THESIS

STUDY OF NEW WIND LOADING CODE TO BE ADOPTED IN SRI LANKA

WANNAKU RALALAGE NILANTHI RUPIKA PREMACHANDRA

GRADUATE SCHOOL, KASETSART UNIVERSITY
2008

THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Engineering (Civil Engineering)

DEGREE

Civil Engineering — **FIELD**

Civil Engineering — **DEPARTMENT**

TITLE: Study of New Wind Loading Code to be Adopted in Sri Lanka

NAME: Miss. Wannaku Ralalage Nilanthi Rupika Premachandra

THIS THESIS HAS BEEN ACCEPTED BY

______________________________ **THESIS ADVISOR**

(Associate Professor Trakool Aramraks, Ph.D.)

______________________________ **THESIS CO-ADVISOR**

(Assistant Professor Piya Chotickai, Ph.D.)

______________________________ **THESIS CO-ADVISOR**

(Mr. Barames Vardhanabhuti, Ph.D.)

______________________________ **DEPARTMENT HEAD**

(Associate Professor Korchoke Chantawarangul, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON ______________________________

______________________________ **DEAN**

(Associate Professor Vinai Artkongharn, M.A.)

THESIS

STUDY OF NEW WIND LOADING CODE TO BE ADOPTED IN SRI LANKA

WANNAKU RALALAGE NILANTHI RUPIKA PREMACHANDRA

A Thesis Submitted in Partial Fulfilment of
the Requirements for the Degree of
Master of Engineering (Civil Engineering)
Graduate School, Kasetsart University
2008

Wannaku Ralalage Nilanthi Rupika Premachandra 2008: Study of New Wind Loading Code to be Adopted in Sri Lanka. Master of Engineering (Civil Engineering), Major Field: Civil Engineering, Department of Civil Engineering. Thesis Advisor: Associate Professor Trakool Aramraks, Ph.D. 115 pages.

The aim of this thesis is to study the adoptability of three standard wind loading codes i.e.; BS 6399, AS/NZS and NBCI to replace the existing practice of quasi static pressure method used as wind loading for building design in Sri Lanka. Since available data from Department of Meteorology, Sri Lanka were not reliable enough for basic wind speeds estimation, therefore existing wind zoning and speeds were used as wind data for the analysis. The study specially focused on the effect of along wind action on high rise buildings. The eight square shape building models under wind load specified by each code for three wind zones specified for Sri Lanka were used. Building models were categorized into four groups considering the variation of height and height to width ratio. The building height range from five to forty stories were used for the analysis as the building models and analyzed using wind codes mentioned for three basic wind zones. Shear wall with frame systems were considered for models with twenty five and forty stories. The suitability and applicability of different factors specified by each code were studied and compared. The maximum induced forces and top displacement of all models affected by wind loading from three standard codes were investigated and compared with those by existing code. From the result of this study, it was found that the Australian/New Zealand code AS/NZS 1170 (2002) Structural Design Action Part 2, with few modifications was recommended to be used as the new wind loading code in Sri Lanka.

____________________ ____________________ ___ / ___ / ___

Student’s signature Thesis Advisor’s signature

ACKNOWLEDGEMENT

The author expresses her heartfelt thanks and indebtedness to her advisor Associate Prof. Trakool Aramraks for his expert guidance, valuable suggestions, and constant encouragement. I value the effective and skilful way in which my manuscript was shaped by him. He was always there when I needed help and ready to share his professional expertise.

The author is gratified by the presence of Assistant Prof. Piya Chotickai and Dr. Barames Vardanabhuti as the distinguished thesis committee members, for their valuable critiques and suggestions. My sincere appreciation goes to the all academic and non academic staff in International Graduate Program in Civil Engineering for their valuable and commendable helping hand to us. Deep appreciation is extended to my colleagues and friends especially in International Graduate Program in Civil Engineering for their help in many ways.

I am thankful to Thailand International Development Cooperation Agency (TICA) and Department of Civil Engineering for awarding me a scholarship during my study period to support my study. This admiration is extended to TICA, for funding this research. The author would like to express her gratefulness to staff of Department of Meteorology, Sri Lanka and Technical advisory committee on the development of guidelines for construction building in disaster prone areas in Sri Lanka for their support and guidance in this study. Finally, I would like to dedicate this piece of work to my parents and sisters as they always wanted to see me grow academically.

Wannaku Ralalage Nilanthi Rupika Premachandra
April 2008

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF TABLES (Continued)

Appendix Table **Page**

LIST OF TABLES (Continued)

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF ABBREVIATIONS

a	=	Diagonal length of the building (m)
A	=	The loaded area (m^2)
A_e	=	Effective frontal area (m^2) considered for the structure at height Z
A_z	=	A reference area (m^2), at a height z, upon which the pressure at height (p_z) acts.
A^*	=	Effective frontal area (m^2)
AS/NZS	=	AS/NZS 1170 (2002) Structural Design Action Part 2
b	=	The dimension of the building normal to the wind
B	=	Excitation by background turbulence
B_s	=	Background factor
BS 6399	=	BS 6399 – Part 2
C_a	=	The size effect factor
C_f	=	Force coefficient applied for the structure as a whole
C_{fig}	=	Aerodynamic shape factor –force coefficients
C_{fs}	=	Cross wind force spectrum coefficient generalized for a linear mode shape
C_{dyn}	=	Dynamic response factor
CP3	=	BS CP 3 Chapter V Part 2
C_{pe}	=	The external pressure coefficient
C_{pi}	=	The internal pressure coefficient
C_r	=	Dynamic Augmentation Factor
d	=	The horizontal depth of structure parallel to the wind stream (m), Base dimension of building at plinth level in m along the considered direction of the lateral force.(m)
E	=	Wind exposure coefficient, The measure of the available energy in the stream at the natural frequency of the fluctuating wind

LIST OF ABBREVIATIONS (Continued)

E_t	=	$\pi/4$ times the spectrum of turbulence in the approaching wind stream
F	=	Gust energy ratio
Fxc	=	Column Shear force in global X direction
Fxs	=	Horizontal reaction at support in global X direction
Fyb	=	Beam shear force in Global Y direction
Fyc	=	Column axial force in global Y direction
Fys	=	Vertical reaction at support in global Y direction
g	=	Peak factor
GEF	=	Gust effective factor
GF	=	Gust factor
g_R	=	Peak factor for resonant response (10 min period)
g_t	=	Peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuating load
g_v	=	Peak factor for the upward velocity fluctuation
hr	=	Hour
h_s	=	Story height for single story.
H	=	Average roof height of structure above ground(m)
H_s	=	Height factor for the resonant response
Hz	=	Hertz
I_h	=	turbulence intensity
k_1	=	Probability factor (risk coefficient)
k_2	=	Terrain, height and structure size factor
k_3	=	Topography factor
$\bar{k}_2$	=	Terrain, and height factor / Hourly mean wind speed factor in different terrain for different heights
kg/m^3	=	Kilo gram per meter cube
km/h	=	Kilo meters per hour

LIST OF ABBREVIATIONS (Continued)

kN	=	Kilo Newton
kNm	=	Kilo Newton Meter
K_b	=	Building Type Factor
K_m	=	Mode shape correction factor for crosswind acceleration
l	=	The greater horizontal dimension of the building
M3	=	Model No. 3
M4	=	Model No. 4
M7	=	Model No. 7
M8	=	Model No. 8
mph	=	Miles per hour
m/s	=	Meters per second
$M_{cat,\phi}$	=	Terrain height multiplier
M_d	=	Wind direction multiplier
M_s	=	Shielding multiplier
M_t	=	Topographic multiplier
Mzb	=	Beam moment around global Z direction
Mzc	=	Column Moment around global Z direction
Mzs	=	Moment at support around global Z direction
n_0	=	natural frequency in Hz
N	=	Return period
NBCI	=	National Building code of India(2000) Part 6 section1 Clause 6
N/m^2	=	Newton per square meter
N/mm^2	=	Newton per square millimeter
p	=	Design wind pressure acting normal to a surface, in Pascal (N/m^2)
p_e	=	The external pressure

LIST OF ABBREVIATIONS (Continued)

p_i	=	The internal pressure
P	=	Normalized average pressure intensities
P_{front}	=	Net pressure across the surface for front face (N/m^2)
P_{rear}	=	Net pressure across the surface for rear face(N/m^2)
p_z	=	Design wind pressure (N/m^2) (normal to the surface) at a height z
$\overline{p}_z$	=	Design pressure (N/m^2) at height Z due to mean hourly wind
q_s	=	The dynamic pressure (N/m^2)
r	=	Roughness factor
R	=	Excitation by turbulence resonant with structure.
s	=	Size deduction factor.
s_m	=	Sample standard deviation for monthly basis
sec	=	Seconds
s_y	=	Sample standard deviation for yearly basis
S	=	Height(m) of the level at which action effects are calculated for the structure
S_a	=	Altitude factor
S_c	=	The fetch factor
S_d	=	Directional factor
S_h	=	The topographic increment
S_p	=	Probability factor
S max	=	Absolute maximum principal stress
S_t	=	The turbulent factor
S_1	=	Topography factor
$SD(\bar{V}_{N,m})$	=	Standard deviation of sampling errors

LIST OF ABBREVIATIONS (Continued)

S_2	=	Ground roughness, building height and height above ground level factor taken
S_3	=	The factor based on statistical concepts
T_n	=	fundamental natural period in seconds
u_g	=	Gust load factor
U	=	Mean daily wind speed
V_b	=	Basic wind speed – gust speed (m/s)
$V_{des,\theta}$	=	Building orthogonal wind speeds (m/s)
V_{e}	=	The effective wind speed (m/s)
V_s	=	Design wind speed(m/s)
V_R	=	Regional 3 second gust speed (m/s)
$V_{sit,\beta}$	=	The site wind speed (m/s)
V_*	=	Friction velocity
$\overline{V}_0$	=	Mean basic wind speed
w	=	The lesser horizontal dimension of the building
W_{eq}	=	The equivalent cross wind static wind force per unit height as a function of height (Z) in Newtons per metre
$\overline{X}$	=	Sample mean for yearly basis
$\overline{X}_m$	=	Sample mean for monthly basis
Z	=	Height above ground
Z1	=	Zone 1
Z2	=	Zone 2
Z3	=	Zone 3
Z_0	=	Surface roughness length
$\overline{b}$ & $\overline{\alpha}$	=	Constant depending on terrain type
β	=	Damping factor

LIST OF ABBREVIATIONS (Continued)

$\varepsilon_{a,m}$	=	Action effect derived from the mean along wind response
$\varepsilon_{a,p}$	=	Action effect derived from the peak along wind response
$\varepsilon_{c,p}$	=	Action effect derived from the peak crosswind response
ε_{t}	=	The total combined peak scalar dynamic action effects
ζ	=	Ratio of structural damping to critical damping of the structure
ρ_{air}	=	Density of air, which shall be taken as 1.2 Kg/m^3

STUDY OF NEW WIND LOADING CODE TO BE ADOPTED IN SRI LANKA

INTRODUCTION

Sri Lanka is a small island nation with an area of 65,525square kilo meters and the population is about 20 million. It is situated in the Indian Ocean south of India. The coastal areas are densely populated and industrialized. The Figure 1 shows the location map of Sri Lanka. The country is to the west of the Bay of Bengal. Bay of Bengal is highly vulnerable to wind actions. Every year, the country will face with North Indian cyclone season and monsoon weather season. Most cyclones will enter the country from northeast coast, east or southeast.

Figure 1 Location Map of Sri Lanka
Source: Woelwine-Moen Group (2007).

Wind is a natural phenomenon that affects the buildings and other civil engineering structures. Increasing sophistication in design and construction, make buildings more susceptible to the effects of wind. The importance of wind loading is recognized by the code of practice. Technologically advance countries were in the process of researching and improving their codes. In 1980 Sri Lanka produced its first wind loading manual. The manual “Design of buildings for high winds –Sri Lanka” was based on BS CP3 chapter V part 3 in conformance with local design practice. The CP3 was superseded by BS 6399, but the practice in Sri Lanka has not changed officially. Even though there are no written rules, it is common practice to refer other international codes to determine wind loading on high rise buildings. Sri Lankan Government recognized the problem and now in the process of producing new codes to be adopted. The manual extensively covers the low rise buildings, the structural integrity of a building with regards to walls and roof. It provided guidelines for Anchorage Bracing and Continuity. The simple guidelines were developed for simple low rise buildings which can be adopted even today.

Investigations of numerous cases of building damages due to wind action had shown that, while some failures were undoubtedly due to defects of workmanship, many cases of damages resulted from under estimate of wind forces and that was frequently due to the lack of appreciation by the designers of the significance of gust action. The Deign manual "Design of Buildings for High Winds Sri Lanka" presented the wind map with 3 basic zones. The basic wind speeds for each zone are given in the Table 1 with the zoning map in Figure 4 and the topography of Sri Lanka in Figure 5. The maximum speeds were decided based on the cyclone damaged sustained in November 1978 and earlier. The values based on 3 seconds gust speed.

Table 1 Basic Wind Speeds of Sri Lanka

Zone	Basic wind speed	
	Post disaster structures	Normal structures
1	120 mph (53.5 m/s)	110 mph (49.0 m/s)
2	105 mph (47.0 m/s)	95 mph (42.5 m/s)
3	85 mph (38.0 m/s)	75 mph (33.5 m/s)

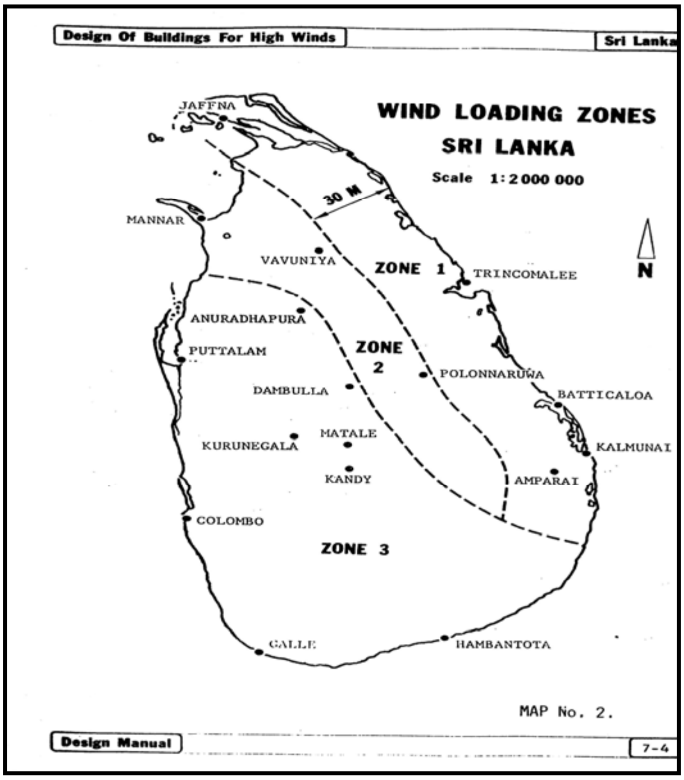


Figure 2 Wind Loading Zones, Sri Lanka

Source: Ministry of Local Government, Housing and Construction, Sri Lanka (1980)

Figure 3 Topography of Sri Lanka

Source: Asia Society (2007)

Normally the reference wind velocity applies for the future and is based on previous data. Estimates of wind speeds are based on measurements taken during a several period of years, but unfortunately such sufficient data were not available at the time of making the manual. In 1978 the anemometer in Baticaloa was blown off at 100 mph before higher wind speeds were experienced. Hence, the map was based on cyclone path and the speeds and zones were estimated on available records, damage sustained and Australian practice.

Statement of Problem

During the past decades buildings and structures become more slender, lighter, taller and larger. The effects of wind forces on modern buildings are more prominent. In most countries, the wind design codes are updated with new advancement of technologies and research. The “Design of Buildings for high winds Sri Lanka” came into effect from July 1980. It was based on the BS CP 3 Chapter V Part 2 (July 1972). CP3 chapter V represents the pressures as “quasi Static”, that is constant pressure acting on the structure. This may be applicable only to low rise buildings. Present codes adopt methods like “gust factor methods” to over come the problem of high rise slender buildings. The Wind design code should address the new challenges faced. The zoning as well as speeds must be checked with recently available wind data and wind damage sustained.

Australian, Indian and British standards are suitable for the comparison. Australian code has been used by many island nations like Fiji, Solomon Island etc. It cover wide spectrum of wind conditions including cyclone. British code is just an improvement for their earlier code, so it may be easy to adopt and follow in Sri Lanka. India which situated west to the bay of Bengal and near proximity to Sri Lanka may be a good alternative.

OBJECTIVES

The objectives of study are as follows,

1. Collection and estimation of wind speeds from available wind data for three wind zones in Sri Lanka.

2. To compare the wind pressures from use of 3 standard codes, i.e.; The Australian/New Zealand code AS/NZS 1170 (2002) Structural Design Action Part 2, BS 6399 – Part2(1997) and National Building code of India(2006) Part 6 section1 Clause 6 with those from CP 3 Chapter V Part 2 (present practice in Sri Lanka).

3. To analyze square shape buildings under wind load specified by each code for three wind zones.

4. To compare the response of buildings under wind loading specified by each code.

5. To recommend the new wind loading code suitable for the structural design.

Scope of Study

Scope of the study are as follows,

1. Consider the wind speed data available at Meteorological Department of Sri Lanka.

2. Consider the direction of wind only normal to the building face under consideration.

3. The number of stories of buildings will be limited between five stories up to forty stories.

4. Consider rigid frame as structural model for buildings with 5 and 15 stories, core shear wall with frame system as structural model for buildings with 25 and 40 stories.

5. Consider typical loading arrangements for all floors.

6. Consider only linearly elastic analysis and service load for analysis.

7. The internal forces used for comparison at support, columns and beams will be shear force, bending moment and reaction only.

8. The internal forces used for comparison of shear wall forces will be base shear and absolute maximum principal stress only.

9 Only square shape buildings are used as structural models so that the torsional forces are neglected.

LITERATURE REVIEW

General

The concept of wind load chain was introduced by Davenport as shown in Figure 4 (Dyrbye and Hansen, 1997). Each link was necessary when wind action and the response to that were to be calculated. This symbolized the total design process. The figure also indicated possible interactions between different phenomena in the chain. Each link deals with random parameters and statistically based methods were recommended.

