Report on recent development of wind code in Sri Lanka

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ABSTRACT

This report outlines some background information for proposed Sri Lankan National Annex to Eurocode 1 on wind actions. The Sri Lankan National Annex on wind actions to Eurocode 1 is mainly based on the British National Annex to Eurocode 1 with inclusion of local wind climatic and characteristics. The basis for calculation of wind velocity and velocity pressure under local wind characteristics of Sri Lanka is briefly discussed.

KEY WORDS: Sri Lankan National Annex to Eurocode 1 (wind actions), Wind velocity, Wind pressure

1.0 INTRODUCTION

Sri Lanka is an island of about twenty one million population situated in the Indian Ocean, at the base of the Indian sub continent, 880 km north of the equator. This pearl shaped island has a maximum length and width of 435 km and 240 km respectively, covering up a land area of 65,525 km^2. It is surrounded by the Bay of Bengal in north direction and by the Indian Ocean on its eastern, western and southern flanks. The Bay of Bengal is one of the places with the severest wind actions on the planet earth. Thus, the country could face highly destructive wind actions during the North Indian cyclone season and the monsoon seasons annually

The only available mandatory document on wind engineering in Sri Lanka is design manual "Design Buildings for High Winds –Sri Lanka"[1], which is primarily based on the CP3:Chapter V-Part 2:1972 [2]. This document only covers the design and construction of low rise buildings with enhanced wind resistant abilities by adequate detailing for the structure. Historically, apart from the design manual, CP3 is the most common practice for evaluating wind loads on building. However, with rapid development in infrastructure and low rise to high rise buildings in city centers in Sri Lanka, design manual and CP3 were not sufficient for the required wind analysis spectrum. Therefore, Sri Lankan engineers trend to use different international wind codes such as BS 6399-:1997 [3], AS 1170-2:1989 [4], AS/NZS1170-2:2002 [5], etc. Some of these codes covers wide spectrum of wind analysis including dynamic response on the structures.

In recent past, after withdrawal of British Standards in 2010, Sri Lanka Standard Institution (SLSI) has decided to implement Eurocode system for Sri Lankan structural analysis and designs with possible National Annexes. Further, most of Sri Lankan National Annexes are guided and based on British National Annexes with inclusion of local characteristics. On this regard, SLSI technical committee on design standard has decided to use Eurocode 1: Part 1-4 as National code for wind load calculations with Sri Lankan National Annex. However, it has been decided to use British National Annex (NA to BSEN 1991-1-4:2005

[6,7]) as mother code to prepare this Sri Lankan National Annex which would be published in future. This paper discusses how British National Annex to Eurocode 1 on wind actions (NA to BSEN 1991-1-4:2005) could be implemented for Sri Lankan wind climatic conditions to calculate the wind velocity and peak velocity pressure.

2.0 BASIC WIND VELOCITY

The local climate in Sri Lanka as an island nation is such that the small scale wind due to thunderstorm produces higher gust speeds than the larger scale wind due to monsoons. Thus, it is appropriate to use 3 sec gust as the basic wind speed in order to capture the extreme event. However, the basic wind speed to be used in Eurocode 1 is 10 minute mean speed. Since the building design using 3 sec gust have so far performed satisfactorily in all island in Sri Lanka, equivalent 10 min. mean speed has been proposed as fundamental value of basic wind speed ($V_{b,zone}$) without altitude factor.

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0}$$

$$v_{b,0} = v_{b,zone} \cdot c_{alt}$$

Where, v_b = basic wind speed, $v_{b,zone}$ = fundamental value of basic wind speed before altitude correction is applied, c_{dir} = directional factor, c_{season} = season factor, c_{alt} = altitude factor

Figure 1 shows the basic wind zone map of the Sri Lanka. Table 1 summarizes the equivalent 10 min mean speed as fundamental value of basic wind speed ($v_{b,zone}$) for 50 years return period. These values have been proposed based in the number of studies using guidelines given in various standards, codes, text books and research studies [8, 9, 10 and 11]. In this table, there is a possibility to consider increasing the value applicable to Zone 3 up to 22 m/s on the basis of concern raised [12].

Figure 1: Wind zones map in Sri Lanka

Table 1: Equivalent 10 min. mean as fundamental basic wind speed

Wind Zone	3 sec gust velocity for 50 years return period (ms^{-1})	$v_{b,zone}$ (ms^{-1}) for 50 years return period
Zone 1	49	28
Zone 2	43	25
Zone 3	33	19 ~22

It is appropriate to use wind speed of 50 years return period for general wind actions since design are carried out using other BSEN equivalent standard with relevant load factors. However, any especial cases can be handled by guidelines provided in NA 2.8 (Eq 4.2 of EN 1991-1-4:2005) multiplying basic wind speed by probability factor (c_{prob}). Probability factor can be calculated based on the shape factor K=0.2 and exponent n=0.5.

