-wind and torsional responses, physical modelling of fluid-structure interactions remains the only viable means of obtaining information on wind loads on a structure with a very high degree of accuracy. According to Kijewski and Kareem (2001), a disadvantage to physical modelling is the time, cost and resources required to conduct a wind tunnel analysis. It is also needed to evaluate numbers of different shapes and models to eliminate aerodynamically unfavourable shapes at preliminary design stage and probably incurring higher cost for this stage. Hence, at present, wind codes and standards assist the structural designers by providing a cost effective tool.

2 PRESENT PRACTISES IN SRI LANKA.

Sri Lankan builders did not pay much attention to wind loading on structures until massive cyclone hit Eastern and Northern Eastern coastal areas of Sri Lanka in 1978. This cyclone can be considered as a milestone of wind engineering in Sri Lanka, as it encourage the production of the first mandatory document on wind engineering, the design manual "Design buildings for high wind – Sri Lanka" was published by the Sri Lankan Government in 1980. The design manual was based on the previous code of practise CP 3 Chapter V – Part 2: 1972;this extensively covers the design and construction of low rise buildings (Clarke et al, 1979).

However, in recent times, there has been a national trend to build tall, slender tower type high rise buildings in Sri Lanka especially in Colombo city limit (Karunarathne, 2001). Not Only due to their heights but also light materials used as building materials for both super structure and the inner partition walls and some complex architectural features these buildings may be prone to excessive dynamic motion induced by winds. Neither design manual nor CP 3 Chapter V-Part 2: 1972, adequately address this kind of complex situations. This means that there is a need to go for a wind loading standard, which can cover more complex wind spectrum as well as dynamic effects arising from the wind. Therefore, designers and structural engineers of Sri Lanka have been looking for advance wind loading standards, which are capable to evaluate more complex dynamic behaviours. International wind loading standards such as Australian, British, American, Japanese and Euro codes are being occasionally used by Sri Lankan engineers. However, use of different wind loading standards in a given design may lead to severe problems such as poor understanding about the use of country specify factors in conjunction with Sri Lankan context, some inconveniences about understanding and comparing wind load calculations, lack of harmonization among wind load design of structures, etc. Therefore, it is necessary to have a broad and clear idea about methods and factors given in different wind loading standards before carrying out any wind load design of a building and gain harmonisation by selecting one appropriate wind loading standard, which can be deal with the prevailing conditions in Sri Lanka.

3 SELECTING CODES AND STANDARDS FOR THE STUDY

Due to the incapability of design manual to address the issues of tall building design, many Sri Lankan engineers used different international wind loading standards as their preferred options. These preferred options may vary from some old code of practise like CP 3 Chapter V – Part 2 to newest codes like Euro code. By considering all of current practises that found in Sri Lankan civil engineering sector, following codes and standards were chosen for the comparison purpose. The selected codes and standards are CP 3 Chapter V – Part 2:1972, BS 6399.2:1997, AS 1170.2:1989, AS/NZS 1170.2:2002 and EN 1991-1-4:2005.

CP 3 Chapter V-Part2:1972 uses quasi-static method to calculate wind loads on a building, this quassi static approach more suitable for evaluating wind loads on low rise buildings rather than to evaluate the performance of a high rise building. Many like to continue to this practice because of its simplicity and familiarity the code. BS 6399.2:1997 is the newer version of the British standard and capable to handle both static and dynamic behaviour of a building. Gust Load factor is a more popular method to calculate wind load by considering both fluctuating wind speeds and dynamic behaviour of a structure. AS 1170.2:1989 use Gust factor method and it generally uses 3 second gust velocity as basic wind speed. AS/NZS 1170.2:2002 has changed the some factors and methods used in previous Australian standard and made it as a simple document to use. Apart from these reasons, Australian standards cover wide spectrum of wind, including cyclones and it is used by many island nations such as Fiji, Solomon Island, etc. EN 1991-1-4:2005 is the newest code and not only it compromises many aspects present in other codes such as BS 6399.2:1997, AS/NZS 1170.2:2002 but also it allows to adjust methods and factors which are suitable for own country by means of a national annex.