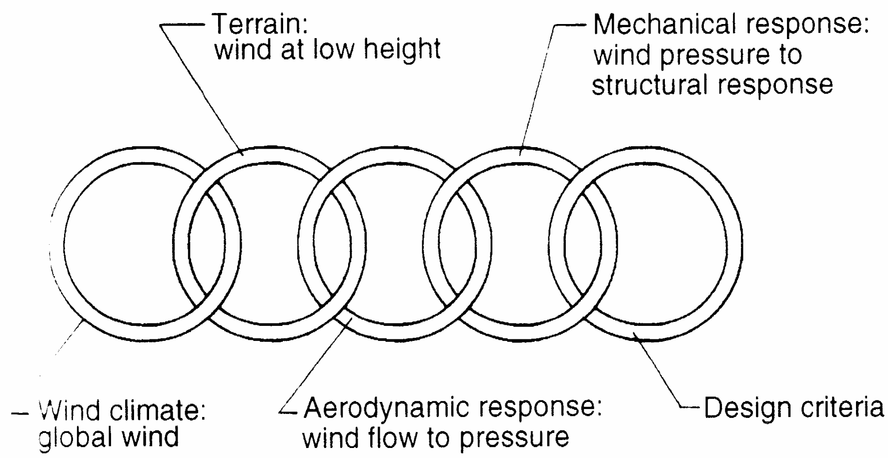


Figure 4 Wind Load Concept Proposed by A.G. Davenport
Source: Dyrbye and Hansen (1997).

Davenport (1967) formulated factors so that it would take proper recognition of the dynamic effects of wind. The procedure proposed was gust loading factor method and most codes used this method for analyzing wind pressures and forces on buildings and structures. The author introduced gust pressure factor which was taken into account of the superimposed dynamic effects of gust. The gust factor (G) was used in conjunction with the mean load and the gust factor was given by $G = 1 + gr\sqrt{B+R}$ where $g =$ peak factor, $r =$ roughness factor, $B =$ excitation by background turbulence and R = excitation by turbulence resonant with structure. R was given by $R = sF/\beta$, where s = size deduction factor, F = gust energy ratio and β = damping factor. Paper provided example that actual measurement on structures recorded indicated the largest dynamic response generally occurred in the lowest mode or modes and the estimation of the amplitudes in lowest modes alone is adequate for most designs.

Vellozzi and Cohen (1968) proposed gust response factor, a measure of the effective dynamic load produced by gusts, and translate the dynamic response phenomena produced by gust loading into simpler static design criteria. Calculation considered a power spectrum analysis of the dynamic structural response of a linear single degree of freedom system with viscous damping, and used reported measurement of gust spectra and gust measurements. The analyses were presented in the form of simple charts and tables.

Solari (1987) studied the analytical models most in use at that time for the description of the structure with turbulence in the surface atmospheric boundary layer. The study gave maximum prominence to the degree of uncertainty involve in these models, and proposed two straightforward expressions of the power spectrum and of the coherence function.

Simiu and Scanlan (1996) studied and calculated methods for estimating the extreme speeds at locations with sufficient data available and same locations with shorter time duration (3 years). 67 sets of records taken from 36 stations were used and it was seen that the estimated speeds are slightly lower than those obtained from longer period. These noteworthy results, confirmed by additional reports, indicated that estimates based on largest monthly speeds recorded over three years or more provide a useful description of the extreme wind speeds in a well behaved wind climate.

Sesma, Aguirre and Sen (1998) proposed a new and simple modelling procedure for the estimation of maximum wind speed due to tropical cyclones.

Method used a fluid dynamic model; the history of cyclonic winds was first reconstructed for places of interest on the coast from information of the cyclone paths and intensities. Then using probabilistic distributions, type 1 extreme, type 3 extreme and Weibull distribution, the extreme wind speeds for required return period was estimated. The results from this method were found to be similar to those obtained by more elaborate methods.

Wegggel (1999) presented an analysis procedure relating maximum daily wind gust speed to mean daily wind speed. A gust factor, G, was proposed, defined as $(u_g / U) - 1$, where u_g = gust load factor and U = mean daily wind speed. A relationship between G and U had the form $G = AU^n$, and data were log normally distributed about the G and U regression line. Six stations data were analyzed and found to fit the proposed model.

Zhou and Kareem (2002) reviewed definitions of wind profiles of major codes and standards, a notable inconsistency was observed. In order to eliminate this discrepancy, a modified definition of the turbulent intensity profile was proposed. The proposed turbulence intensity profile resulted in a consistent relationship between the mean wind speeds, turbulence intensity, and gust speed profiles without altering current description of the mean and gust speeds.

Zhou, Kijewski and Kareem, (2002) compared the wind loading effect on a building of a height of 200m with 33m length and breath using ASCE 7-98 (United State), ASI 1170.2-89 (Australia), NBC-1995 (Canada), RLB-AIJ-1993 (Japan) and Eurocode-1995 (Europe). They concluded that even though their common use of “Gust Loading Factor” (GLF) approach sizeable scatter exists among the wind effect predicted by the various codes and standards under similar flow conditions. The comparison considered the definition of wind characteristic, mean wind loads, GLF, equivalent static wind loads, and attendant wind load effects.

Mendis *at el.*, (2007**)** provided an outline of advanced level of wind design, in the context of the Australian Wind code (2002). Paper discussed key issues like dynamic response with regard to effect of resonance, acceleration, damping and structural stiffness. It illustrated the exceptional benefits the procedure posses over simplified approaches. It suggested that main advantages of quasi static/peak gust format were the simplicity, continuity with previous practice, little adjustments to the pressure coefficient and direct usage of existing meteorological data on wind gust**.** But the disadvantages were its unsuitability to very large structures and natural variability of the peak gust tend to be incorporated into the wind loads estimate. The philosophy used in Australian code to overcome this was to adjustments of quasi-steady pressures using factors like area reduction factors and local pressure factors.

Theory

1. Reference wind speeds

Most codes use the term as basic wind speed or mean wind speed. Major codes and standards, express reference speed in terms of 1 hour, 10 min. or 3 second averaging times. The wind speeds depend upon the averaging times. As the length of averaging time increases the speed corresponding to that length decreases. Normally the reference wind speed taken at a height of 10 m level that could occur if the roughness of the terrain was uniform every where and equal to typical open country. The Averaging times depend on meteorological data base of that country. These data has to be processed for the required return period.

Durst proposed a relationship of maximum speed average over a short period of time to an hourly mean wind speed and the relationship is shown in Figure 5 (Simiu and Scanlan, 1996). The codes of practices provide their own methodology to convert the gust speed to hourly speeds.

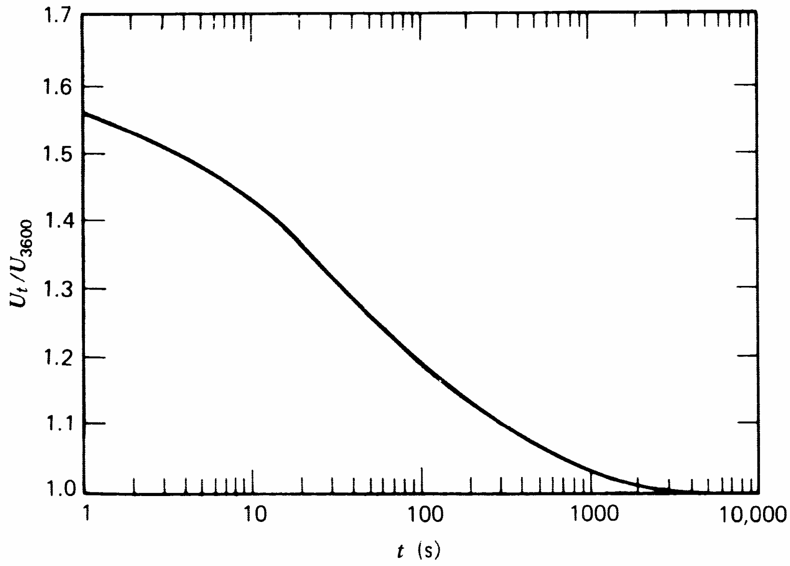


Figure 5 Mean Wind Speed Dependence on Speed on Averaging Time t
Source: Simiu and Scanlan (1996)

2. Wind profile

The mean wind speed as a function of height above the ground can be computed by the logarithmic profile (Dyrbye and Hansen,1997**)**. Only surface roughness is taken into account. This method has a sound theoretical basis.

$$V(z) = V_* \frac{1}{k} \ln \frac{Z}{Z_0} \tag{1}$$

Where k is won karman constant and is approximately equal to 0.4

V_* = Friction velocity

Z_0 = Surface roughness length given in Table 2

Z = Height above the ground

Table 2 Roughness Lengths Z_0 for Different Terrain Categories

Roughness lengths Z_0	Terrain type
10^{-5}	Plane ice
10^{-4}	Open sea without waves
10^{-3}	Costal areas , onshore wind
0.01	Open land with little vegetation and few houses
0.05	Agricultural areas with few houses and wind breaks
0.3	Villages and agricultural areas with lot of wind breaks
1-10	Urban areas

Source: Dyrbye and Hansen (1997)

An alternative and more popular description is given by a power law.

$$\overline{V}(z) = \overline{V}_0 E(z) = \overline{V}_0 \overline{b} (Z/10)^{\overline{\alpha}} \quad (2)$$

Where $\overline{V}_0$ = Mean basic wind speed,

E = Wind exposure coefficient

$\overline{b}$ & $\overline{\alpha}$ = Constant depending on terrain type

CP3 and NBCI used the power low descriptions for their wind profiles. AS/ NZS and BS6399 used Logarithmic profile.

4. Extreme wind speeds

This provides a prediction of wind condition at a location. The extreme value theory can be used to predict the maximum wind speed for an N years return period. The accuracy of results from wind analysis mainly depends on the reliability of the collected data (Simiu and Scanlan, 1996).

Gumbel distribution (type 1 distribution) gives the extreme maximum wind speed in well behaved climates and can be represented as a function as follows. The sample is yearly maximum wind speeds.

$$\overline{V}_N = \overline{X} + 0.78(\ln N - 0.577)s \tag{3}$$

Where $\overline{X}$ = Sample mean for yearly basis

s_y = Sample standard deviation for yearly basis

N = Return period

For a location where no sufficient maximum yearly wind speed data is available, the following expression can be used with the sample as maximum monthly wind speed for about 3 years period.

$$\overline{V}_{N,m} = \overline{X}_m + 0.78(\ln 12N - 0.577)s_m \tag{4}$$

Where $\overline{X}_m$ = Sample mean for monthly basis

s_m = Sample standard deviation for monthly basis

N = Return period

5. Wind induced forces on structures

Along wind forces

Defined as drag forces, which act in the direction of the mean flow.

Cross wind forces

Defined as lift forces, which act perpendicular to the mean flow.

Torsional Forces

If the distance between the elastic centre of the structure and the aerodynamic center (the point of application of the aerodynamic force) is large, the structure will subjected to torsional moments.

A schematic diagram of forces acting on a building due to wind loads are shown in Figure 6 below.

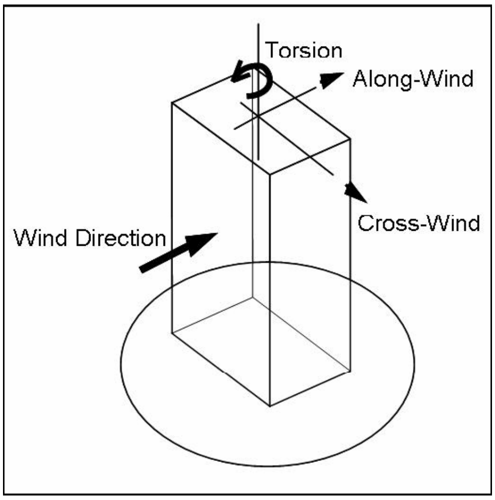


Figure 6 Wind Induced Forces on Structures
Source: Mendis *at el.*, (2007**)**

Design wind pressures, force coefficients and forces act on buildings –based on code of practices

1. BS CP 3 Chapter V Part 2(July 1972) – the present Practice in Sri Lanka

CP3 chapter V part 2 defines it as the dynamic pressure (N/m^2) and is given by:

$$q = kV_s^2 \tag{5}$$

Where “k” is a constant (kg/m^3) which depends on air density at sea level, atmospheric temperature and standard atmospheric pressure. The values given in the Table 3 below are for the Sri Lankan Conditions (Given in design manual for Sri Lanka). In CP3 a single value of 0.613 is used. It is quite unclear how the air density and other factors changes with 3 zones for a very small area. The value given in CP3 is used for the calculations. Code use 3 second gust speeds.

Table 3 Values of “k” for Sri Lanka

Wind zone	Constant k(kg/m^3) (for metric units, using N/m^2 and m/sec)
1	0.56
2	0.57
3	0.59

V_s = Design wind speed (m/s) and can be calculated from the below equation:

$$V_s = V_b S_1 S_2 S_3 \tag{6}$$

Where V_b = Basic wind speed – gust speed (m/s)

S_1 = Topography factor- normally taken as 1 or refer Table of code

S_2 = Ground roughness, building height and height above ground level factor taken from Table of code.

S_3 = The factor based on statistical concepts and normally taken as 1 for permanent buildings

The applied force F on an enclosed building is given by following equation:

$$F = C_f q A^* \tag{7}$$

Where q = Design wind pressure (N/m^2)

C_f = Force coefficient applied for the structure as a whole

A^* = Effective frontal area (m^2)

The procedures used by existing British. Indian and Australian codes are given below. These codes consider the dynamic effects of wind on buildings.

2. BS 6399 - Part2 (1997)

BS 6399 - Part 2 (1997) provides two methods for calculation of wind pressures. The code provides a guideline for choosing the structure to be analyzed using the procedures given by the code. This depends on the dynamic classification of the building. Dynamic classification of the building is depends on the dynamic augmentation factor which depend on the building type factor K_b and the height. The building type factor is given in Table 4.The buildings falling outside these limits shown in Figure 7 should be assessed by using established dynamic methods.

For all the structures where the wind loading can be represented by equivalent static load, wind loads can be determine either by the standard method from section 2 of code or directional method of section 3 of code. It suggested that the standard method will be about 14% higher in the case of low heights and almost 0% at about height of 100 m. Code use hourly mean wind speed.

Table 4- Building Type Factor K_b

Type of building	K_b
Welded steel unclad frames	8
Bolted steel and reinforced concrete unclad frames	4
Portal sheds and similar light structures with few internal walls	2
Framed buildings with structural walls around lifts and stair	1
Framed building with structural walls at lifts & stairs with additional masonry subdivision walls	0.5

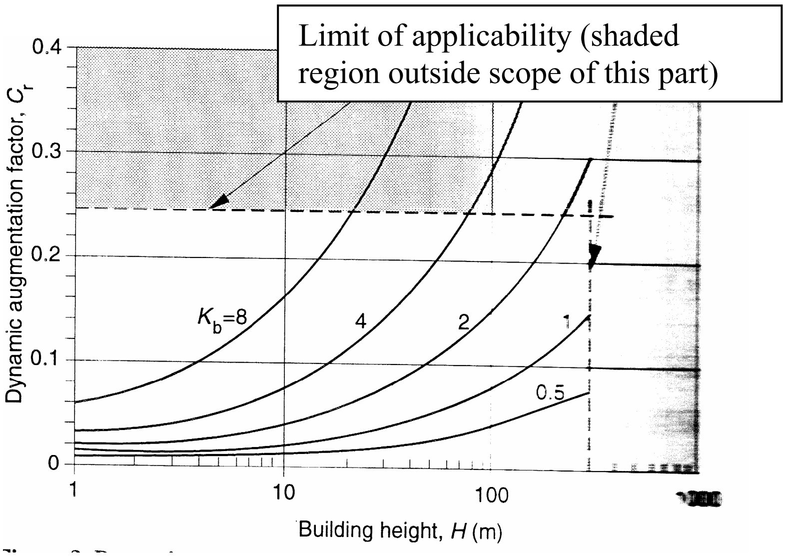


Figure 7 Dynamic Augmentation Factor C_r

Source: BS 6399 (1997)

Standard method- dynamic wind pressure

The value of the dynamic pressure q_s of the standard method is given by:

$$q_s = 0.613V_e^2 \tag{8}$$

0.613 is the k factor.

V_e = The effective wind speed (m/s) and given by the following equation:

$$V_e = V_s S_b \tag{9}$$

Where S_b = The terrain and building factor which can be obtain from table of the code

V_s = The site wind speed (m/s) and given by the following equation:

$$V_s = V_b \times S_a \times S_d \times S_s \times S_p \qquad (10)$$

Where V_b = Basic wind speed viz the mean hourly wind speed (m/s)

S_a = Altitude factor is the factor to adjust the basic wind speed for the altitude of the site above sea level

S_d = Directional factor. It can be taken from table of the code. If the orientation of the building is unknown or ignored it can be taken as 1.00 for all directions

S_s = Seasonal factor and can be taken as 1.00 for permanent structures

S_p = Probability factor and for normal design applications it can be taken as 1.00

Directional method- dynamic wind pressure

The value of the dynamic pressure q_s and the effective wind speed of the directional method are given by same equations. But the determination of factor S_b has been changed to more elaborate method. S_b is the terrain factor and building factor appropriate to the wind direction considered. In this method the factor are defined separately for sites in country terrain and sites in town terrain.

For country terrain S_b is given by following equation:

$$S_b = S_c[1 + (g_t \times S_t) + S_h \qquad (11)$$

Where S_c = The fetch factor obtained from the table of the code

S_t = The turbulent factor obtained from table of the code

g_t = The gust peak factor

S_h = The topographic increment

For town terrain S_b should be calculated from an equation similar to above equation.

The overall horizontal load applied on a building is determined by the following equation for both standard and directional methods.

$$P = 0.85(\sum P_{front} - \sum P_{rear})(1 + C_r) \tag{12}$$

Where P_{front} = Net pressure across the surface for front face (N/m^2)

P_{rear} = Net pressure across the surface for rear face(N/m^2)

$$p_{front} = p_{rear} = (p_e - p_i)A \tag{13}$$

Where A = The loaded area (m^2)

p_e is the external pressure and given by the equation:

$$p_e = q_s C_{pe} C_a \tag{14}$$

Where q_s = The dynamic pressure (N/m^2)

C_{pe} = The external pressure coefficient

C_a = The size effect factor

p_i is the internal pressure and given by the equation:

$$p_i = q_s C_{pi} C_a \tag{15}$$

Where q_s = The dynamic pressure (N/m^2)

C_{pi} = The internal pressure coefficient

C_a = The size effect factor

The code simplified the calculation by providing guideline for the area to use in calculations and the size reduction factor. For building where the height is less than the crosswind breath of the structure the building can be consider as a one part and when height lies between cross wind breath and 2 times the cross wind breath, the structure can be considered in two parts. For building with height greater than two times the crosswind breath , the structure to be consider in multiple parts , comprising a lower part extending upwards from ground by a height equal to crosswind breath , an upper part extending downwards from the top by a height equal to crosswind breath. The middle region between two parts may be divided in to a number of horizontal parts. This procedure reduces the computational time. For Directional method factor C_a is not considered. The factor of $(1+C_r)$ is for the mildly dynamic nature and 0.85 for the non simultaneous action between faces.