It can be recommended to use c_{dir} =1.0 and c_{season} = 1.0 conservatively. It is important to apply altitude correction factor on the basic wind speed since altitude changes in especially at wind zone 3 is considerable. It varies from 0 – 1500 m or more. It is recommended to use altitude correction factor conservatively as follows:

$$c_{alt} = 1 + 0.001A;\ c_{alt} \leq 1.5 \text{ (maximum)}$$

where A is the site altitude in meters above mean sea level. c_{alt} is mainly applicable for wind zone 3 in Sri Lanka. Since the wind zone 3 has fairly high fundamental basic wind speed, it is advisable to limit altitude correction factor to a value of 1.5. Sri Lanka has hilly and undulating ground in the central part. The use of the equation given in UK National Annex to determine the effect of altitude could result in significantly high figures such as 1.8 or 2.0 for c_{alt} in some parts of the country. However, the normal experience is that the varying nature of these undulating ground could shelter the buildings to a certain extend and hence the adoption of full effect of c_{alt} could overestimate the effects. Therefore, it would be desirable to have an upper ceiling for c_{alt}.

3.0 TERRAIN ROUGHNESS CATEGORIES

In the British National Annex to Eurocode 1, the terrain categories has been simplified as terrain category 0 is referred as Sea terrain, terrain categories I and II have been combined together to give a single terrain category referred to as County terrain and terrain categories III and IV have been considered together to give single terrain category referred to as Town terrain. Since Sri Lanka is a small island nation with cities having not too many tall buildings (e.g Colombo is the main city in Sri Lanka, see Figure 2), it is possible to recommend the use of similar terrain categories proposed in NA to BSEN 1991-1-4:2005.

Figure 2: A view of Colombo city area

4.0 MEAN WIND VELOCITY

The mean wind velocity $v_m\ (z)$ at a height z above the terrain is given by

$$v_m(z) = c_r\ (z).\ c_0(z)\ v_b$$

Where, $c_r\ (z)$ = roughness factor and $c_0(z)$ = orography factor

4.1 Terrain roughness factor (c_r (z))

The roughness factor ($c_r\ (z)$) depends on upwind distance to sea and additionally on the distance upwind to the edge of the urban areas for the sites in Town terrain. The Table 2 summarizes the roughness factor calculations for different terrain categories in accordance with guidelines provided in NA to BSEN 1991-1-4:2005. For sites adjacent to sea terrain (sea or in large inland lakes), the distance upwind from the shoreline should be taken as 0.1 km.

Table 2: Guidelines for calculation of roughness factor

Terrain category	$c_r\,(z)$	h_{dis} in accordance with Figure 3 (A.5 of BSEN 1991-1-4:2005)
Sites adjacent to sea terrain	Refer Figure 4 distance upwind from the shoreline should be taken as 0.1 km.	$h_{dis} = 0$
Country	Refer Figure 4	$h_{dis} = 0$
Town	Multiply Figure 4 values by roughness correction factors given in Figure 5	Refer A.5 of BSEN 1991-1-4:2005 to calculate h_{dis}