4 A CASE STUDY FOR COMPARISON

A 183 m high rectangular shaped building was modelled and analysed by using SAP 2000 software, in order to determine dynamic behaviour of tall building and the effect of using various standards to calculate the wind induced behaviour. The plan dimensions of the building are 46 m x 30 m (Figure 1(a)). The building is typical column - beam frame structures with service core of shear walls. Within the service core, all lifts, ducts and toilets are located. The hard zoning lift system was used for the building to simulate a more actual scenario. The diaphragm constraint was used for slabs to move all points of the slabs together. Other than the dead load of the structural members, super imposed and live loads were applied in the model according to the BS6399: Part 1: 1996. Wind loads on the building were calculated for all three wind zones as given in design manual and applied with respect to two orthogonal directions as joint loads at the column - beam junctions on the wind ward and leeward faces separately as shown in Figure 1 (b).

Wind forces were calculated as provisions given in different wind loading standards by encountering different factors and methods. For British and Euro codes, wind loads were calculated according to the division –by –parts rule. Only for wind zone 1, importance factor 1.1 used with special terrain – height multiplier as given in AS 1170.2:1989, but to calculate wind loads according to the AS/NZS 1170.2:2002, only higher terrain – height multiplier for cyclonic region was used

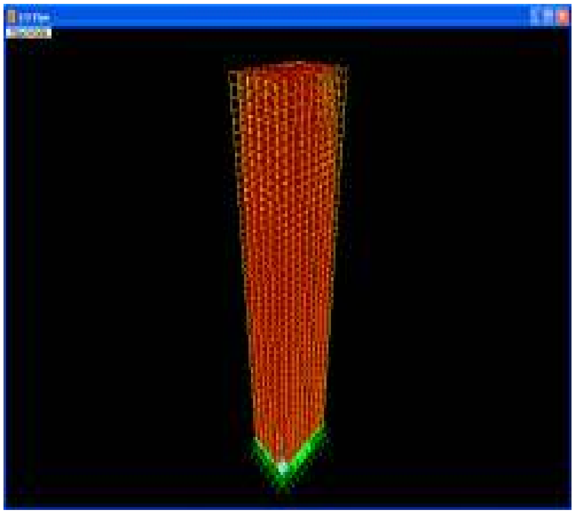

Fig1a Finite element 3 – D models of 183 m height building

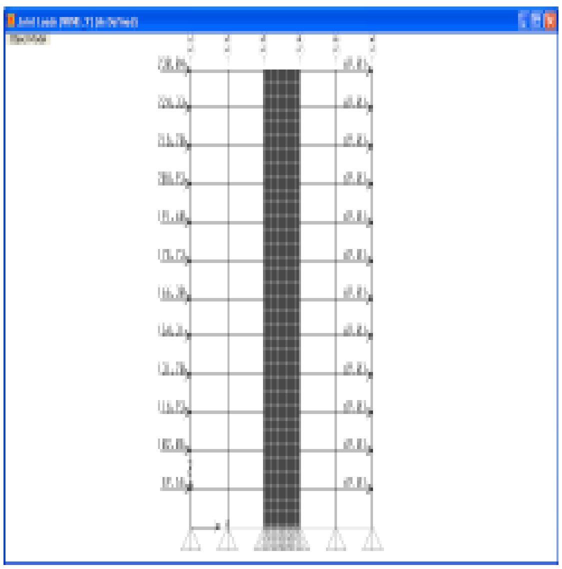

Figure 1bWind loads applied in windward and leeward side of the 183 m high building

5 BASIC WIND SPEEDS VALUES WITH DIFFERENT AVERAGING TIMES

Wind loading standards use different averaging time wind speeds to calculate wind induced loads on structures. When it comes to Sri Lankan context, available wind speed data is only the 3 second gust wind speed. Therefore, 3 second gust wind speed values need to be converted into different averaging times by using some conversion factors. The value of 1.06 was used as conversion factor to convert mean hourly wind speeds to 10 minute mean speed, as proposed by the Institute of Civil Engineers in United Kingdom (ICEUK) and the method propose by Cook (1999) was used to convert 3 second gust wind speeds into mean hourly wind speed. The wind speeds in all three zones with different average times are shown in Table 1.