3. Australian/New Zealand code AS/NZS1170 2002 Structural Design Action Part 2

Code specifies two separate methods for non dynamic effects and dynamic effect. The following guidelines are given for checking the structure for wind induced oscillation. Structures which are having there natural frequency greater than 1Hz, dynamic effect is not included. For structures which are having natural frequency less than 1 Hz but greater than 0.2Hz, dynamic effects are included. If a structure is having a natural frequency less than 0.2Hz, established dynamic method should be used for the analysis. Code used the 3 seconds gust speed.

Method 1

The design wind pressure p is given by following equation:

$$p = (0.5\rho_{air})(V_{des,\theta})^2 C_{fig} C_{dyn} \tag{16}$$

Where p = Design wind pressure acting normal to a surface, in Pascal (N/m^2).

ρ_{air} = Density of air, which shall be taken as 1.2 Kg/m^3

$V_{des,\theta}$ = Building orthogonal wind speeds (m/s), the maximum wind speed $V_{sit,\beta}$

C_{fig} = Aerodynamic shape factor –force coefficients

C_{dyn} = Dynamic response factor (the value is taken as 1.0 except where the structure is wind sensitive)

$V_{sit,\beta}$ = The site wind speed (m/s) is for the 8 cardinal directions at reference height and given by following equation,

$$V_{sit,\beta} = V_R M_d M_{Z,cat} M_s M_t \tag{17}$$

Where V_R = Regional 3 second gust speed (m/s)

M_d = Wind direction multiplier

$M_{cat,\phi}$ = Terrain height multiplier

M_s = Shielding multiplier

M_t = Topographic multiplier

Method 2

The Dynamic response factor C_{dyn} for structures having there natural first mode fundamental frequency less than 1 Hz, but not less than 0.2Hz is analyzed for the dynamic effects. This includes along wind and cross wind effects.

The along wind effect

C_{dyn} is given by the following equation:

$$C_{dyn} = \frac{1 + 2I_h \left[g_v{}^2 B_s + \frac{H_s g_R{}^2 s E_t}{\zeta} \right]^{0.5}}{(1 + 2g_v I_h)} \tag{18}$$

Where S = Height(m) of the level at which action effects are calculated for structure

H = Average roof height of structure above ground(m)

I_h = turbulence intensity

g_v = Peak factor for the upward velocity fluctuation

B_s = Background factor

H_s = Height factor for the resonant response

g_R = Peak factor for resonant response (10 min period)

s = Size reduction factor

E_t = $\pi/4$ times the spectrum of turbulence in the approaching wind stream

ζ = Ratio of structural damping to critical damping of the structure

The cross wind effect

The equivalent cross wind static wind force per unit height as a function of height (Z) in newtons per metre is given as follows:

$$W_{eq} = 0.5\rho_{air}[V_{des,\theta}]^2 d C_{fig} C_{dyn} \tag{19}$$

Where $V_{des,\theta}$ (m/s) = Evaluated at overall building height

d (m) = The horizontal depth of structure parallel to the wind stream

$C_{fig}C_{dyn}$ as follows:

$$C_{fig}C_{dyn} = 1.5 g_R (\frac{b}{d}) \frac{K_m}{(1+g_v I_h)^2} (\frac{z}{h})^k \sqrt{\pi C_{fs} / \varsigma} \qquad (20)$$

Where K_m=Mode shape correction factor for crosswind acceleration and given by:

$$K_m = 0.76 + 0.24k \qquad (21)$$

Where k is mode shape power exponent for the fundamental mode and 0.5 for slender framed structures.

C_{fs} is cross wind force spectrum coefficient generalized for a linear mode shape.

Forces on surface or structure derived by considering wind pressure is given by the following equation:

$$F = \sum p_z A_z \qquad (22)$$

Where p_z = Design wind pressure (N/m^2) (normal to the surface) at a height z

A_z = A reference area (m^2), at a height z, upon which the pressure at height (p_z) acts

Combination of along wind and crosswind response

The total combined peak scalar dynamic action effects (ε_t), such as an axial load in a column, shall be as follows:

$$\varepsilon_t = \varepsilon_{a,m} + \left[(\varepsilon_{a,p} - \varepsilon_{a,m})^2 + (\varepsilon_{c,p})^2 \right]^{0.5} \qquad (23)$$

Where $\varepsilon_{a,m}$ = Action effect derived from the mean along wind response, given as $\varepsilon_{a,p} / C_{dyn}(1+2g_v I_h)$

$\varepsilon_{a,p}$ = Action effect derived from the peak along wind response

$\varepsilon_{c,p}$ = Action effect derived from the peak crosswind response

The above procedure for combination of along wind and cross wind response using mean and peak values is complicated and the combination has to be done for the induced forces. But code suggested an approximated load combination to be applied to the structure which will give fairly accurate resultant forces. The Combination of along wind and crosswind loading from two orthogonal directions are as follows:

1 [mean along wind load + 0.75 (peak- mean) along wind] with 0.75 [peak-mean] cross wind

2 [mean along wind load + 1.0 (peak- mean) along wind]

3 [1.0(peak-mean) crosswind

The mean loads are obtained from dividing the peak loads by a gust factor given by: $[C_{dyn}(1+2g_v I_h)]$.

4. National Building code of India Part 6 section1 Clause 6

Code specified two separate methods for dynamic and non dynamic structures. Buildings and closed structures with a height to minimum lateral dimension ratio of more than 5.0 or Building and structures whose natural frequency in the first mode less than 1.0Hz, then the structure has to be examined for dynamic effects of winds. Code use 3 second gust speeds. Two methods are completely different from each

Method 1 - no dynamic effects

Deign wind pressure p_z is given by following equation:

$$p_z = 0.6V_z^2 \tag{24}$$

0.6 is the k factor .

Where V_z , design wind speed and can be calculated from the below equation:

$$V_z = V_b k_1 k_2 k_3 \tag{25}$$

Where V_b = Basic wind speed – gust speed (m/s)

k_1 = Probability factor (risk coefficient) - can be obtained from table of the code

k_2 = Terrain, height and structure size factor – can be obtained from the table of the c ode

k_3 = Topography factor-will range from 1.36 to 1.0

The applied surface load F for enclosed building is given by the following equation:

$$F_s = C_f A_e \overline{p}_z \tag{26}$$

Where C_f = Force coefficient for the building

A_e = Effective frontal area (m^2) considered for the structure at height Z

$\overline{p}_z$ = Design pressure (N/m^2) at height Z due to gust wind speed

Method 2- Gust factor (GF) or Gust effective factor (GEF) method

Deign wind pressure p_z is given by same equation as for the non dynamic situation. But V_z is taken as design hourly wind speed in m/s and given from the below equation:

$$\overline{V}_z = V_b k_1 \overline{k}_2 k_3 \quad (27)$$

Where V_b = Basic wind speed – gust speed (m/s)

$\overline{k}_2$ = Terrain, and height factor / Hourly mean wind speed factor in different terrain for different heights– can be obtained from the table of the code

The horizontal load applied on a building is given by the following equations for non dynamic and dynamic structures.

The applied surface load F, the along wind load is given by the following equation**:**

$$F_s = C_f A_e \overline{p}_z G \quad (28)$$

Where C_f = Force coefficient for the building

A_e = Effective frontal area (m^2) considered for the structure at height Z

$\overline{p}_z$ = Design pressure (N/m^2) at height Z due to mean hourly wind

G = Gust factor $\dfrac{peakload}{meanload}$ and is given by

$$G = 1 + g_t r \sqrt{[B(1+\phi)^2} + \frac{sE}{\beta}] \quad (29)$$

Where g_t = Peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuating load

B = Back ground factor

r = A roughness factor which depend on the size of the structure in relation to the ground roughness

β = Damping ratio

E = The measure of the available energy in the stream at the natural frequency of the fluctuating wind

s = Size reduction factor

$\phi = \dfrac{g_r \sqrt{B}}{4}$ and accounted only for buildings

The calculation of gust factor involved several readings from figures which may be based on personal judgment of the user. Factors $g_t r$, E, B and S has to be taken from figures given by the codes. As an example the back ground factor to be used for the calculation has taken from Figure 8.

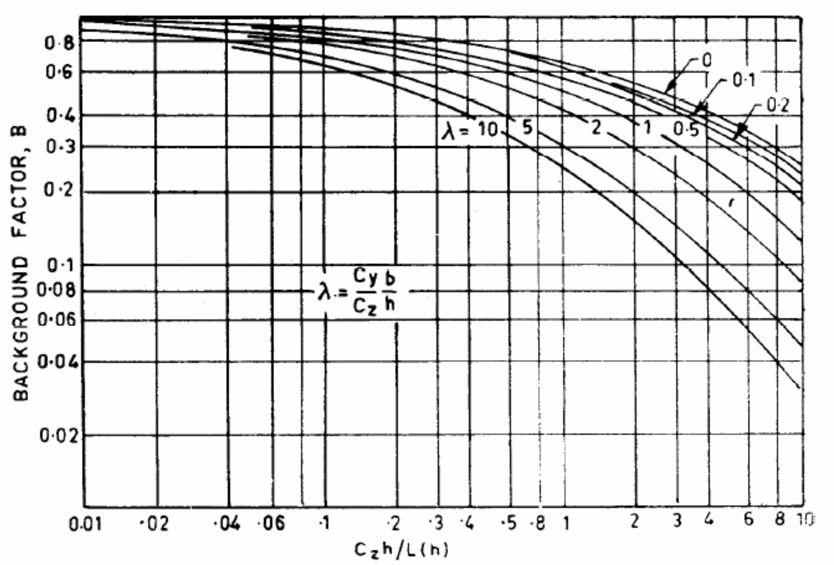


FIG. 9 BACKGROUND FACTOR B

Figure 8 Back Ground Factor, B

Source : IS 456 (2006)

As explained above, the procedures for calculation of wind load applied on a building follows similar theories and concepts. But they differ due to assumptions made by each code procedure. The basic wind load calculation is given in Table 5.

Table 5 Wind Load Calculation Procedure

	CP3	BS6399	AS/NZS	NBCI
Basic wind speed (m/s) averaging times	3 sec	1 hr	3 sec	3 sec
Design wind speed Vs (m/s)	Vs = basic wind speed ×site factors			
q –wind pressure N/m ^{2}	$q = kV_s^2$			
k factor	0.613	0.613	0.6	0.6
Pressure on building P_z - kN/m^2	Final pressure intensity = q x force coefficient (aerodynamic shape factor) x factor for dynamic response			
Total force applied F -kN	$F = P_z \times area$			
Comments	CP3, no dynamic response factor. In BS 6399 total force multiplied by 0.85 for non simultaneous action on both faces and AS/NZS specify a action combination factor			

AS/NZS considered the crosswind effects and provided load combinations to be considered for the analysis of structure.

The design wind velocity has a very significant effect on the applied load as it was squared for the wind analysis. The comparison of each code procedures for the calculation of basic wind speeds was given Table 6 and subsequent discussion. It can be seen that the procedure given by BS 6399 is very country specific. Then force coefficient (aerodynamic shape factor) and dynamic response factor discussed in detail from each code.

Table 6 Comparison of Factors Affecting the Design Wind Speed

CP3/ Sri Lanka manual	BS 6399	NBCI	AS/NZS
V_s - design wind speed $V_s = V_b S_1 S_2 S_3$ S_1 Topography factor – normally taken as 1 unless special local effect s are present S_2 ground roughness, building size and height about ground factor- Ground roughness categorized for 4 types as below **Category 1** Open country with no obstruct **Category 2** Open country with scattered wind breaks **Category 3** Country with many wind breaks , small towns outskirts of large cities **Category 4** Surface with large	V_e design wind speed $V_e = V_s S_b$ $V_s = V_b \times S_a \times S_d \times S_s \times S_p$ S_a altitude factor is the factor to adjust the basic wind speed for the altitude of the site above sea level S_d directional factor. S_s Seasonal factor S_p probability factor All above factors which are climate dependent specially calibrated for UK conditions. So they are only applicable to sites in UK The factor S_b depend on the methodology use for calculation	V_z - design wind speed **Non dynamic structures** $V_z = V_b k_1 k_2 k_3$ k_1 -Probability factor (risk coefficient) - can be obtained from table of the code k_2 -Terrain, height and structure size factor – can be obtained from the table 5 of the c ode Approach is similar to that of CP3. Categorized into four categories of roughness and 3 classes of building type.. The building types are as given below **Class A** – building or other components such as cladding having maximum dimension of less	$V_{sit,\beta}$ design wind speed $V_{sit,\beta} = V_R M_d M_{Z,cat} M_s M_t$ M_d -Wind direction multiplier Specifically specified for the regions in Australia. $M_{cat,\phi}$ - terrain height multiplier Given for 4 categories as below **Category 1** exposed open terrain with few , no obstruction and water surfaces **Category 2** water surface, open terrain , grass lands with few well scatter obstruction **Category 3** terrain with numerous closely spaced obstructions (suburban housing) **Category 4-** terrain with

Table 6 (Continued)

CP3/ Sri Lanka manual	BS 6399	NBCI	AS/NZS
and frequent obstructions, city centre Building size categorized to 3 types as below **Class A** – all unit of cladding, glazing and roofing **Class B** – All building and structures where neither the greatest horizontal dimension or vertical exceeds 50m **Class C**- all building and structures whose greatest horizontal or vertical dimension exceeds 50 m S_3 - factor based on statistical concepts	**Standard method** – buildings up to 100 m S_b -Taken from Table 4 of the code- categorized in to two **1 Site in country**-divided in to 4 sup categories depending on the distance to sea **2 Site in towns-** similarly sub divided in to 3 categories **Directional method** – similar approach with different procedure to calculate S_b factor as shown in discussion below	than 20 m **Class B-** Building or other component such as cladding having maximum dimension between 20 & 50m **Class C -** Building or other component such as cladding having maximum dimension more than 50m k_3 - topography factor **Dynamic structures** $\overline{V_z} = V_b k_1 \bar{k}_2 k_3$ Where k_1 and k_3 are similar to non dynamic case $\vec{k}_2$ =Terrain, and height factor – can be obtained from the table 28 of the code, four categories only	numerous large high and closely spaced obstructions such as large city centres M_s - shielding multiplier – can be obtained from clause 4.3 and table 4.3 of the code. M_t -topographic multiplier- can be either calculate using equations given in clause 4.4 or use the values in table 4.4 according to the site location

C P3- Change of values for difference classes of building were due to different in averaging times. From Class A to class C averaging times changed as 3 seconds, 5 seconds and 15 seconds.

In BS 6399 the directional wind speeds were also in two categories with county and town. For country terrain S_b is given by following equation, Equation (11) as below.

$$S_b = S_c[1+(g_t \times S_t)+S_h]$$

Where S_c= the fetch factor obtained from the table of the code, S_t= the turbulent factor obtained from table of the code, g_t = the gust peak factor and S_h = the topographic increment. The procedure is different from other codes, the correct location of the site is very important for the calculation of design wind speed. This may be a minus factor for Sri Lankan conditions, where detailed location maps and other information are not readily available for design engineers. If we consider the topographic increment factor S_h as an example, the factor can be taken as zero if the average slope of the ground does not exceed 0.05 within a kilometer radius of the site. Such information may be not possible as the data bases are not fully developed.

In NBCI the procedure for non dynamic structures are similar to that of CP3. For the dynamic structures the factor for terrain height is taken as both terrain factor as well as hourly mean wind speed conversion factor.

In AS/AZS the procedure for calculation of design wind speeds for both non dynamic and dynamic building structures is same.

One of the most important factors to be considered is the increase in wind velocity with height. In other words, this is the retarding effects of the surface friction on wind velocity nearer the surface. All other factors considered as 1 and the terrain category was taken as open country for the study. The terrain height multiplier used for the open country category up to 150 m from each code is given in Table 7.

Table 7 Terrain Height Multiplier

Height, m	CP3	[1] BS 6399		ASNZ	[2] NBCI	
		Standard method	Directional		Method1	Method 2
10	0.9	1.78	1.77	1.12	0.99	0.78
20	0.96	1.90	1.90	1.19	1.06	0.85
30	1.0	1.96	1.96	1.22	1.09	0.88
50	1.06	2.04	2.04	1.25	1.14	0.93
100	1.13	2.12	2.12	1.29	1.20	0.99
150	1.18		2.16	1.31	1.24	1.03

[1]Calculated from code equations considering 2 km upwind from sea to site with gust peak factor taken as 3.44. [2]Method 1-no dynamic effect and method 2 with dynamic effects

It can be seen that ASNZ factor is 20±% higher than the CP3 value. The NBCI – dynamic method factor only is 10±% lesser than CP3 value.

Force coefficient (aerodynamic shape factor)

When air flows over a surface, the frictional drag of the surface reduced the velocity of the closest layer of air and adjacent layers of air slide over each other. The velocity increases with the distance from the fixed surface. This conditioned layer of air near the fixed surface term as boundary layer. The pattern of air flow over an obstruction is governed by the viscosity of air. With higher wind speed with larger obstruction inertial forces become important and flow tend to become turbulent. The relationship between inertial force and viscous force is expressed by Reynolds number. The force coefficient factor normally considers the relationship between mean wind speed and mean pressure on a structure. This is a non dimensional ratio and depends on geometry of the structure, mean wind profile, wind direction and Reynolds number. These factors are obtained by full scale models and small scale models experiments. The factor can be categories as external and internal aerodynamic factor or force coefficient.

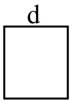
Comparison of each code procedure for determination of force coefficient for a rectangular enclosed building is given below.

Table 8 Procedure to Obtain Force Coefficient (Aerodynamic Shape Factor)

CP3	BS6399	AS/NZS	NBCI
Given by a single factor – A force coefficient depending on the height to breath ratio given by Table 10 of the code.	Given by pressure coefficient on front and rear surfaces and include external and internal pressure coefficients- depending on breath and height of the structure	Given by pressure coefficient on front and rear surfaces and include external and internal pressure coefficients- depending on breath and height of the structure	Given by a single factor- A force coefficient depending on the crosswind and along wind breath of structure and height of the structure- figure 4 of the code

CP 3- Provide an extensive range of buildings with different heights and breath ratios. As an example following table for square type building can be given.