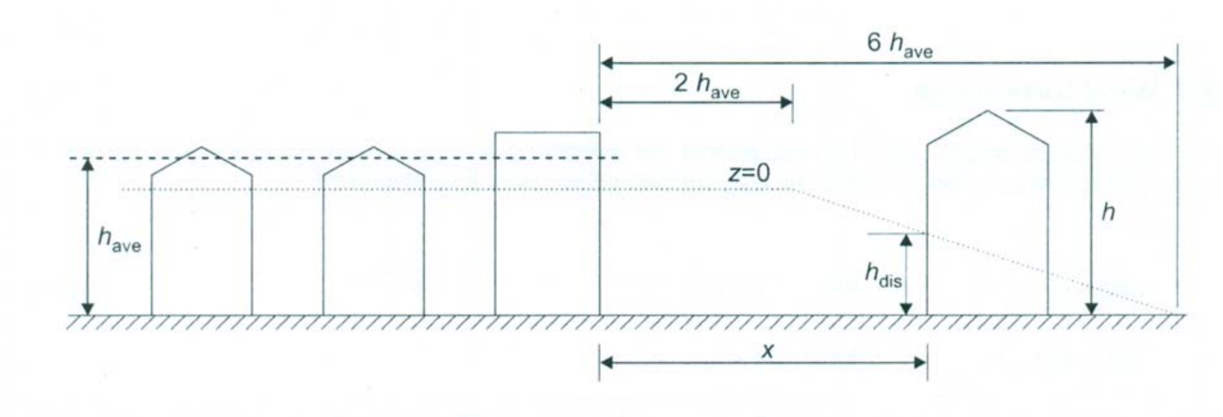
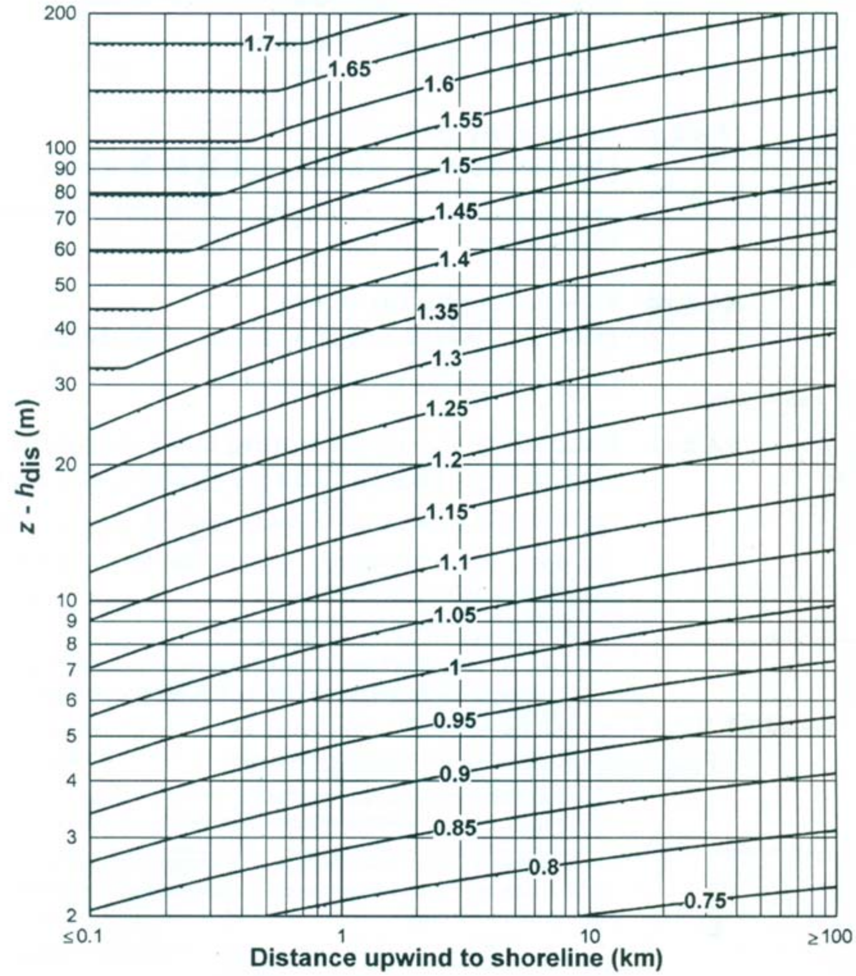
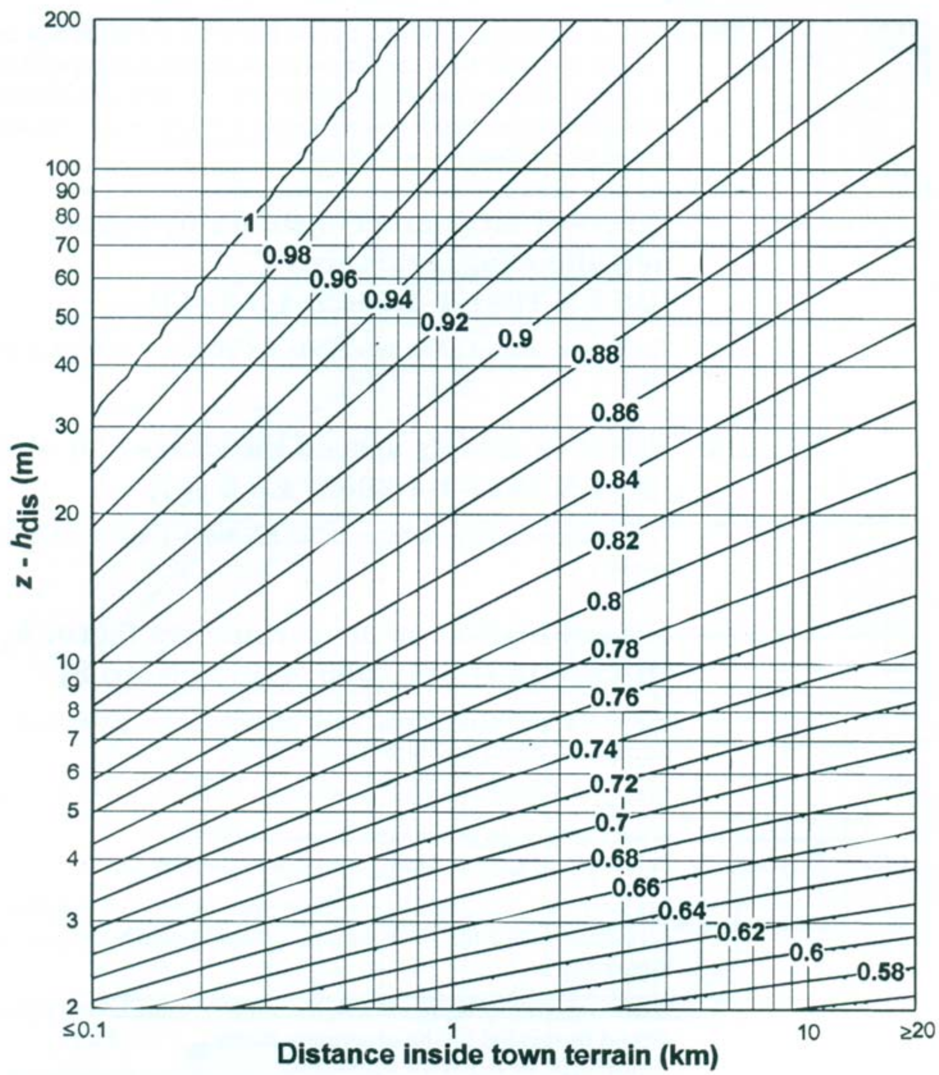