Table 01Basic wind speeds with different averaging time

	Zone 1 (ms^{-}		Zone 2 (ms^{-}		Zone 3 (ms^{-}	
	Normal structure	Post disaster	Normal structure	Post disaster	Normal structure	Post disaster
CP 3 : Chapter V : Part 2 : 1972 (3 second gust wind speed)	49	54	43	47	33	38
BS 6399 - 2:1997 (Mean hourly wind speed)	27	30	24	26	18	21
BS EN 1991-1-4:2005 (10 minutes mean wind speed)	28	32	25	28	19	22
AS 1170.2 - 1989 (3 second gust wind speed)	49	54	43	47	33	38
AS/NZS 1170.2:2002 (3 second gust wind speed)	49	54	43	47	33	38

6 WIND INDUCED FORCES

Wind loading standards only facilitate to calculate wind pressures at different heights of the building. Multiplying these values by contributory areas will enable the calculation of wind forces at a particular height. However, it is not the actual force experienced by the structural members such as beam, columns etc due to the various behaviours of a structure like load sharing among structural members. These actual member forces are necessary to design structural members against lateral loads such as wind load. Actual member forces can be obtained by using finite element 3-D model by applying forces derived from different standards. For the purpose of comparison, the obtained results are shown as normalised forces. This is the ratio between a force obtained from a particular standard and the same force obtained from CP 3 Chapter V- Part 2:1972, most common practice in Sri Lanka.

The member forces used for comparison in this study are maximum values of axial forces, shear forces and bending moments in columns, shear forces and bending moments in beams, base moment and base shear at the support level and maximum compressive stresses in shear wall.

The member forces are calculated for the following load combinations:

1. 1.2(Dead loads)+1.2(Live load)+1.2(Wind load)
2. 1.0 (Dead loads) + 1.4(Wind load)
3. 1.4 (Dead loads) + 1.4(Wind load) and
4. Wind load only.

Wind induced forces in columns and beams, on 183 m high building for governing load case 1.2G+1.2Q+1.2W in all three zones are shown in Figure 2 (a) and (b) respectively.

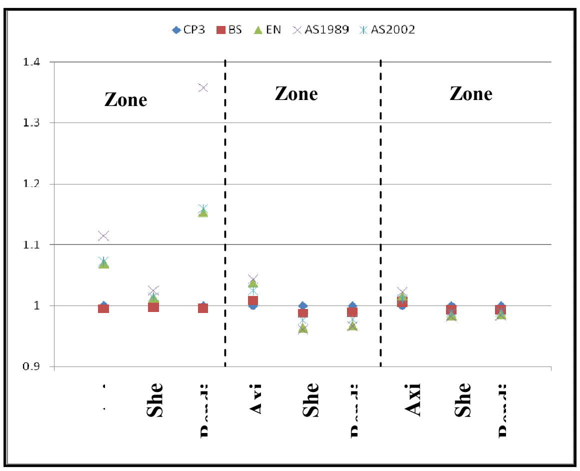

Fig2a Column loads for load combination 1.2G+1.2Q+1.2W (wind flow perpendicular to 46 m long side)

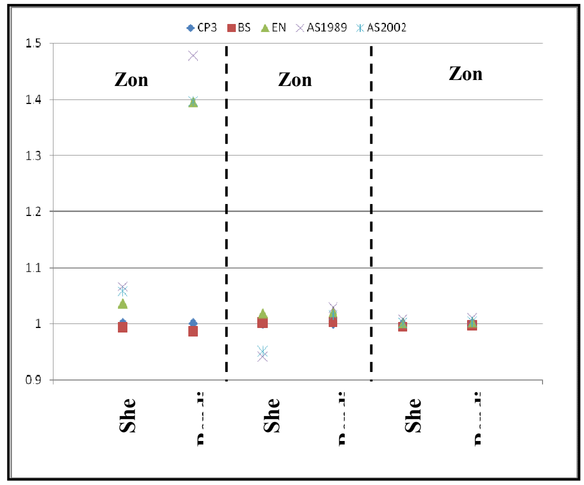

Fig 2b Beam loads for load combination 1.2G+1.2Q+1.2W (wind flow perpendicular to 46 m long side)