Table 9 A Part from the Table 10 of the Wind Code CP3 – Force Coefficient C_f for Rectangular Clad Buildings with Flat Roofs (Acting in the Direction of the Wind)

Plan shape	l/w	b/d	C_f for height /breath ratio						
			Up to1/2	1	2	4	6	10	20
d  b	1	1	0.9	0.95	1.0	1.05	1.1	1.2	1.4

b is the dimension of the building normal to the wind , d is the dimension of the building measured in the direction of the wind, l is the greater horizontal dimension of the building and w is the lesser horizontal dimension of the building.

BS 6399- Provide as external and internal pressure coefficients. There are two different tables for standard and directional method. A part of a Table 5- External pressure coefficient for vertical wall of the code is given in Table 10 below.

Table10 A Part of Table 5 of BS 6399- External Pressure Coefficient C_{pe} for Vertical Walls

	D/H≤1	D/H≥4
Windward (front) face	+0.8	+0.6
	-0.3	-0.1

D is the dimension of the building parallel to the wind direction and H is the height of the building. Interpolation can be use for buildings having 1 <D/H < 4

AS/NZS- Provide as external and internal pressure coefficients. The table for external pressure coefficient for enclosed buildings given by Table 5.2 (A) of the code is given in below Table 11.

Table 11 External Pressure Coefficient of (C_{pe}) for Rectangular Enclosed Buildings- Wind Ward Wall

h – height in m	External pressure coefficient of (C_{pe})
> 25 m	0.8 (wind speed varies with height)
≤ 25 m	For building on ground 0.8, when wind speed varies with height or 0.7, when wind speed taken as z = height of the building
	For elevated buildings – 0.8 (wind speed taken at h)

Similar table is given for the external pressure coefficient for leeward face.

NBCI- Provide an extensive range of buildings with different heights and breath ratios. The relationship is given in a figure. The values taken from the figure will be approximations. A part of the figure 4 of the code "Force coefficient for rectangular clad building in uniform flow" is given below by Figure 9.

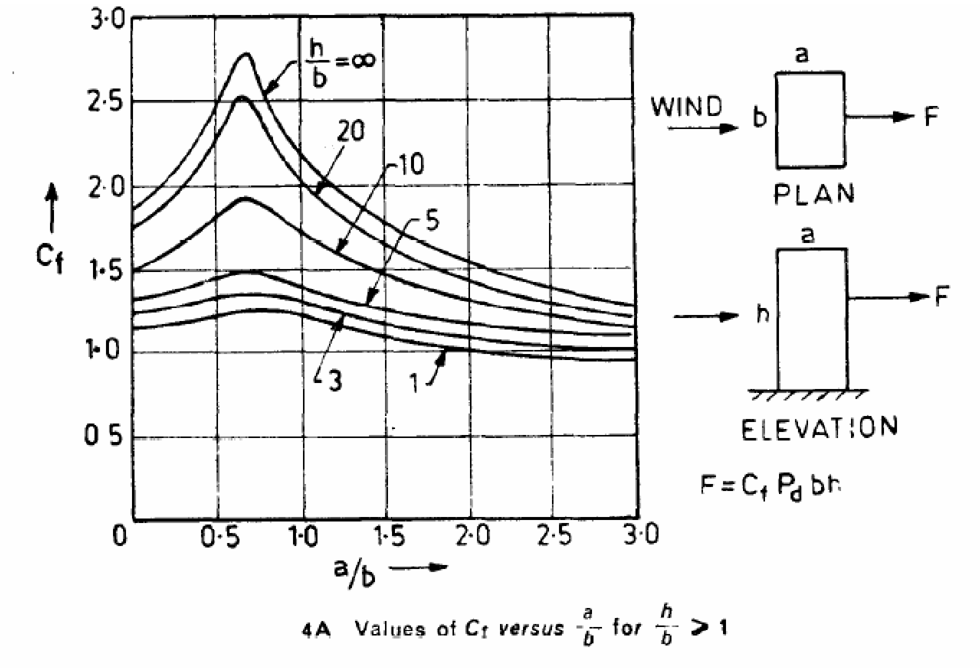


Figure 9 A Part of Figure 4 of the NBCI Code -Force Coefficient for Rectangular Clad Building in Uniform flow

Source: IS 456 (2006)

If surface design pressure varies with height, the surface area of the building/structure may be sub divided that specified pressure are taken over appropriate area.

Dynamic response factor

The wind pressure causes the deflection of structures in the direction parallel to direction of wind. The total along wind deflection consists of two parts, the mean deflection which corresponds to mean wind and the fluctuating deflection, which corresponds to corresponds to gustiness of winds. The maximum deflection of the structure can be estimated by multiplying structural mean deflection by a factor called dynamic response factor. There are many procedures to develop this factor and did not discussed in this study.

CP3- Does not provide any guideline for the dynamic response calculations.

BS6399- The augmentation factor used for account the mild dynamic nature of structures. The procedure explained earlier and quite difficult to use explicitly any structures as it is given by a figure and many buildings does not fit to the building types specified.

AS/NZS- The Dynamic Response Factor used for account of dynamic nature of structure. The procedure explained earlier.

NBCI- The Gust Factor used for account of dynamic nature of structure. The procedure includes several factors to be taken from Figures as explained earlier.

Building classifications- dynamic response

The dynamic nature of a building was determined using natural frequency of the structure. BS6399 related this concept to dynamic augmentation factor which depend on the building type and height. AS/NZS and NBCI use natural frequency for classification. Structures which are having natural frequency greater than 1 Hz as non dynamic structures and natural frequency lower than 1Hz as dynamic structures. AS/NZS recommended to use established dynamic calculation methods if the natural frequency is less than 0.2 Hz. Natural frequency calculation formula from each code given below. CP3 does not provide an equation for natural frequency calculation.

BS6399- natural frequency- n_0 Hz is given by:

$$n_0 = 60 / \sqrt{aH} \tag{30}$$

Where a (m) is the diagonal length of the building and H (m) is the height

AS/NZS- natural frequency- n_0 Hz is given by:

$$n_0 = 46 / H \tag{31}$$

Where H (m) is the height

NBCI- fundamental natural period - T_n seconds is given by:

$$T_n = 0.09H / \sqrt{d} \tag{32}$$

Where H (m) is the height and d (m) is the base dimension of building at plinth level in m along the considered direction of the lateral force.

RESEARCH METHODOLOGY

1. Wind Data Collection

Department of Meteorology of Sri Lanka now has 22 meteorological stations through out the island. Due to lack of persons, equipments and maintenance problems continuous data in all 22 stations were not available. The prediction of basic wind velocities depend on the past data available. The wind speed observations done using manual based instrument. Observation done for 3 hourly basis and some stations only day time data was available .Continuous gust recorders were available at some stations of Department of Meteorology, Sri Lanka since early 90's and most of them not functioning now due to many reasons. From those gust records two stations had continuous data for 3 or 4 years. The data was collected for 2 stations which come under zone 1 and zone 3 of the island. Trincomalee in zone 1 and Colombo in zone 3 shown in Figure 2. The continuous data for those 2 stations were attached as Appendix A , Table A1 and Table A2.

2. Methodology

Procedure for evaluation of basic wind speeds

Procedure for analysis of basic wind speeds represented by below flow chart**:**

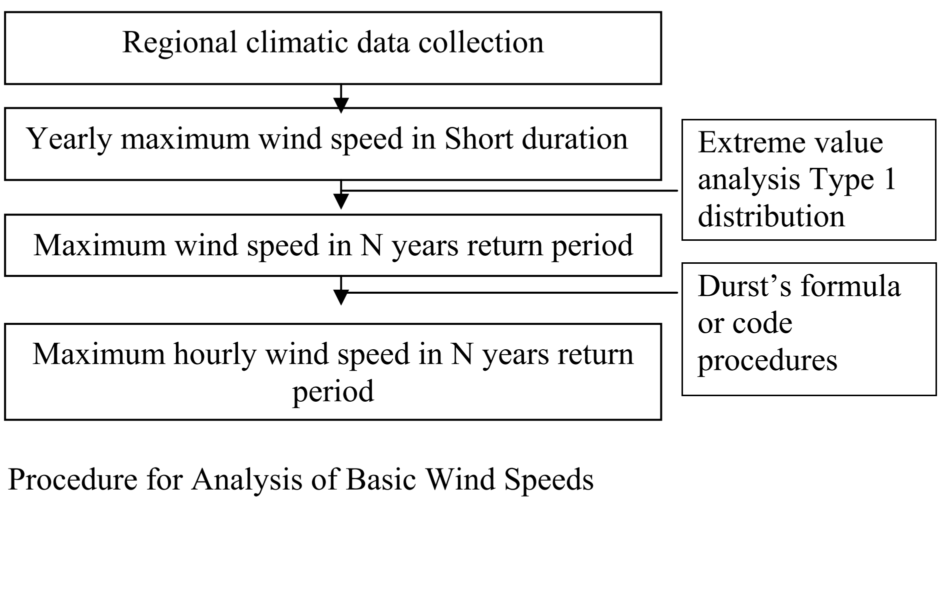


Figure 10 Procedure for Analysis of Basic Wind Speeds

Design basic wind speeds

Wind speed calculation based on available data from Table A1 for Trincomalee was as follows.

For Trincomalee- monthly basic wind speed in Km/h-Wind Zone 1

Sample mean ($\overline{X}$) =5709.8/39 =146.4

Standard deviation (s) =27.59

Expected wind pressure for 50 year return period was given by Equation (4)

$$\overline{V}_{N,m} = \overline{X}_m + 0.78(\ln 12N - 0.577)\,s_m$$

$\overline{V}_{N,m} = 146.4 + 0.78(\ln 12 * 50 - 0.577)27.59$ =271.6 Km/h

=75 m/s

Error in calculation was given by the following equation

Standard deviation of sampling errors $= SD(\bar{V}_{N,m})$

$0.78\{1.64 + 1.46(\ln \bar{N} - 0.577) + 1.1(\ln \bar{N} - 0.577)^2\}\ {}^{s}\!/\!\sqrt{n}$ =± 14.9 Km/h

Wind speed calculation based on available data from Table A2 for Colombo was as follows.

For Colombo – monthly basic wind speed in Km/h

Sample mean ($\overline{X}$) =2851.5/54 =52.8

Standard deviation (s) =12.19

Expected wind pressure for 50 year return period was given by Equation (4)

$$\overline{V}_{N,m} = \overline{X}_m + 0.78(\ln 12N - 0.577)\,s_m$$

$\overline{V}_{N,m} = 52.8 + 0.78(\ln 12 * 50 - 0.577)12.19$ =103.14 Km/h

= 30 m/s

Error in calculation was given by the following equation:

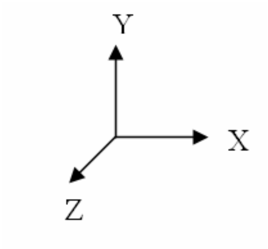
Standard deviation of sampling errors $= SD(\bar{V}_{N,m})$

$0.78\{1.64 + 1.46(\ln \bar{N} - 0.577) + 1.1(\ln \bar{N} - 0.577)^2\} \, {}^{s}\!/\!\sqrt{n}$ =± 3.3

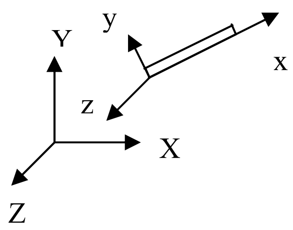
The values predicted by the analysis were extremely higher than 53.5 m/s given by existing wind zoning in Table 1 for the Trincomalee region. This falls under zone 1 of the wind zoning map of Sri Lanka. The maximum wind speed predicted by the zoning map was 53.5 m/s. By the available data a proper rezoning was not possible .The data were for a very short period and further investigations have to be done in that regard. The wind pressure calculation was done based on the wind zoning map of Sri Lankan manual.

3. Analysis of Structures

The analysis will be done using STAAD. Pro2006 computer analysis program. This is a general purpose program. The stiffness analysis implemented in program is based on the matrix displacement method. In the matrix analysis of structures by the displacement method, the structure is first idealized into an assembly of discrete structural components (finite elements). Each component has an assumed displacement in a manner which satisfies the force equilibrium and displacement compatibility at the joints. For a complete analysis of the structure, the necessary matrices are generated by idealizing the structure into an assembly of beams, plates and solid type elements joint together at their nodes. A beam member is a longitudinal structural member having a constant cross section along its length. They carry axial forces, shear and bending forces. A plate element is a three or four noded planar element having variable thickness. A frame member has six degrees of freedom. Two types of coordinate systems are used in the generation of matrices, the global coordinate(X,Y,Z) and local coordinate systems(x,y,z). The figures below illustrate the two coordinate systems.



Global Coordinate System



Local Coordinate System

Figure 11 Global Coordinate System and Local Coordinate System

4. Analysis of Buildings for Wind Loads

Buildings were idealized as rigid frame reinforced concrete structures. The columns and beams joined by moment resisting rigid joints. The shear wall was modelled using plate elements. In the study the height (H) and the width to height ratio (W/H) was changed. Buildings models were categorized into 4 groups considering their height and two values of W/H as follows.

Group 1	18m	- 1: 1 W/H	1:1.33 W/H
Group 2	54m	- 1:1.8 W/H,	1:3 W/H
Group 3	90m	- 1:2.14 W/H,	1:5 W/H
Group 4	144m	- 1:2.67 W/H,	1:4.8 W/H

The height range of all models represents the actual building heights in Sri Lanka. The number of model used for the analysis were 8 and all 8 models analyzed using 4 wind codes mentioned for 3 basic wind zones. The column spacing was taken as 6.0 m. The floor height of the building was 3.6 m. For 25 storied and 40 storied structures shear wall systems are considered. The detail of the models was summarized in Table 12 and the figures of models were shown from Figure 12 to Figure 20.

Section sizes for models were checked for the BS 8110 loading combination using STAAD.Pro2006 program. The direction of wind was assumed as normal to the face concerned. Typical loading arrangement was considered for all floors for simplicity. Live load for residential building is taken as 2.5kN/ m^2 and infill brick wall loads as 3kN per m height considering fairly big openings in walls. The details of the structural models were given in Table 13. Shear walls were modeled as plate elements and mesh by 0.6 m x 0.6 m. Rigid floor diaphragm was used at each floor level to make the whole floor to move together.

Table 12 Building Models Details

Model No.	Height(m)	Width (m)	W : H	No of floors	No of bays
1	18	18	1:1	5	3
2	18	12	1:1.33	5	2
3	54	30	1:1.8	15	6
4	54	18	1:3	15	3
5	90	42	1:2.14	25	7
6	90	18	1:5	25	3
7	144	54	1:2.67	40	9
8	144	30	1:4.8	40	5

Table 13 Structural Details of Models

	Model No.1& 2	Model No.3 &4	Model No.5 &6	Model No.7 &8
Beam size in mm	300 × 600	300 × 600	350 × 675	350 × 750
Column size in mm	400 × 400	750 × 750	850 × 850	1000 × 1000
Shear wall in mm	-	-	300	350
Concrete strength in N/mm^2	25	30	35	40

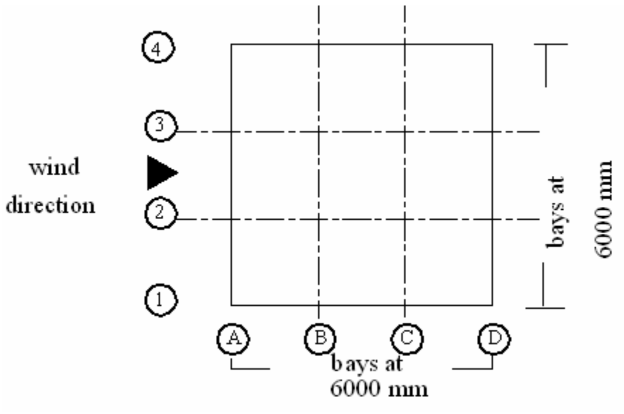


Figure 12 Plan View of Model No. 1 and Model No. 4

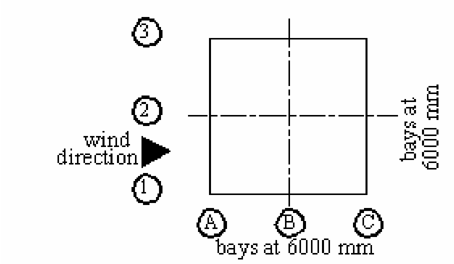


Figure 13 Plan View of Model No. 2

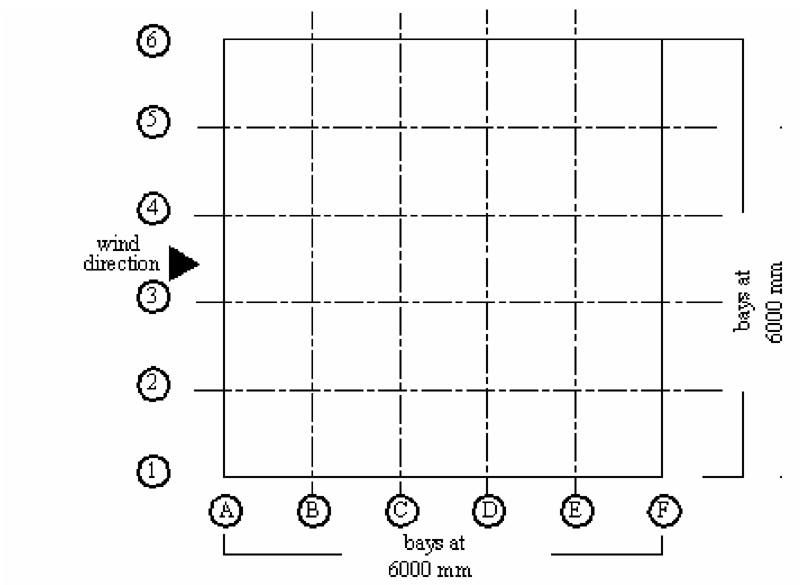
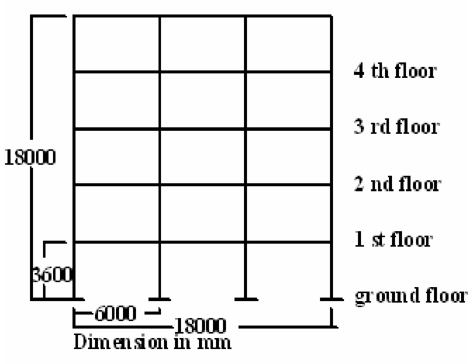
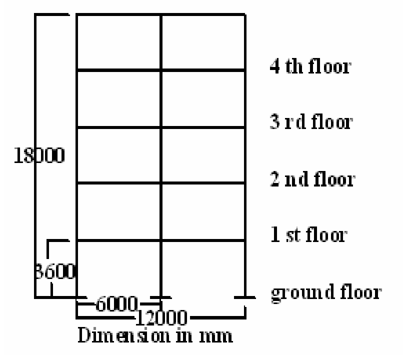


Figure 14 Plan View of Model No. 3



Model No. 1



Model No. 2

Figure 15 Elevations of Model No. 1 and Model No. 2

The building Model No. 3 and Model No. 4 are similar to Model No. 1 and Model No 2. Only number of floors and number of bays differed.