Figure 3: Obstruction height and upwind spacing (Figure A.5 of BSEN 1991-1-4:2005)



The height z is the height at which v_m is sought.

Figure 4: Roughness factors c_r *(z)* (Figure NA.3 of NA to BSEN 1991-1-4:2005)



NOTE The height z is the height at which v_m is sought.

Figure 5: Roughness correction factors $c_{r,T}$ for town terrain (Figure NA.4 of NA to BSEN 1991-1-4:2005)

The recommended value of angular sector can be taken as 30° within ±15° from the wind direction [6]. The procedure described in Table 2 covers terrain roughness assessment of upstream distances of terrain and terrain changes [7].

4.2 Terrain orography ($c_o(z)$)

Orography factor accounts for the increase of mean wind speed over isolated hills and escarpments. The recommended procedure in BSEN 1991-1-4:2005 appendix A.3 can be recommended for the sites that lie in the shaded zones shown in Figure 6. Out side the shaded zone orography factor can be taken as 1.0 but the altitude *A* should be taken as site altitude. The effect of orography can be neglected when the average slope of upwind terrain is less than 3°.

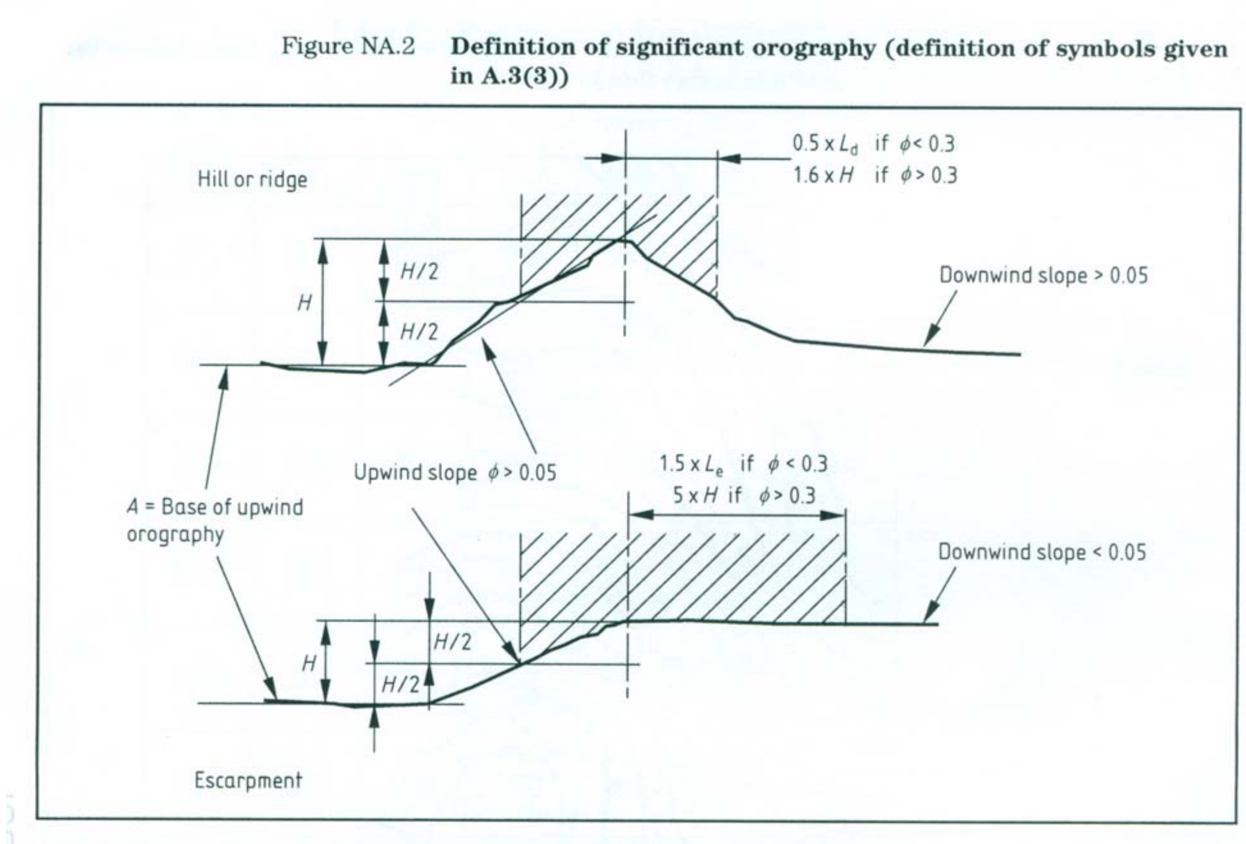


Figure 6: Definition of significant orography (Figure NA.2 of NA to BSEN 1991-1-4:2005)