The 183 m tall building is more susceptible to wind loading due to its exceptional height. However, the governing load can be observed for load combination 1.2G+1.2Q+1.2W. The variation in the zone 1 is much larger due to higher wind loads derived from Australian standards, especially for AS 1170.2:1989 which uses as importance factor 1.1 in zone 1. Normalised bending moment has maximum variation about 35% in column and about 48% for the beams. However, column maximum axial load variation is in the range of 10%. This value is as high as 17% when wind load is governing as in load combination 1.0G+1.4W. The bending moment value is higher as 50% for the column and more than 55% for beam bending moments for load combination 1.4G+1.4W, higher normalised bending moments can be obtained for column such as value of a 1.8 for wind in both directions in zone 1. However, for the other zones normalised forces are very close to 1. When wind flow perpendicular to 46 m wall, normalised forces for Australian standards are higher as 2.0-2.4 in zone 1. These higher values are getting lesser from zone 2 to zone 3. When wind flow perpendicular to 30m wall, normalised forces in zone 1 are as high as 2.5

7 BASE REACTIONS

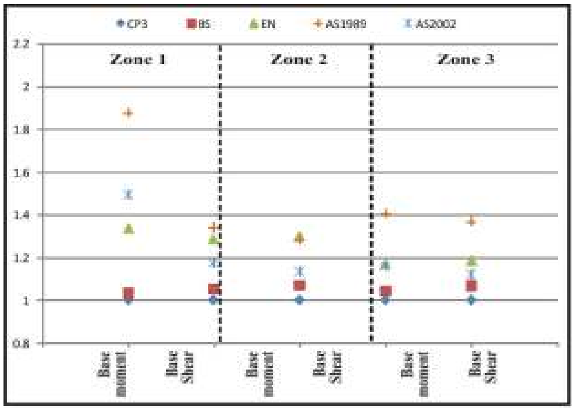

Fig 03a Base moment and base shear of the 183m building, wind flow perpendicular to 46 m wall

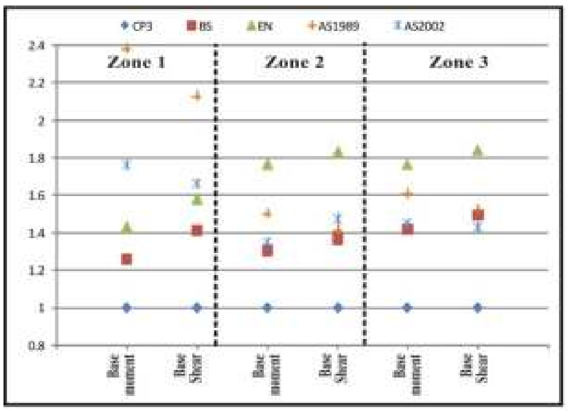

Figure 03b Wind flow perpendicular to 30 m wall

The maximum base moment and base shear can be observed for Australian codes, because of their higher wind speeds resulting from special terrain-height multiplier used in zone1. These values are almost twice the valued derived from CP 3 Chapter V: Part2:1978. However, these codes have a difference in 183 m building due to importance factor used by AS 1170.2:1989. In the zone 2 and zone 3, Euro codes yield higher base moment as well as base shears values. The maximum value 1.6 can be observed in zone 2 for wind flow perpendicular to 30 m side of the building. BS 6399.2:1997 has almost same values for base moment and base shear for 183 m building when wind flow perpendicular to 46 m long side.

8 MAXIMUM SHELL STRESS IN SHEAR WALLS

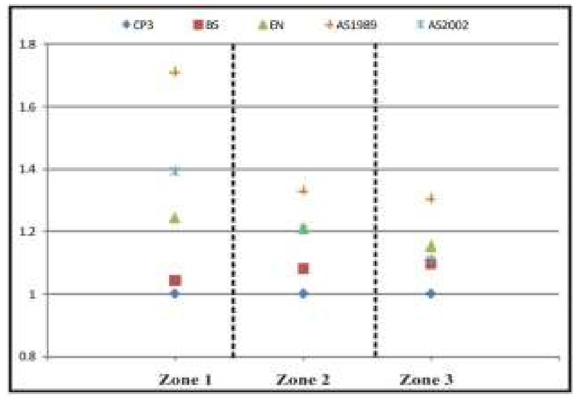

Fig 04a Maximum shell stress in shear wall of the 183m building (a) wind flow perpendicular to 46 m wall