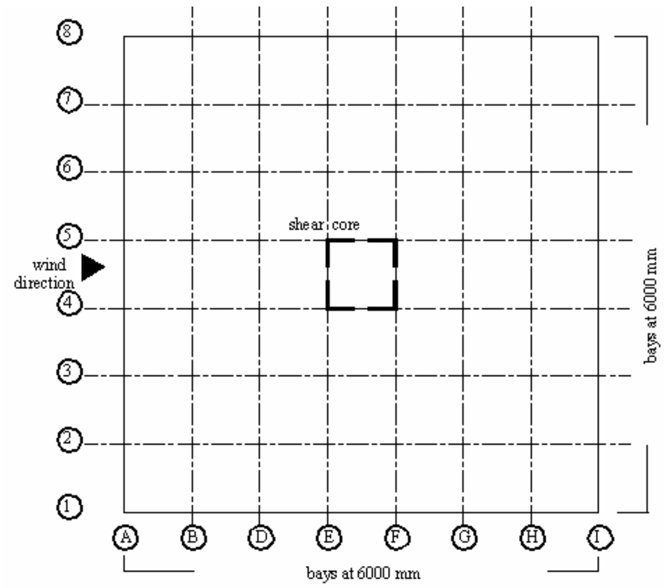


Figure 16 Plan View of Model No. 5

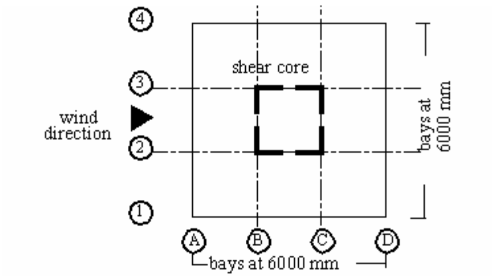


Figure 17 Plan View of Model No. 6

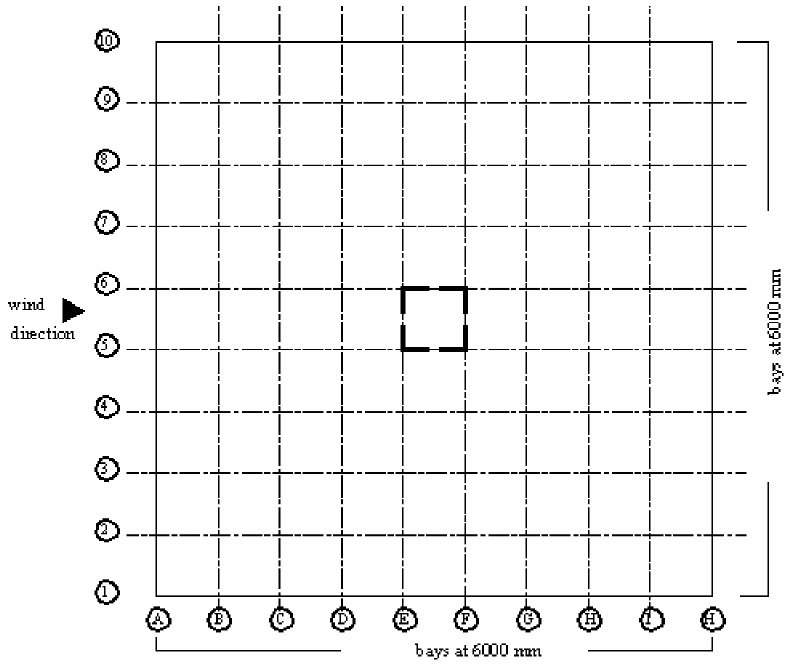


Figure 18 Plan View of Model No. 7

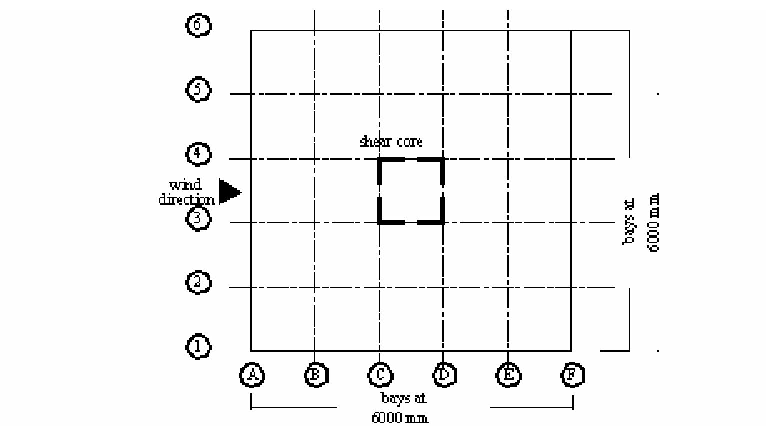
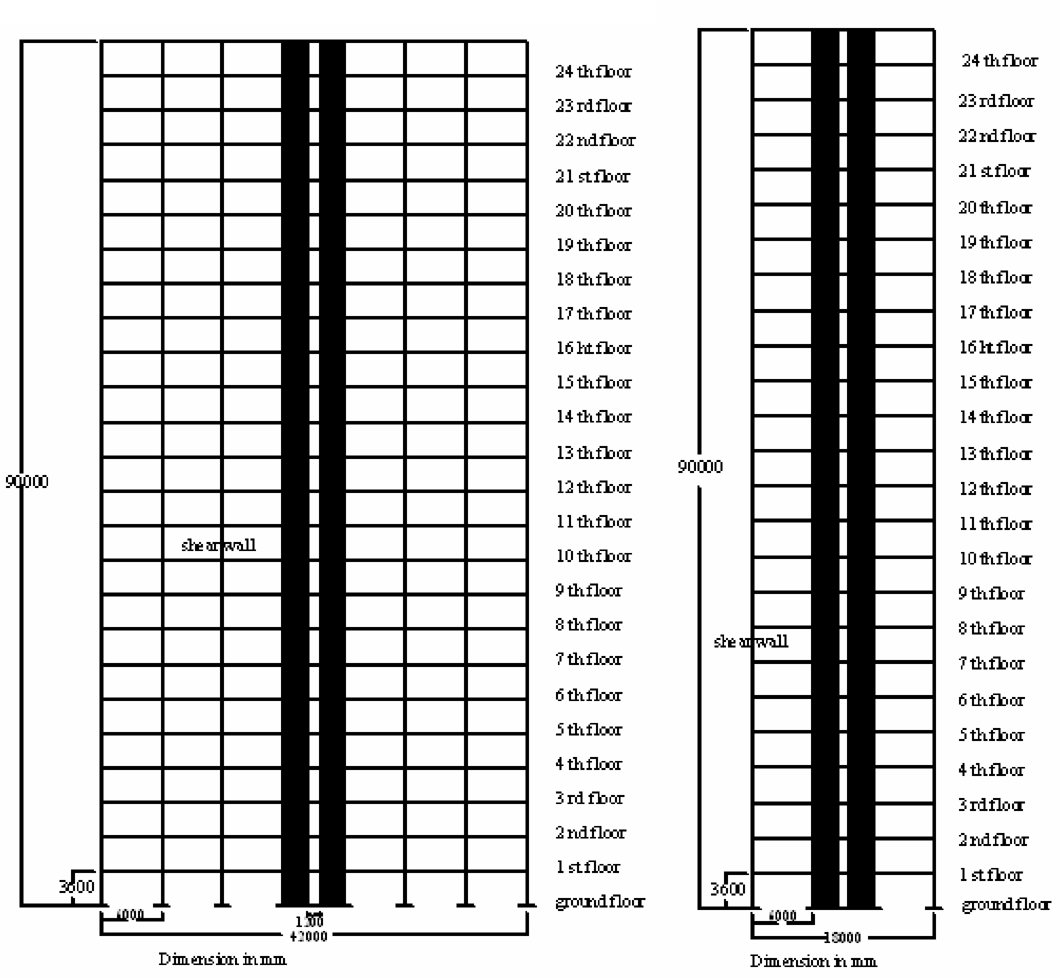


Figure 19 Plan View of Model No. 8



Model No. 5 Model No. 6

Figure 20 Elevations of Model No. 5 and Model No. 6

The building Model No. 7 and Model No. 8 are similar to Model No. 5 and Model No 6. Number of floors and number of bays differed.

RESULT AND DISCUSSION

Comparison of Natural Frequencies

The natural frequencies based on code formulas were given in Table 14. Code values were based on measurement of actual buildings and testing. The actual buildings normally consist of infill walls, lintel bands, intermediate staircase beams, reinforcements etc. So they are much stiffer than the modelled structures. Due to this reason, for the calculation of dynamic effects, code formulas were used.

Table 14 Comparison of Natural Frequency Values

Model no.	Height-m	BS6399	[1] AS/NZS	[2] NBCI
1	18	2.80	2.55	2.62
2	18	3.04	2.55	2.14
3	54	1.04	0.85	1.18
4	54	1.08	0.85	0.87
5	90	0.63	0.51	0.80
6	90	0.66	0.51	0.52
7	144	0.57	0.32	0.57
8	144	0.41	0.32	0.42

[1]Model no 3 to model no 8 come under dynamic structures. [2]Model no 4 to model no 8 come under dynamic structures.

Wind Loading Calculation

The calculations were based on each code procedure specified. The sample comparison presented in Table 15 is for the Model No. 7 at 144 m height for Zone 1. It can be seen that the NBCI method produced much higher wind pressure on buildings. The sample calculations were given in Appendix B for the Model No. 7.

Table 15 Comparison of Applied Along Wind Pressure on Building Model No. 7 at 144 m Level (Zone1)

	CP3	BS6399[2]	AS/NZS[3]	NBCI
Basic wind speed (m/s)	53.5	30.05	53.5	53.5
[1] Terrain height factor	1.174	2.05	1.308	1.025
Design wind speed (m/s)	62.81	61. 3	70.00	54.84
q –wind pressure N/m ^{2}	2418	2305		1804
Dynamic response factor	-	1.1	1.02	1.66
Force coefficient	1.0167	1.1	1.3	1.3
Final pressure intensity at 90 m-kN/m^2	2.46	2.39	3.50	3.89
% difference at top	0	-2.8	42.3	58.1

[1]Reffer Table 7 or relevant code. [2]Multiplyed by 0.85 for non simultaneous action between faces. [3]Multiplied by 0.9 as action combination factor. The wind pressure values calculated as above used for the analysis of structures. For AS/NZS, three load combinations specified by the code were used for the analysis and the peak along wind pressures plotted in pressure diagrams. The along wind pressure intensities used for analysis are given in Appendix C from Table C 1 to C8 and the pressure diagrams are given in Figure 21 to Figure 28.

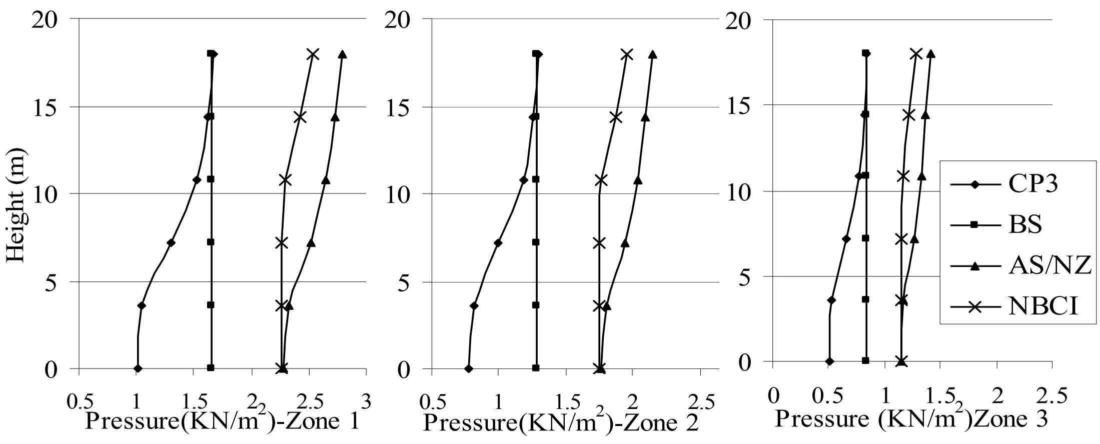


Figure 21 Pressure Intensity Applied in kN/m^2 for Model No.1

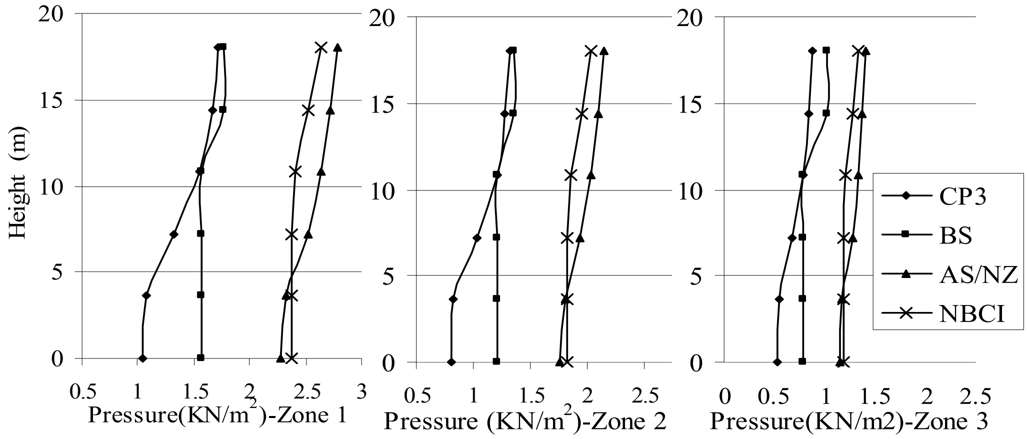


Figure 22 Pressure Intensity Applied in KN/m^2 for Model No.2

It can be seen from the above graphs that the change of pressure intensity applied on the building due to change in width of the building was quite insignificant for low rise buildings. The pressures were based only on static analysis.

NBCI and AS/NZS, analyses were done using dynamic analysis from Model No. 4 to 8 and Model No. 3 to 8 respectively. AS/NZS, along wind and cross wind load combinations were considered.

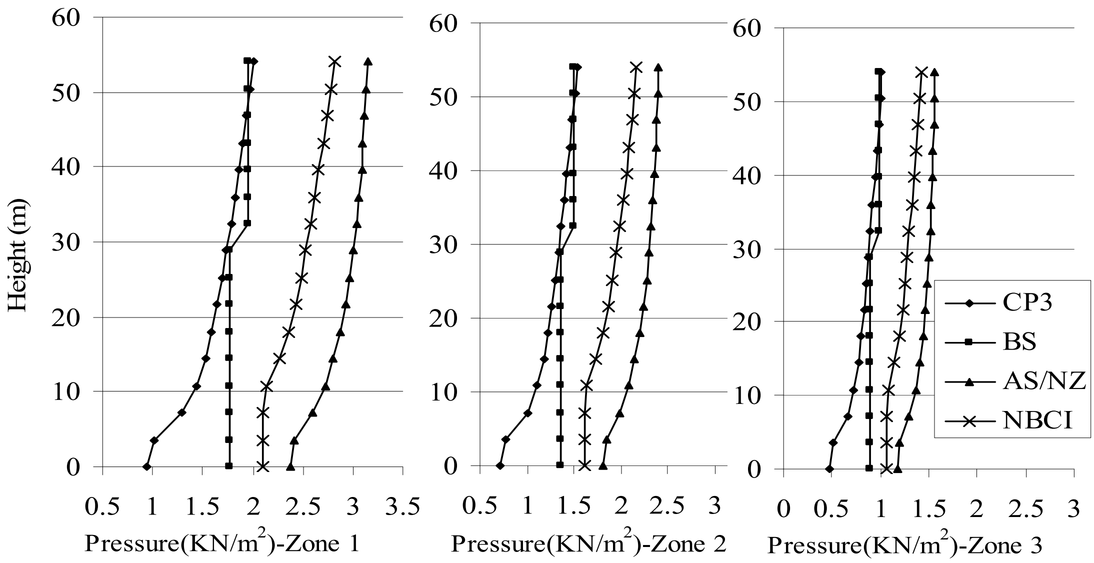


Figure 23 Pressure Intensity Applied in kN/m^2 for Model No.3

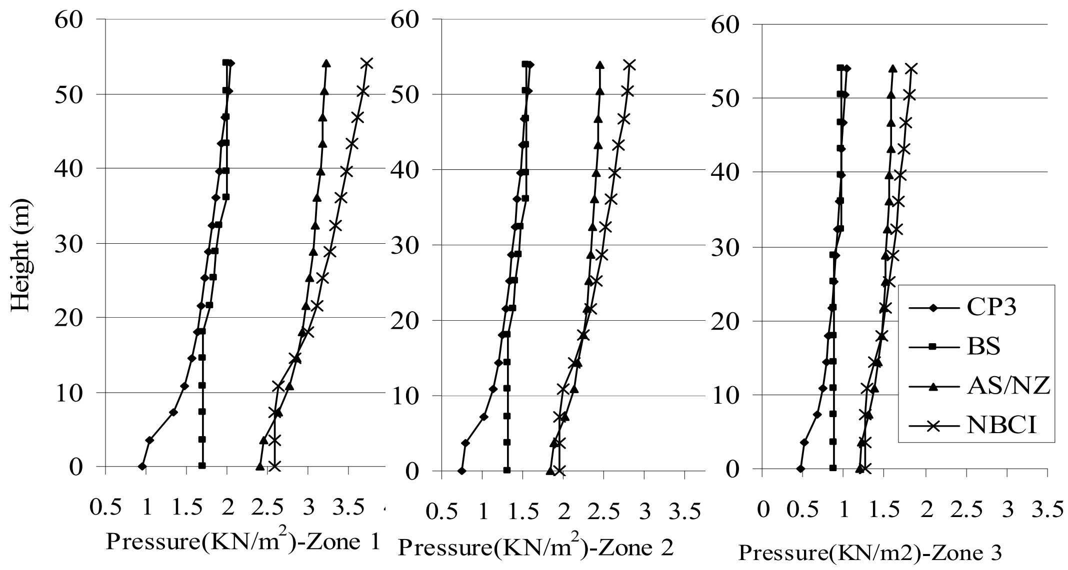


Figure 24 Pressure Intensity Applied in kN/m^2 for Model No.4

From the NBCI, The pressure intensity at 54 m level for Model No. 3 for zone 1 is 2.81 kN/m^2. The pressure intensity at 54 m level for Model No. 4 for zone 1 is 3.73 kN/m2. The change in two Models is very significant. The other codes do not indicate such behaviour.