The effects of closely space buildings and obstacles and considerable taller neighboring structures on the mean wind speed can be calculated based on the procedure recommended in the BSEN 1991-1-4:2005 appendices A.4 and A.5. These effects would be more on town terrain with closely spaced and taller buildings. However, as far as Sri Lanka concern still such effects could be minimal except in some areas in Colombo.

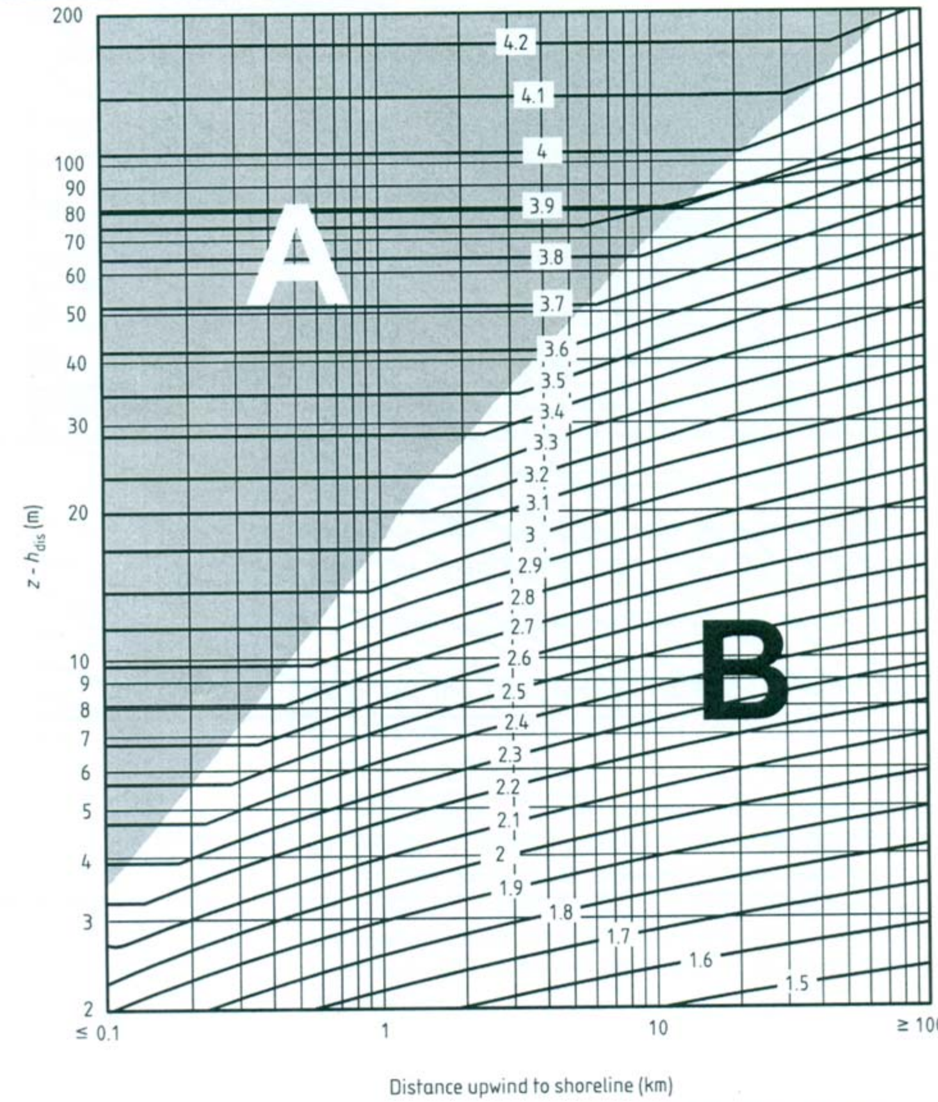
5.0 PEAK VELOCITY PRESSURE

The peak velocity pressure $q_p(z)$ at height z, which includes mean and short term velocity fluctuations can be calculated based on procedure describe in Table 3 as guidelines provided in NA to BSEN 1991-1-4:2005. This type Table can simplify a procedure which appears with some complications in BSEN 1991-1-4:2005 and the National Annex for UK.