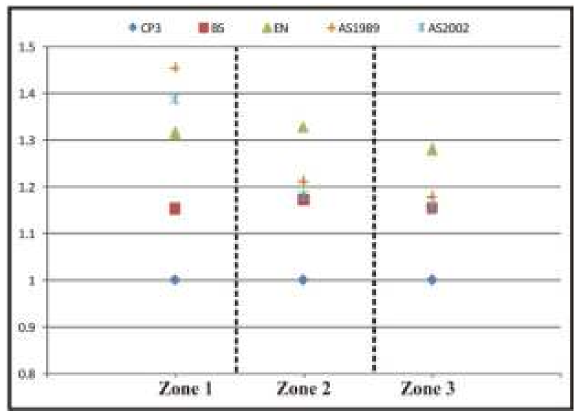

Figure 4b Wind flow perpendicular to 30 m wall

Maximum shell stress can be observed for wind load derived by using AS 1170.2:1989 for the building. The maximum normalized values is 1.7 in 183 m high building. For 183 m high building wind loads derived from Euro code exert maximum shell stress in zone 2 and 3.

9 DRIFT LIMIT

Wind loading standards and design codes limit the allowable wind drift of the buildings in order to prevent damage to the cladding, partition and interior finishes, to reduce effect ofmotion perceptibility and to limit the P–Delta or secondary loading effects (Mendis et al, 2007). Therefore, drift limit is checked for 183 m height building in order to determine the wherther buildings is exceeded the drift index limit or not. The maximum values of deflection in serviceability limit condition were obtained by wind loads applying to the finite element 3-D model for all three zones. According to the BS 8110-Part 2: 1985 the maximum allowable deflection is calculated as hs/500, where hs is the storey height for single storey building. Therefore, maximum allowable deflection value calculated for 183 m height building is 366 mm. The average drift index is defined as a ratio between maximum deflections to total height of the building. The calculated drift index values are shown in Table 2.

Table 02Drift index for 48m and 183 m height buildings in zone 1, 2 and 3

Wind loading standard	Average drift Index		
	Zone 1	Zone 2	Zone 3
CP 3 Chapter V - Part 2:1972	1/961	1/1250	1/1785
BS 6399.2:1997	1/935	1/1219	1/1754
AS 1170.2:1989	1/425	1/862	1/1471
AS/NZS 1170.2:2002	1/565	1/1020	1/1562
BS EN 1991-1-4:2005	1/561	1/1010	1/1538

The generally acceptable average drift index limit for the high rise building is 1/500 (Mendis et al., 2001). By reference to Table 2, only the building model with wind loads derived from AS 1170.2:1989 in zone 1 exceeds the generally accepted drift limit because of it uses both importance factor and the cyclonic terrain-height factor. However, rest of the cases satisfies the drift index requirement. In zone 3, all models have lower drift values, which are approximately half of the threshold value.

10 CONCLUSION

For the governing load case 1.2G + 1.2Q + 1.2W, all wind loading standards gave almost the same wind load except wind loads for the Australian standards in zone 1. Australian Standards gave higher wind loads in zone 1 because of they used higher terrain-height multiplier and an importance factor for cyclonic region, zone 1. The use of higher terrain height multiplier in cylconic region can be justified because of higher risk level are required to design buildings in cyclonic regions. However,the use of importance factor 1.1 may leads to more conservative wind load design and thus it is recommended not to use it with higher terrain height multiplier. Euro code also derived higher wind loads due to higher pressure coefficient values used by the code.

Neither Design manual “Design buildings for high winds in Sri Lanka” nor CP 3 Chapter V:1972 is adequate to addressed wind loads design for tall buildings. By considering facts like available wind speed data, Australian standards are more suitable than other standards. Between two Australlian standards, newer version AS/NZS 1170.2:2002 is much more convience by the mean. ofsimliplicit. Therefore, Australian standard AS/NZS 1170.2:2002 can be used with the Sri Lankan context until Country produce its own wind loading standard. As an interim measure, Sri Lanka can prepare a national annex for Euro code , which has much more flexibility to adjust country specific factors, which facilitates to adopt real condition prevailing in Sri Lanka through an international wind code.

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