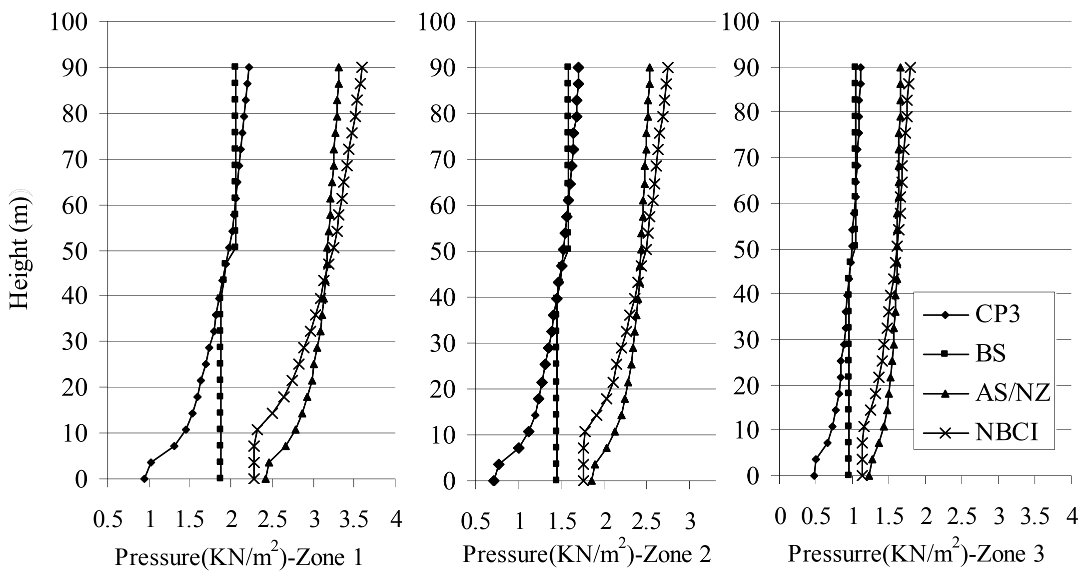


Figure 25 Pressure Intensity Applied in kN/m^2 for Model No.5

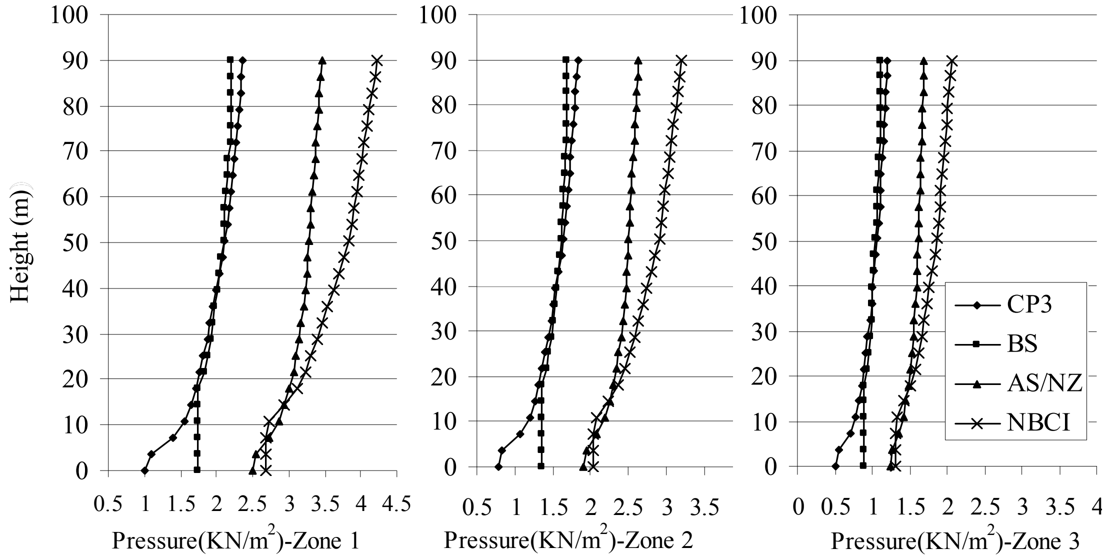


Figure 26 Pressure Intensity Applied in kN/m^2 for Model No.6

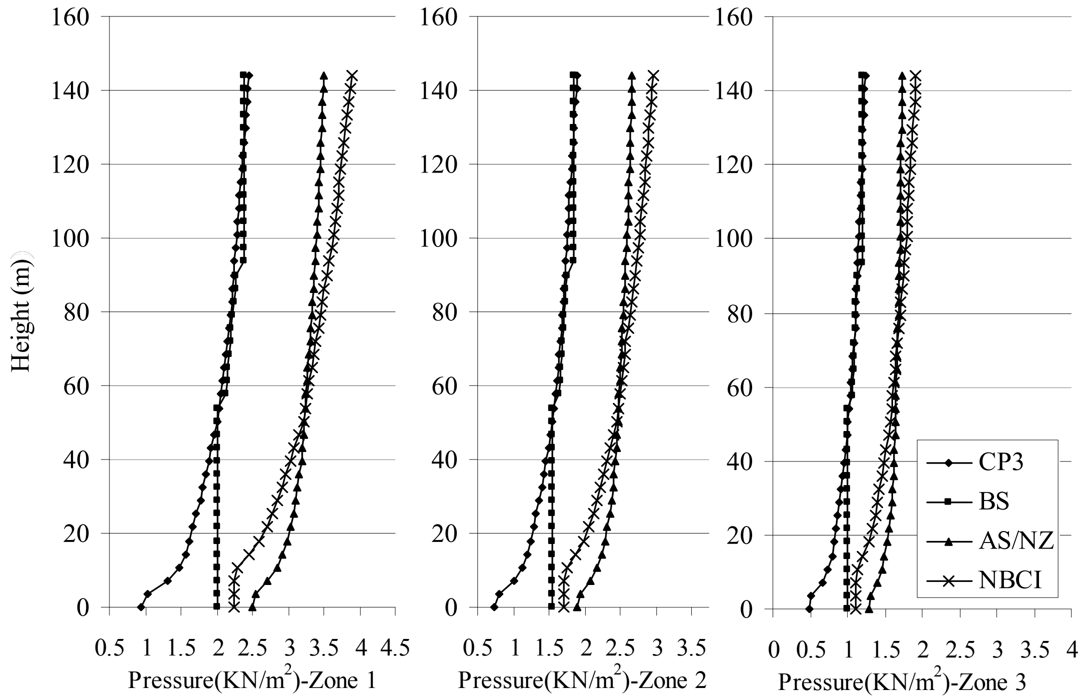


Figure 27 Pressure Intensity Applied in kN/m^2 for Model No.7

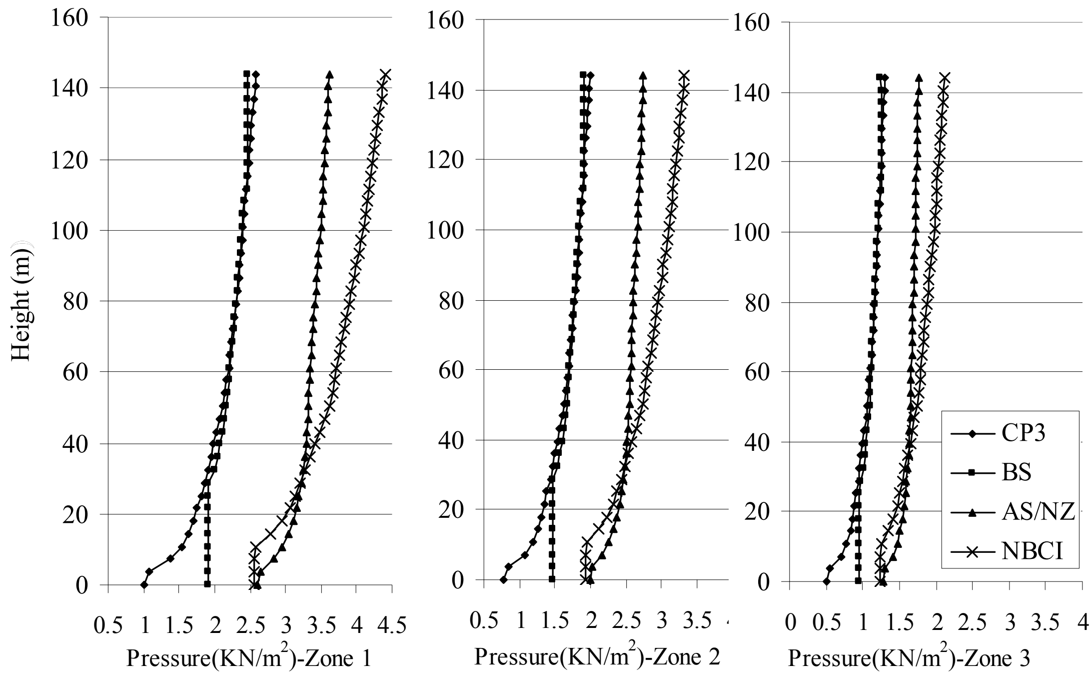


Figure 28 Pressure Intensity Applied in kN/m^2 for Model No.8

Figure 25, 26, 27 and 28 show similar pattern of behaviour with the pressure intensities for different widths of buildings. The NBCI method produced highest values in all cases. For AS/NZS, Model No. 7 and Model No. 8, the maximum induced forces for the said direction is mainly by peak along wind load.

Figure 29 and 30 show the change of applied along wind pressure intensities on structures for 15 storied and 40 storied models, Model No.3, 4 and Model No.7, 8 for zone 1. Models were denoted by M3, M4, M7 and M8 in the graphs. Codes indicate similar behaviour for all wind zones.

Table 16 shows the effect of wind speeds on factors which determine the applied pressure on structure for Model No. 6 and Model No 7. The values were obtained by dividing the final wind pressure by square of reference wind speed. It can be seen that for CP3 and BS6399, there is no effect as they do not consider the wind velocity for the calculation of factors. AS/NZS and NBCI take wind velocity for the calculation of dynamic response factor and gust factor respectively.

Table 17 contained the cross wind pressures applied from the perpendicular direction to the applied wind for AS/NZS. From the data it can be seen that for square building structures having height to breath to depth ratio between 3:1:1 and 6:1:1 , the cross wind effect is more significant than structures having height to breath to depth ratio less than 3:1:1. Model No.6 and Model No. 8 indicate high cross wind pressures against same height buildings Model No. 5 and Model No.7.

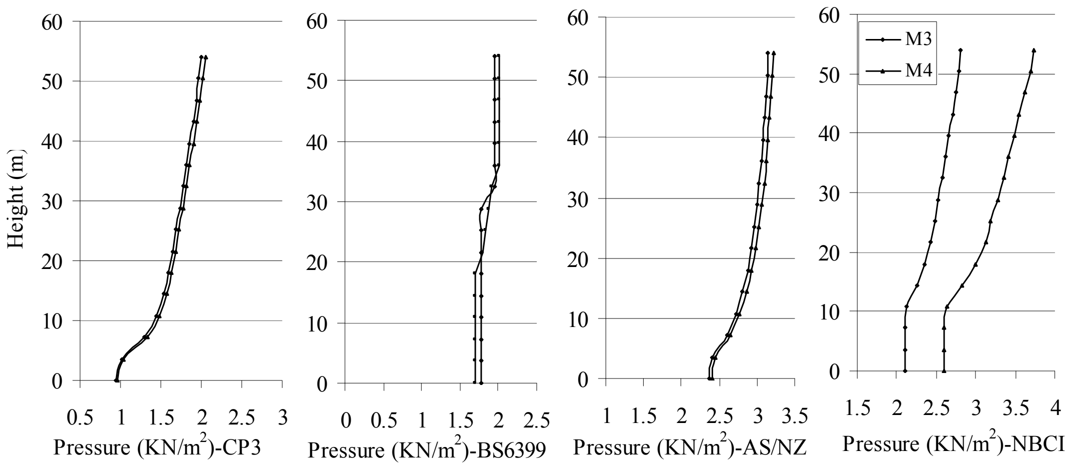


Figure 29 Pressure Intensity in kN/m2 for Model No. 3 and Model No. 4

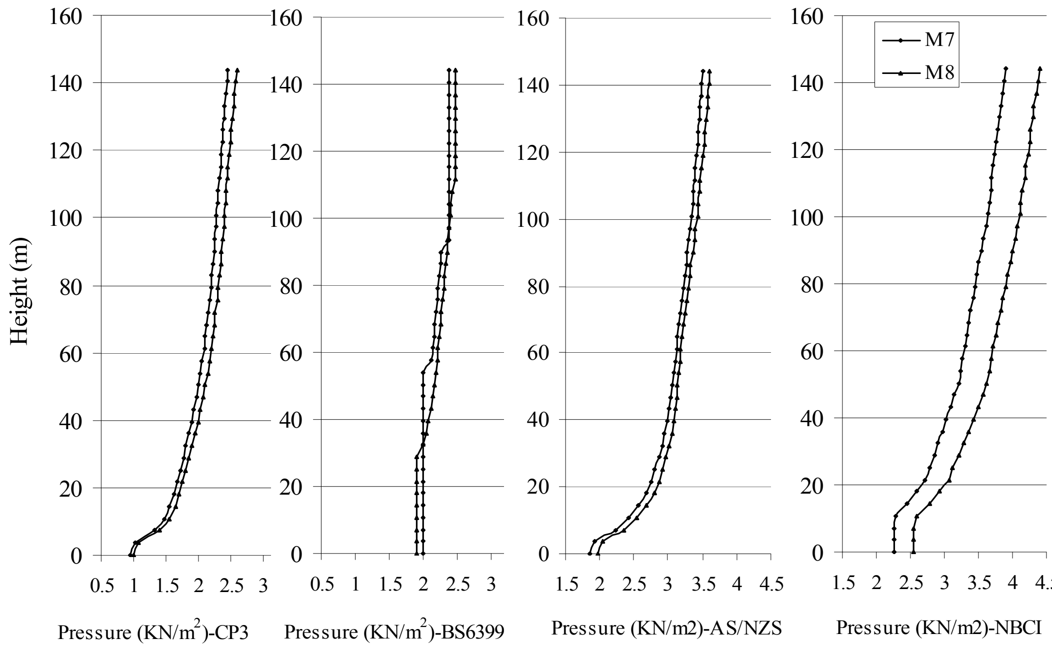


Figure 30 Pressure Intensity in kN/m2 for Model No. 7 and Model No. 8

Table 16 Effect on Relevant Factors from Different Wind Speeds

Height (m)	CP3		BS6399		AS/NZS						NBCI					
	Model No. 6	Model No. 7	Model No. 6	Model No. 7	Model No. 6			Model No. 7			Model No. 6			Model No. 7		
	For all speeds	For all speeds	For all speeds	For all speeds	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3
0	0.35	0.33	0.61	0.70	0.87	0.86	0.85	0.87	0.86	0.86	0.94	0.93	0.91	0.79	0.78	0.77
7.2	0.49	0.46	0.61	0.70	0.95	0.95	0.93	0.95	0.94	0.93	0.94	0.93	0.91	0.79	0.78	0.77
14.4	0.58	0.55	0.61	0.70	1.03	1.02	1.01	1.02	1.01	1.00	1.03	1.01	0.99	0.86	0.85	0.84
21.6	0.61	0.58	0.64	0.70	1.07	1.06	1.05	1.06	1.05	1.04	1.13	1.11	1.09	0.95	0.93	0.92
28.8	0.65	0.62	0.67	0.70	1.10	1.09	1.07	1.09	1.08	1.07	1.19	1.17	1.15	0.99	0.98	0.97
36	0.68	0.65	0.79	0.70	1.12	1.11	1.09	1.10	1.09	1.09	1.24	1.22	1.2	1.04	1.02	1.01
43.2	0.71	0.67	0.71	0.70	1.13	1.12	1.11	1.12	1.11	1.10	1.29	1.27	1.25	1.08	1.07	1.05
50.4	0.74	0.7	0.73	0.70	1.15	1.14	1.12	1.13	1.12	1.11	1.34	1.32	1.29	1.12	1.11	1.09
57.6	0.76	0.72	o.74	0.74	1.16	1.15	1.13	1.14	1.13	1.12	1.36	1.34	1.32	1.14	1.13	1.11
64.8	0.78	0.74	0.75	0.75	1.17	1.16	1.14	1.15	1.13	1.12	1.39	1.37	1.34	1.16	1.15	1.14
72	0.79	0.75	0.77	0.77	1.18	1.17	1.15	1.15	1.14	1.13	1.41	1.39	1.37	1.18	1.17	1.16
79.2	0.81	0.77	0.77	0.78	1.19	1.18	1.16	1.16	1.15	1.14	1.44	1.42	1.39	1.21	1.19	1.18
86.4	0.82	0.78	0.77	0.79	1.20	1.19	1.17	1.17	1.16	1.15	1.47	1.44	1.42	1.23	1.21	1.2
90	0.83	0.78	0.77	0.79	1.21	1.19	1.17	1.18	1.16	1.15	1.48	1.45	1.43	1.24	1.22	1.21
93.6		0.79		0.84				1.18	1.17	1.16				1.25	1.23	1.22
100.8		0.8		0.84				1.19	1.18	1.16				1.27	1.26	1.24
108		0.81		0.84				1.20	1.18	1.17				1.29	1.27	1.25
115.2		0.82		0.84				1.20	1.19	1.17				1.3	1.28	1.27
122.4		0.83		0.84				1.21	1.19	1.18				1.32	1.3	1.28
129.6		0.84		0.84				1.21	1.20	1.18				1.33	1.31	1.3
136.8		0.85		0.84				1.22	1.20	1.19				1.35	1.33	1.31
144		0.86		0.84				1.22	1.21	1.19				1.36	1.34	1.33