Table 3: Summery of peak velocity pressure calculation for different terrain categories

Terrain category	Orogrpahy is not significant ($c_o = 1$)	Orogrpahy is significant	
		z≤ 50 m	z> 50 m
Site adjacent to sea terrain (Distance upwind from the shoreline should be taken as 0.1 km)	$q_p = c_e(z) \, . \, q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7	$q_p = c_e(z) \, . \, ((c_0(z) + 0.6)/1.6)^2 q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7	$q_p = (1 + \left(\frac{3 l_v(z)_{,flat}}{c_0(z)}\right))^2 . 0.613 . v_m^2$ $v_m = c_r(z) \, . \, c_0(z) \, . \, v_b$ Turbulence factor related $I_v(z)_{flat}$ is given in Figure 9
Country	$q_p = c_e(z) \, . \, q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7	$q_p = c_e(z) \, . \, ((c_0(z) + 0.6)/1.6)^2 q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7	$q_p = (1 + \left(\frac{3 l_v(z)_{,flat}}{c_0(z)}\right))^2 . 0.613 . v_m^2$ $v_m = c_r(z) \, . \, c_0(z) \, . \, v_b$ Turbulence factor related $I_v(z)_{flat}$ is given in Figure 9
Town	$q_p = c_e(z) \, . c_{e,T} \, . \, q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7 Exposure correction factor $c_{e,T}$ is given in Figure8	$q_p = c_e(z) \, . \, c_{e,T} \, . ((c_0(z) + 0.6)/1.6)^2 q_b$ $q_b = 0.613 \ v_b^2$ Exposure factor $c_e(z)$ is given in Figure 7 Exposure correction factor $c_{e,T}$ is given in Figure 8	$q_p = (1 + (3 l_v z_{flat} \cdot \frac{k_{I,T}}{c_0(z)}))^2 . 0.613 \, . v_m^2$ $v_m = c_r(z) \, . \, c_0(z) \, . \, v_b$ Turbulence factor related $I_v(z)_{flat}$ is given in Figure 9 Turbulence correction factor related $k_{I,T}$ is given in Figure 10

Figure NA.7 **Values of $c_e(z)$**

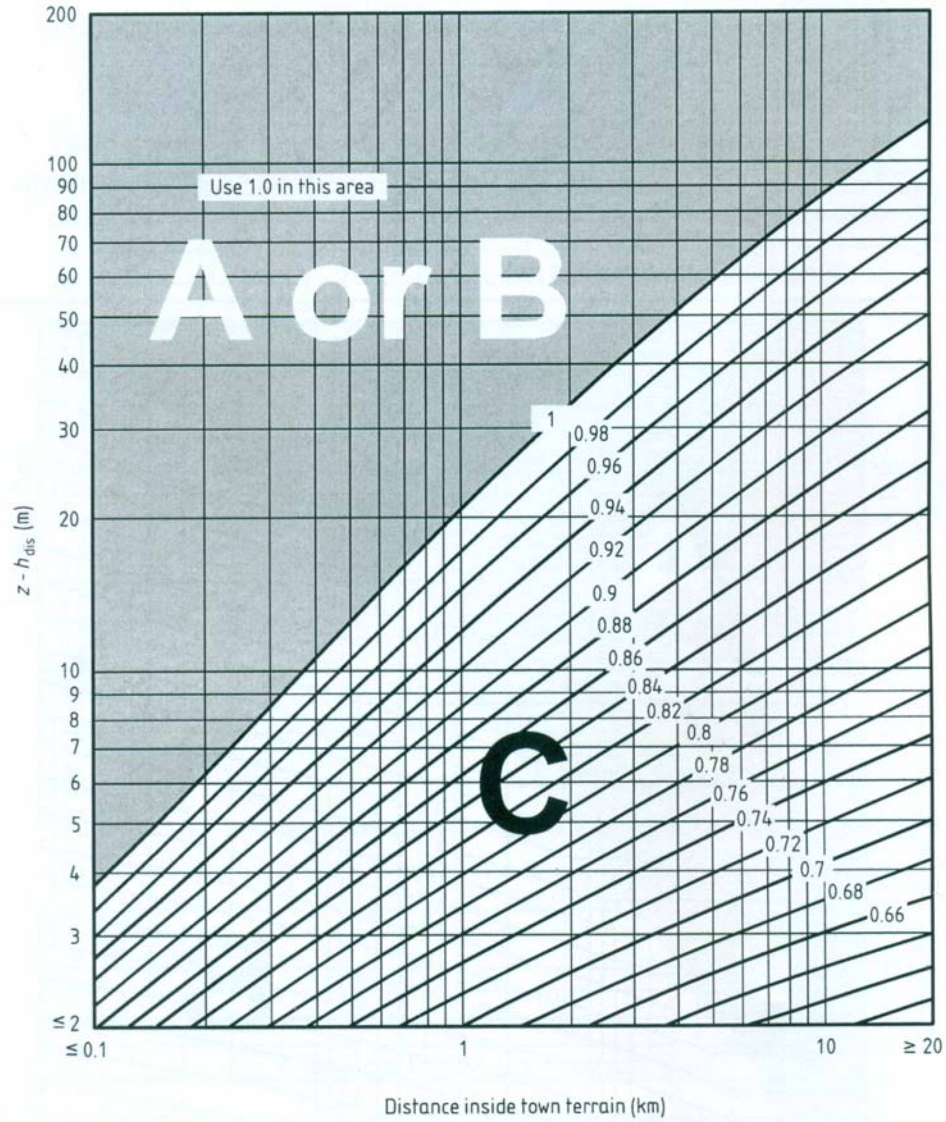


NOTE 1 *The height z is the height at which q_p is sought using Equations NA.3a) or NA.3b).*

NOTE 2 *Zones A and B are indicated for use in Table NA.3.*

Figure 7: Values of exposure factor ($c_e(z)$) (Figure NA.7 of NA to BSEN 1991-1-4:2005)

Figure NA.8 **Values of exposure correction factor $c_{e,T}$ for sites in Town terrain**

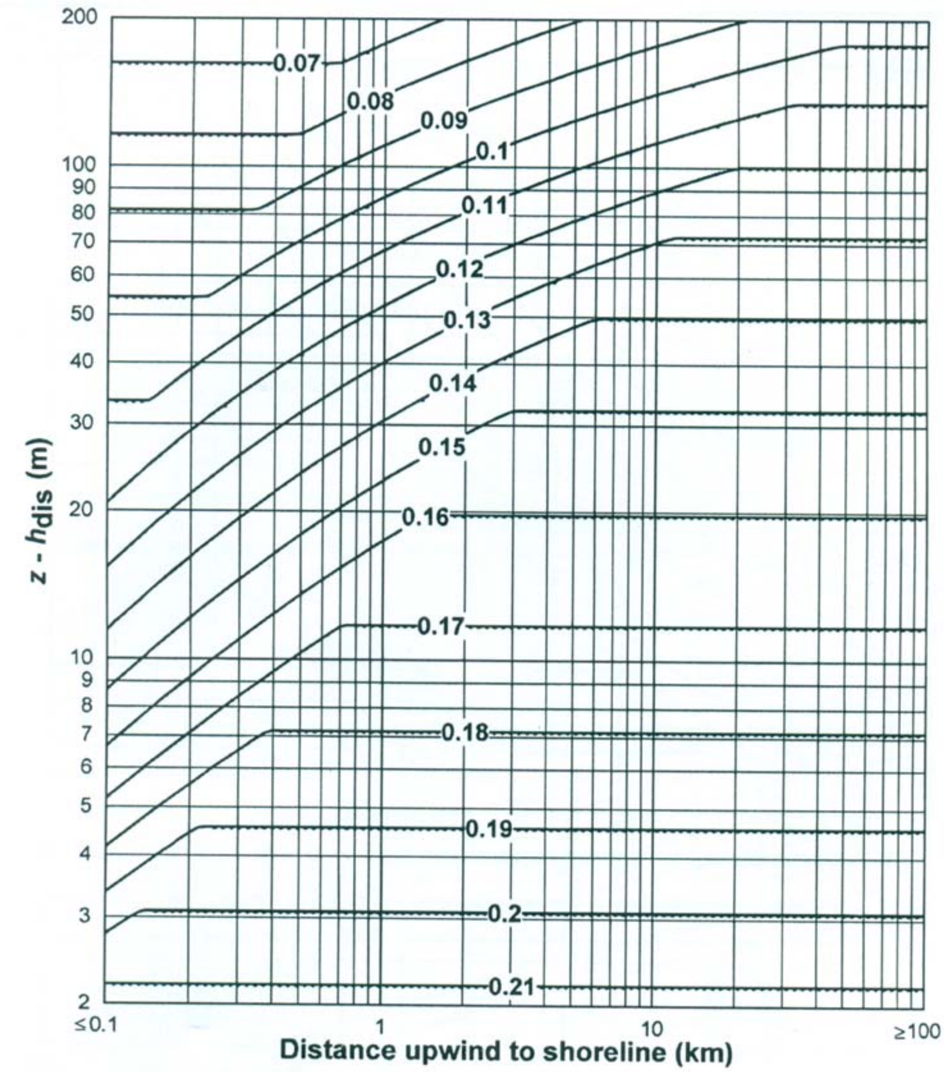


NOTE 1 The height z is the height at which q_p is sought using Equation NA.3a) or NA.3b).

NOTE 2 Zones A, B and C are indicated for use in Table NA.3.

Figure 8: Values of exposure correction factor ($c_{e,T}$) for town terrain (Figure NA.8 of NA to BSEN 1991-1-4:2005)

Figure NA.5 **Values of $I_v(z)_{flat}$**



NOTE The height z is the height at which q_p is sought using Expression NA.4b).