Table 17 Crosswind Pressure in kN/m^2 by AS/NZS

Height (m)	Model No. 3			Model No. 4			Model No. 5			Model No. 6			Model No. 7			Model No. 8		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.6	0.19	0.14	0.09	0.21	0.16	0.1	0.03	0.16	0.07	0.08	0.21	0.11	0.02	0.02	0.06	0.05	0.03	0.08
7.2	0.3	0.23	0.15	0.34	0.27	0.16	0.08	0.23	0.11	0.17	0.33	0.17	0.06	0.04	0.09	0.11	0.07	0.14
10.8	0.41	0.31	0.2	0.45	0.35	0.21	0.13	0.28	0.15	0.28	0.44	0.23	0.09	0.06	0.13	0.19	0.12	0.18
14.4	0.49	0.37	0.24	0.55	0.43	0.26	0.18	0.33	0.18	0.4	0.54	0.28	0.13	0.09	0.15	0.26	0.16	0.22
18	0.57	0.43	0.28	0.63	0.5	0.3	0.23	0.37	0.21	0.51	0.63	0.33	0.16	0.12	0.18	0.34	0.21	0.26
21.6	0.64	0.49	0.32	0.71	0.56	0.34	0.28	0.4	0.23	0.64	0.71	0.37	0.20	0.15	0.20	0.42	0.26	0.29
25.2	0.71	0.54	0.35	0.79	0.62	0.37	0.34	0.44	0.25	0.75	0.78	0.4	0.24	0.17	0.22	0.50	0.31	0.32
28.8	0.77	0.59	0.38	0.86	0.67	0.4	0.39	0.47	0.28	0.88	0.85	0.44	0.28	0.20	0.24	0.58	0.36	0.35
32.4	0.83	0.63	0.41	0.92	0.72	0.43	0.45	0.5	0.3	1	0.91	0.47	0.32	0.23	0.26	0.66	0.41	0.37
36	0.88	0.67	0.44	0.98	0.77	0.46	0.5	0.53	0.32	1.13	0.97	0.5	0.36	0.26	0.27	0.75	0.46	0.40
39.6	0.94	0.71	0.46	1.04	0.82	0.49	0.56	0.56	0.34	1.25	1.03	0.53	0.40	0.29	0.29	0.83	0.51	0.42
43.2	0.99	0.75	0.49	1.09	0.86	0.52	0.61	0.59	0.35	1.38	1.08	0.56	0.44	0.31	0.31	0.91	0.56	0.44
46.8	1.03	0.78	0.51	1.15	0.9	0.54	0.67	0.61	0.37	1.5	1.13	0.59	0.48	0.34	0.32	0.99	0.61	0.46
50.4	1.08	0.82	0.53	1.2	0.94	0.57	0.72	0.64	0.39	1.62	1.18	0.61	0.52	0.37	0.33	1.08	0.66	0.48
54	1.12	0.85	0.55	1.24	0.98	0.59	0.78	0.67	0.4	1.75	1.23	0.64	0.56	0.40	0.35	1.16	0.71	0.50
57.6							0.83	0.69	0.42	1.87	1.28	0.66	0.60	0.43	0.36	1.24	0.76	0.52
61.2							0.89	0.71	0.43	2	1.32	0.69	0.64	0.46	0.37	1.33	0.81	0.54
64.8							0.95	0.74	0.45	2.13	1.37	0.71	0.68	0.49	0.38	1.41	0.87	0.56
68.4							1	0.76	0.46	2.25	1.41	0.73	0.72	0.52	0.40	1.50	0.92	0.58
72							1.06	0.78	0.48	2.38	1.45	0.75	0.76	0.55	0.41	1.58	0.97	0.59

Table 17 (Continued)

Height (m)	Model No. 3			Model No. 4			Model No. 5			Model No. 6			Model No. 7			Model No. 8		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
75.6							1.12	0.8	0.49	2.51	1.5	0.78	0.81	0.58	0.42	1.67	1.02	0.61
79.2							1.18	0.82	0.5	2.65	1.54	0.8	0.85	0.61	0.43	1.76	1.08	0.63
82.8							1.24	0.84	0.52	2.78	1.58	0.82	0.89	0.64	0.45	1.84	1.13	0.64
86.4							1.3	0.86	0.53	2.91	1.62	0.84	0.93	0.67	0.46	1.93	1.19	0.66
90							1.36	0.88	0.54	3.05	1.66	0.86	0.98	0.70	0.47	2.02	1.24	0.68
93.6													1.02	0.73	0.48	2.11	1.30	0.69
97.2													1.06	0.76	0.49	2.20	1.35	0.71
100.8													1.11	0.79	0.50	2.29	1.41	0.73
104.4													1.15	0.82	0.51	2.38	1.46	0.74
108													1.19	0.85	0.52	2.47	1.52	0.76
111.6													1.23	0.88	0.53	2.56	1.57	0.77
115.2													1.28	0.91	0.54	2.65	1.62	0.78
118.8													1.32	0.94	0.55	2.73	1.68	0.80
122.4													1.36	0.97	0.56	2.82	1.73	0.81
126													1.41	1.01	0.57	2.91	1.79	0.83
129.6													1.45	1.04	0.58	3.00	1.84	0.84
133.2													1.49	1.07	0.59	3.09	1.90	0.85
136.8													1.54	1.10	0.60	3.18	1.96	0.87
140.4													1.58	1.13	0.61	3.27	2.01	0.88
144													1.62	1.16	0.62	3.37	2.07	0.89

Comparison of Top Displacement of Buildings

Table 18 Normalized Top displacement of each code compared with CP3

	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 2
		Model No. 1			Model No. 2	
CP3	1.00	1.00	1.00	1.00	1.00	1.00
BS	1.04	1.10	1.07	1.01	1.05	1.04
AS/NZS	1.72	1.78	1.84	1.68	1.66	1.66
NBCI	1.52	1.59	1.54	1.55	1.54	1.55
		Model No. 3			Model No. 4	
CP	1.00	1.00	1.00	1.00	1.00	1.00
BS	1.03	1.03	0.99	1.03	1.03	1.04
AS/NZS	1.66	1.63	1.53	1.65	1.64	1.63
NBCI	1.44	1.44	1.36	1.83	1.79	1.60
		Model No. 5			Model No. 6	
CP	1.00	1.00	1.00	1.00	1.00	1.00
BS	0.99	0.99	0.99	1.01	1.01	1.03
AS/NZS	1.57	1.56	1.56	1.59	1.53	1.58
NBCI	1.63	1.61	1.59	1.88	1.80	1.84
		Model No. 7			Model No. 8	
CP	1.00	1.00	1.00	1.00	1.00	1.00
BS	1.02	1.02	1.01	1.00	0.99	1.00
AS/NZS	1.50	1.48	1.47	1.46	1.48	1.42
NBCI	1.59	1.57	1.55	1.68	1.67	1.62

Related to Top Displacement in mm, Table D1 was attached in Appendix D. The difference by BS 6399 was always the lowest difference as indicated by the pressure diagrams. Apart for the Model No. 1 and Model No. 2, in AS/NZ code the change of top displacement was about 50 ±% range. NBCI produced the highest values for all models except Model No.1 to 3. Even though the change in deflections are high for these models, the magnitudes are at the acceptable range. The difference between gust factor method by NBCI and dynamic response method by AS/NZS can be seen from these deflection patterns. NBCI produced higher deflections for slender models, Model No. 4, 6 and 8. But AS/NZS which use along wind and cross wind effects produced 20% less deflection for all range of wind speeds.

Comparison of Induced Forces

For the comparison of resultant forces, all forces were normalized compared with CP3 values. Normalized average pressure intensities (P) were also plotted with resultant force. Induced absolute values of forces due to wind, dead and live loads at support, columns and beams were considered. The averaging of % variation of pressure done by summing % variation at each floor height of the building and dividing it by number of floors. The actual values of forces are given in Appendix E with location. For support, forces denoted as follows-The resultant maximum vertical reaction Fys, horizontal reaction Fxs, and bending moment Mzs. Forces were indicated in global coordinate system. Three zones were denoted as Z1, Z2 and Z3.

Comparison of Support Reactions

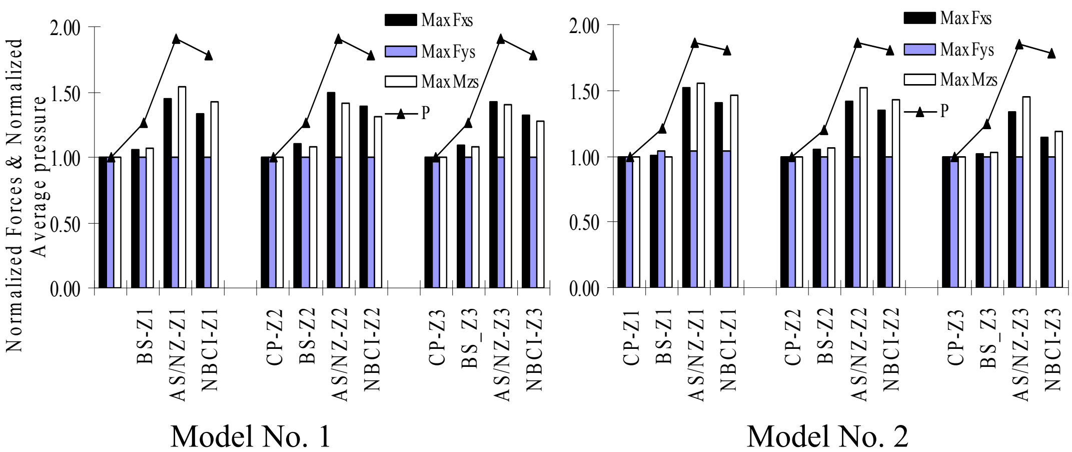


Figure 31 Normalized Induced Forces at Support– Model No. 1 and Model No. 2

The forces induced at support with respect to CP3 are about 1.5 times the CP3 values for the Model No.1. It is about 1.6 times for the model No. 2. The average pressures applied on models are higher from AS/NZS method. Both models produced similar behaviours and the resultants induced forces are comparatively smaller for stiffer model, Model No. 1.

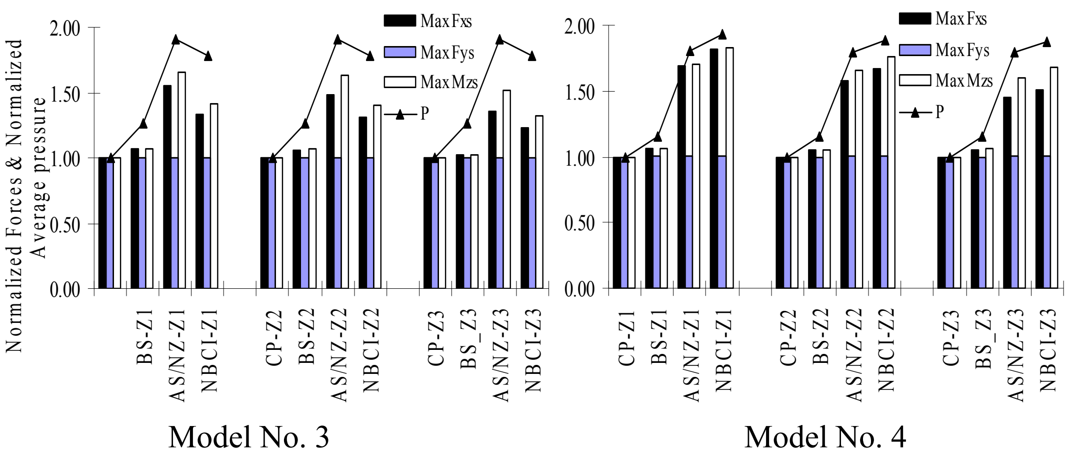


Figure 32 Normalized Induced Forces at Supports– Model No. 3 and Model No. 4

Model No. 3 and Model No. 4 have similar behaviour as previous models with high difference for slender model, especially with respect to NBCI. Model No. 1 up to model No. 4 are frame models.

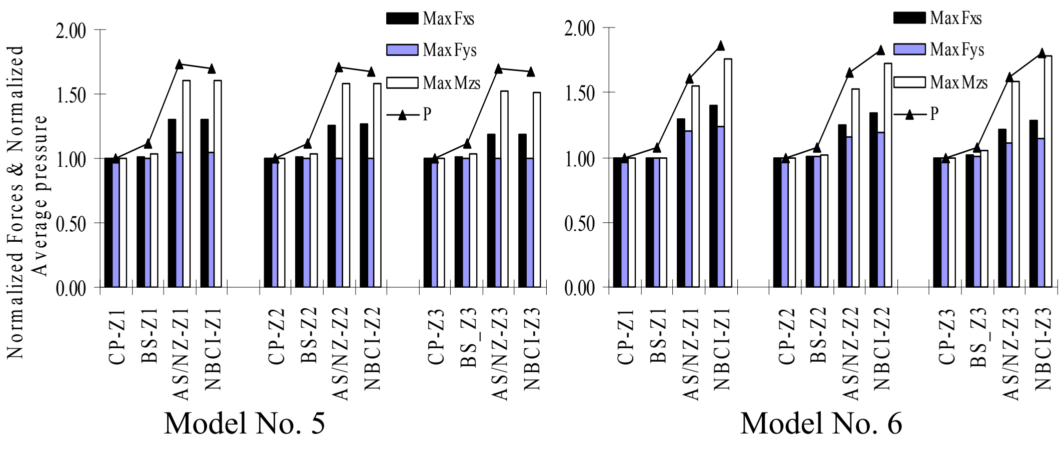


Figure 33 Normalized Induced Forces at Supports– Model No. 5 and Model No. 6

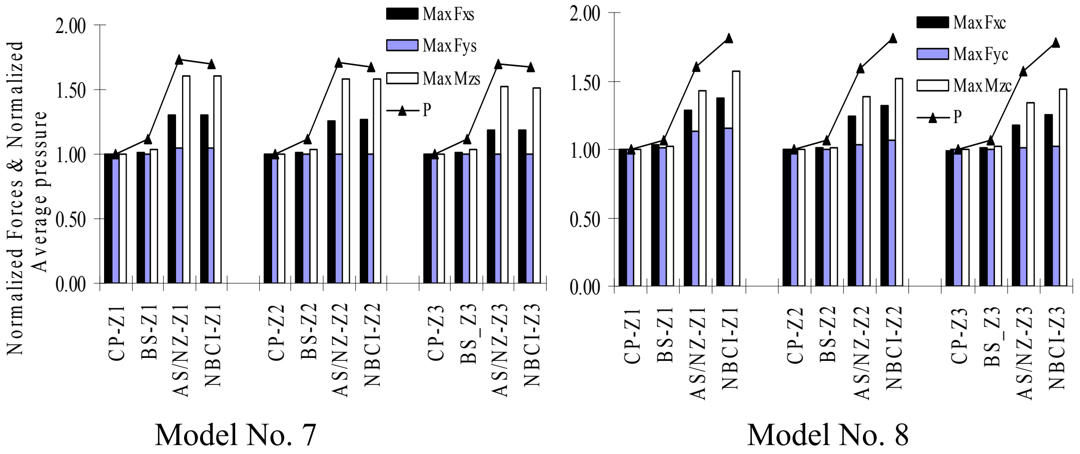


Figure 34 Normalized Induced Forces at Supports– Model No. 7 and Model No. 8

Model No. 5 to Model No. 8 represent the shear wall frame structures. The induced forces at support mainly the support moment have a higher variation. NBCI method produced the highest changes and more prominent in the slender structures.

When overall normalized resultant forces for all models were average with respect to each zone and the following table, Table 19 can be obtained.

Table 19 Normalized Average Resultant Induced Forces at Support

	BS 6399			AS/NZS			NBCI		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Fx	1.03	1.05	1.03	1.41	1.36	1.28	1.40	1.36	1.26
Fy	1.00	1.00	1.00	1.07	1.04	1.02	1.08	1.05	1.03
Mx	1.04	1.07	1.05	1.57	1.53	1.48	1.60	1.54	1.49

From above table it can be seen that both AS/NZS and NBCI methods produced values in same range even though NBCI produced higher responses from Model No. 4. The BS 6399 values are the lowest. Maximum induced moment Mz is about 50% more than CP3 values. The horizontal reaction Fx and axial force Fy have lower effects from the increase in applied wind loads.

Comparison of Induced Forces on Columns

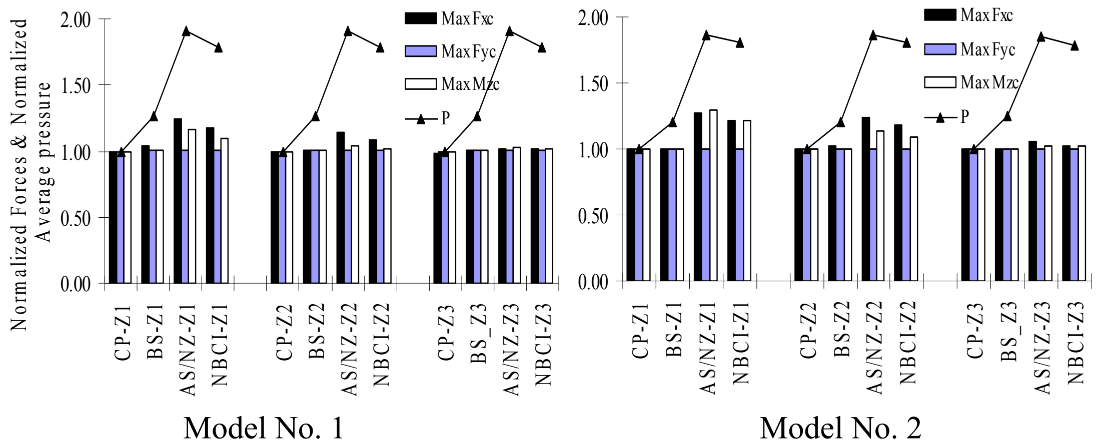


Figure 35 Normalized Induced Forces at Columns– Model No. 1 and Model No. 2

The effect on the 5 storied buildings; Model No. 1 and Model No. 2 are comparatively low when considering the applied average pressure. The maximum induced forces occurred at different location with respect to maximum shear force and maximum bending moment.