Figure 9: Values of turbulence factor related ($I_v(z)_{flat}$) (Figure NA.5 of NA to BSEN 1991-1-4:2005)

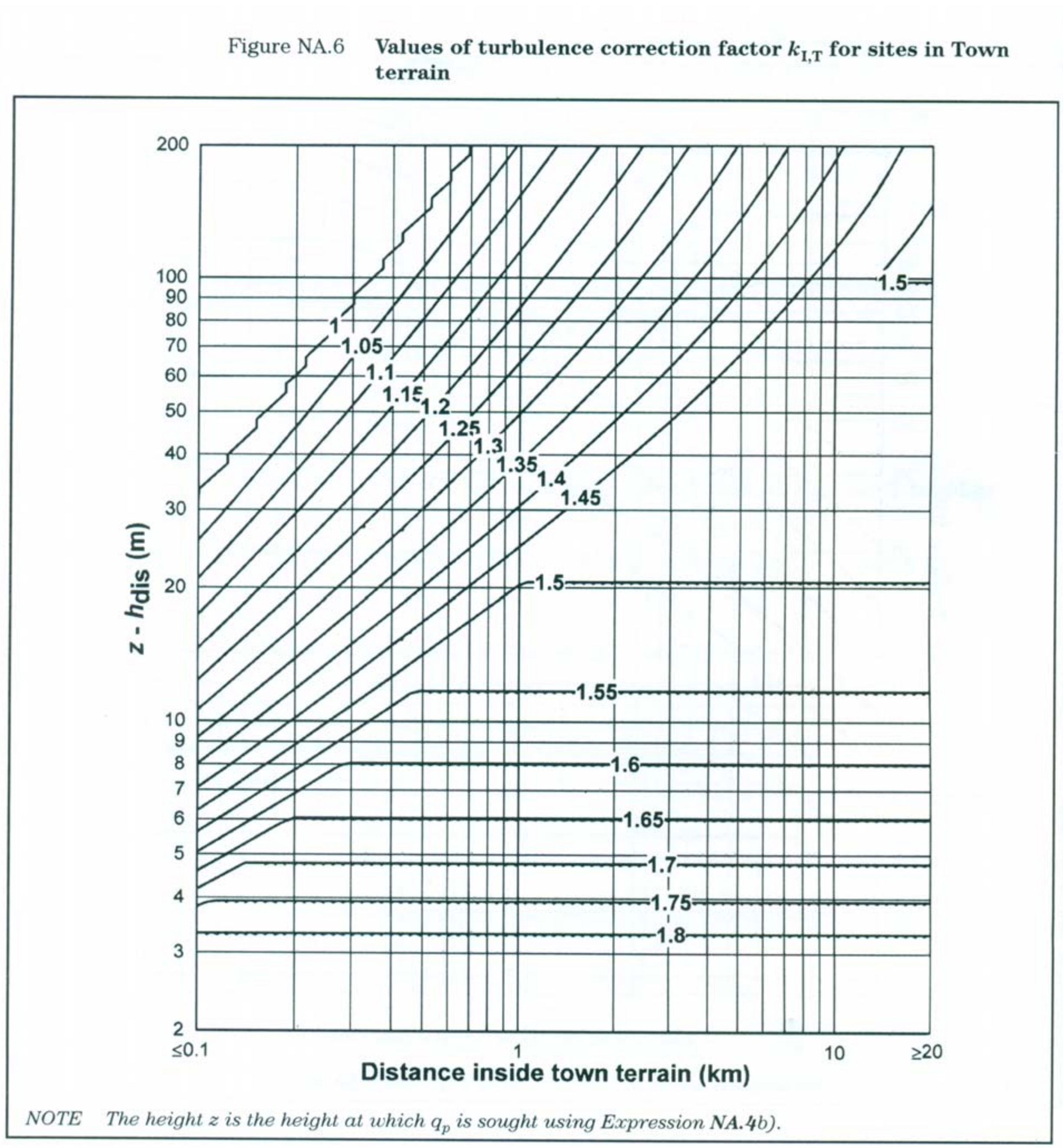


Figure 10: Values of turbulence correction factor $k_{I,T}$ for town terrain (Figure NA.6 of NA to BSEN 1991-1-4:2005)

6.0 CONCLUSIONS

A new Sri Lankan wind code is necessary due to rapid infrastructure development in Sri Lanka. The design engineers have used CP3: Chapter V: Part 2 over three decades. Therefore, adapting to Eurocode would be seen as a challenge. In that context, the presentation of information in tabular form as given in Table 2 and 3 would clearly present the different equations and methods that can be adopted for various situations. Once the peak velocity pressure determined, it would be possible to determine the appropriate forces using either wind external and internal pressure or structural factors. The proposed methods to calculate wind velocity and pressure largely based on the NA to BSEN 1991-1-4:2005.

ACKNOWLEDGEMENT

Authors of this paper thank to Prof. Yukio Tamura, Director, GCOE, Tokyo Polytechnic University, Japan for invitation to APEC-WW 2012 and extending necessary financial support.

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