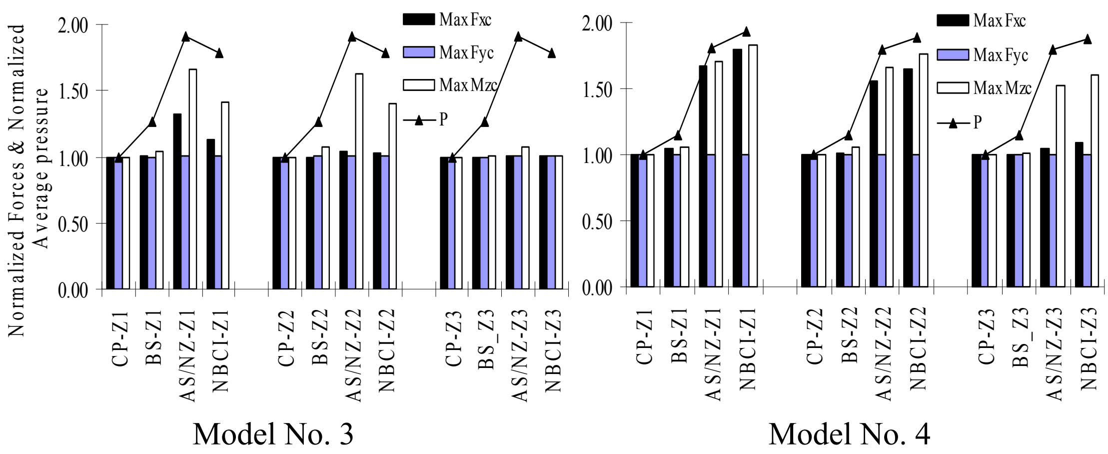
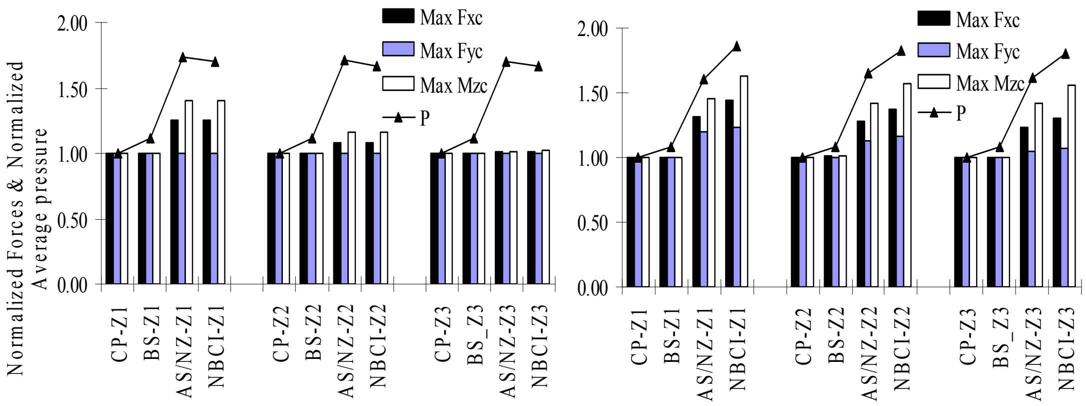


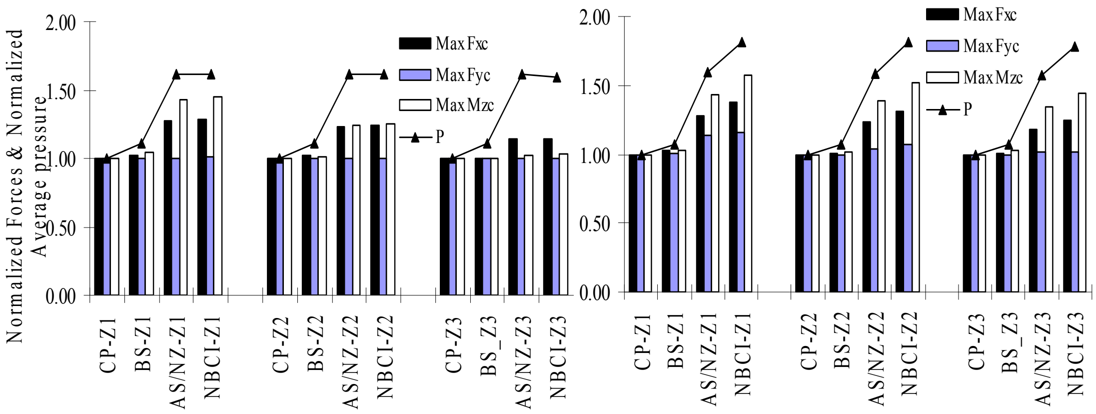
Figure 36 Normalized Induced Forces at Columns– Model No. 2 and Model No. 4

Maximum change can be observed for the maximum bending moment. Change of two procedures by NBCI method can be seen clearly from results.



Model No. 5 Model No. 6

Figure 37 Normalized Induced Forces at Columns– Model No. 5 and Model No. 6



Model No. 7 Model No. 8

Figure 38 Normalized Induced Forces at Columns– Model No. 7 and Model No. 8

From all results it can be seen that the effect on the stiffer building is less than that of the slender building. NBCI produced highest values from Model No. 4. The change of location of maximum forces can be observed. Effects on columns due to applied wind reduced with introduction of shear walls as expected. Similar to induced forces at supports, NBCI method produced high values for slender buildings with compared to that with stiffer buildings at same height. When overall normalized resultant forces for all models were average with respect to each zone the following table, Table 20 can be obtained.

Table 20 Normalized Average Resultant Induced Forces at Columns

	BS 6399			AS/NZS			NBCI		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Fx	1.02	1.01	1.00	1.32	1.22	1.08	1.35	1.24	1.10
Fy	1.00	1.00	1.00	1.04	1.02	1.00	1.05	1.03	1.01
Mx	1.02	1.02	1.01	1.44	1.33	1.18	1.45	1.35	1.21

From above table it can be seen that both AS/NZS and NBCI methods produced values in same range.

Comparison of Induced Forces on Beams

Maximum shear force indicated by Fyb and Maximum Moment indicated by Mzb for the beams

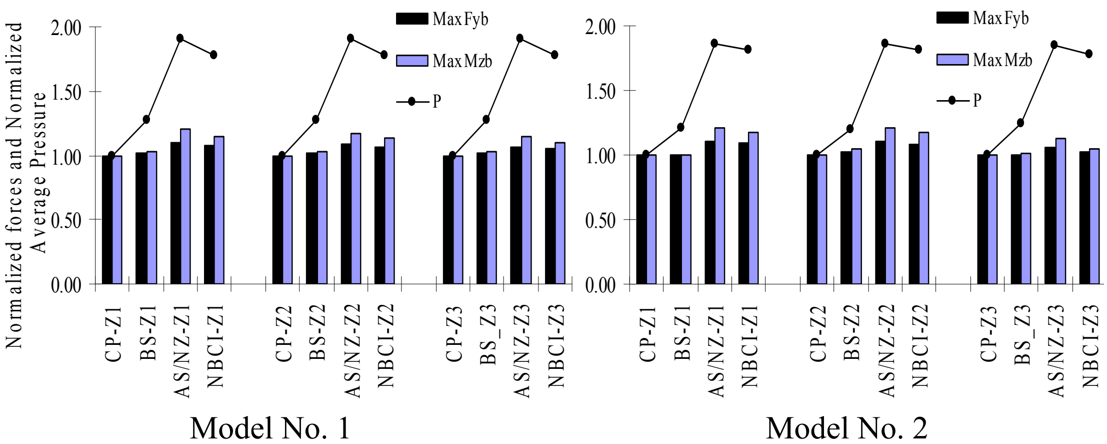


Figure 39 Normalized Induced Forces at Beams– Model No. 1 and Model No. 2

Both maximum shear force Fyb and maximum moment Mzb occurred at same location for both models. The variation due to differences in applied pressure is comparatively very low in both cases. Results indicate that for low rise buildings apart for support reactions, different design pressures evaluated by codes procedures have no significant effect on column and beam reactions.

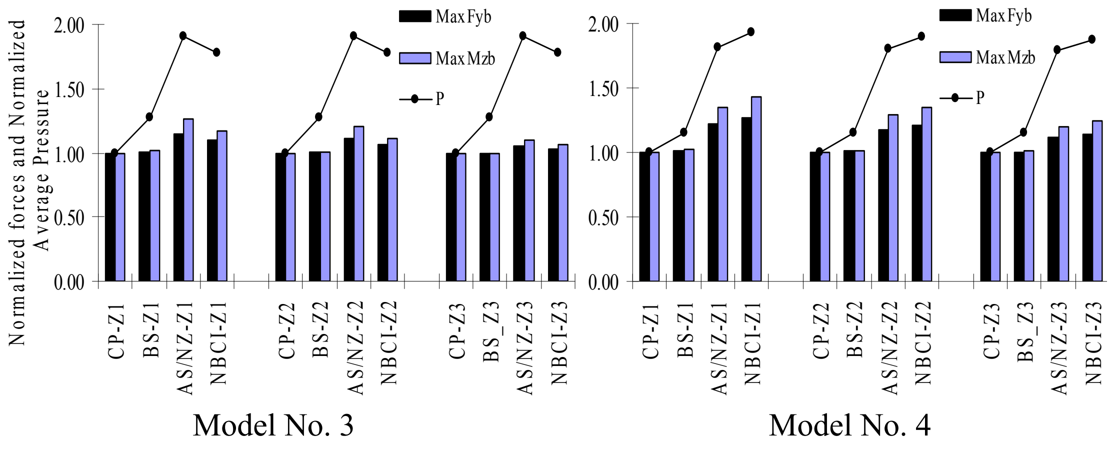


Figure 40 Normalized Induced Forces at Beams– Model No. 3 and Model No. 4

For Model No. 3 and Model No. 4, the effect of change in wind pressures is relatively low. The location of the maximum forces changed only from the floor level it occurred.

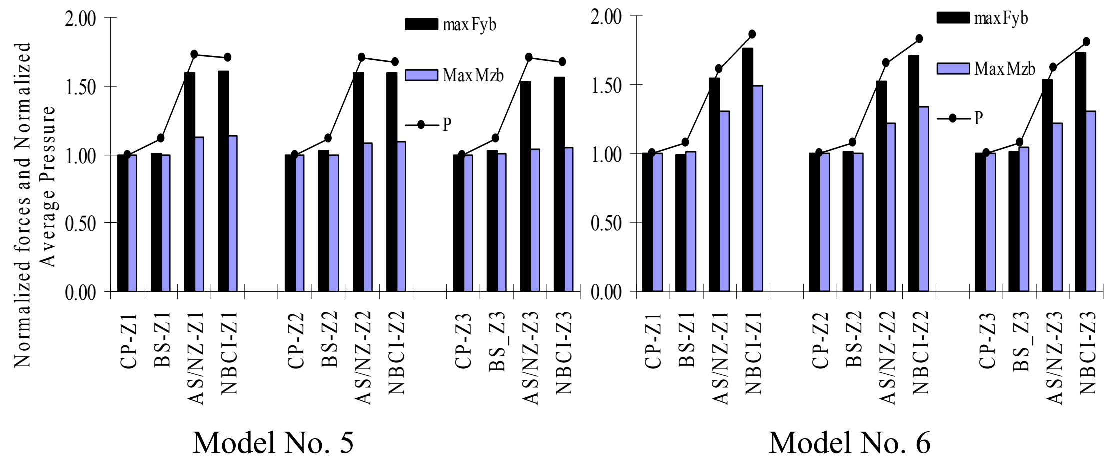


Figure 41 Normalized Induced Forces at Beams– Model No. 5 and Model No. 6

Model No. 5 to Model No. 8 represents the shear wall frame structure. The Maximum shear occurred at the 3 rd floor level beam at the shear core. The maximum moment occurred at same location but at different floor levels. The effects of wind on induced forces are high for these 25 storied models.

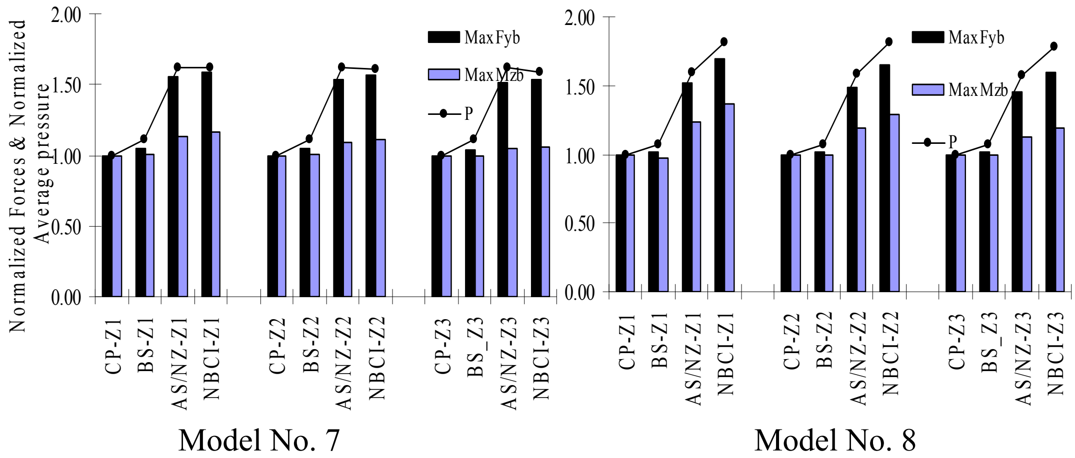


Figure 42 Normalized Induced Forces at Beams– Model No. 7 and Model No. 8

Similar to Model No.5 and Model No. 6 maximum shear force occurred at 3 rd floor level shear core beam. The average forces on all models can be represented by below Table, Table 21.

Table 21 Normalized Average Resultant Induced Forces at Beam

	BS 6399			AS/NZS			NBCI		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Fy	1.01	1.02	1.02	1.34	1.32	1.28	1.38	1.35	1.32
Mz	1.00	1.02	1.01	1.22	1.17	1.1	1.23	1.18	1.12

Above results indicates even though the underlying theories are generally similar in every code, the resultant applied pressure on buildings and the induced forces are different from each other. The values given by BS6399 do not differ from the CP3 code when considering the applied pressure, but much complicated and difficult to implement in a less develop country like Sri Lanka. It can be seen that NBCI produced highest values in each average case and the procedures given by the code based on figure values of the codes. It might have better interpretation of relevant factors if they were produced as some form of formulation so the need of taking approximate values from code figures can be eliminated.

Comparison of Induced Forces on Shear Wall

Absolute maximum principal stress at shear wall is denoted as S max.

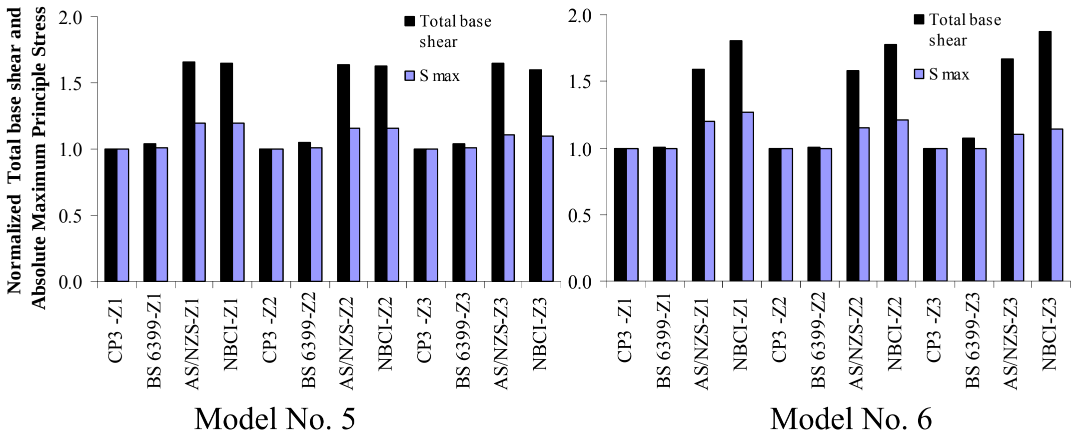


Figure 43 Normalized Induced Forces at Shear Wall– Model No. 5 and Model No. 6

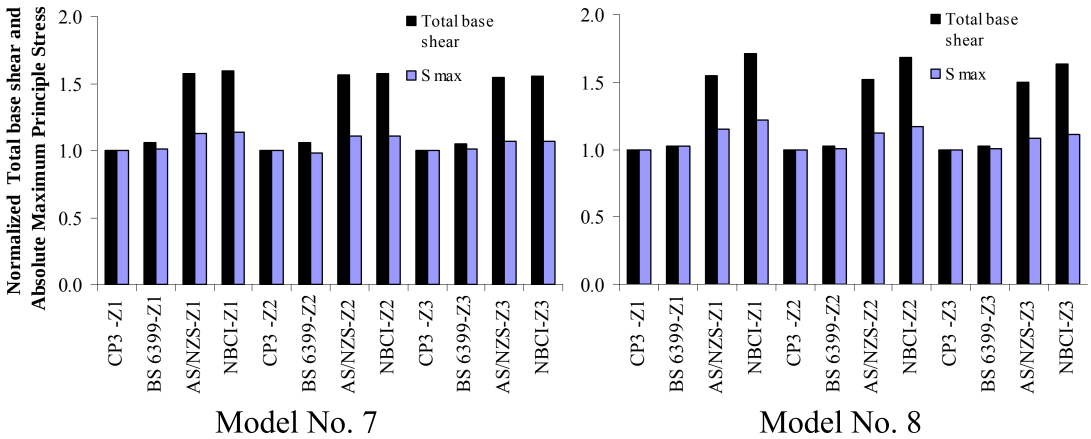


Figure 44 Normalized Induced Forces at Shear Wall– Model No. 7 and Model No. 8

Total base shear and absolute maximum stress of shear walls for Model No. 5 to Model No. 8 indicate that effect due to applied pressure is low for absolute maximum stress induced at shear wall.

Summary

The objective of this thesis was to study the modern wind loading codes used by other countries such as BS 6399, AS/ NZS and NBCI to replace the existing Sri Lankan wind code which was based on BS CP3 Chapter V Part 2(July 1972). The Sri Lankan Manual was published in 1980 and since then no further improvement has been done on this regard.

The proper prediction of design wind speed is one of most important factor for an accurate analysis of the structures. The historical wind data was widely used for the prediction of uncertain wind speeds. Sri Lankan Wind manual divides country in to 3 basic wind zones according to prevailing wind condition in Sri Lanka. North, northeastern and eastern part is zone 1 and west, southwest and south part is zone 3. Remaining middle portion includes vast area of land taken as zone 2. The basic wind speeds for 3 zones from zone 1 to zone 3, given as 53.5 m/s, 47 m/s and 38 m/s for post disaster conditions and later converted as basic gust speed for any type of structure. Reliable gust record data available only from 2 locations for about 4 years on monthly basis, one in zone 1, Trincomalee and other in zone 3, Colombo. The predicted values by proposed method are 75 m/s and 30 m/s. The value predicted for Trincomalee is 40% higher than the value in wind zoning map. At least few more 3 year periods data are available, the above values can be verified. Due to this reason it can be concluded that use of available map is more suitable than a value predicted based on very few data.

The study mainly focused on the enclosed buildings and the buildings models were ranged by their heights from 5 stories to 40 stories. Advance experiments and researches were done from the time of making of Sri Lankan wind code and incorporated in modern wind codes. The effectiveness of each code with respect to design wind speed, the height of the building and width of the building were considered. All building models were square type and categorized into 4 groups considering height, each group with different horizontal dimension. 5 storied and 15 storied buildings were modelled as frame structures and 25 storied and 40 storied

models were modelled as frame with shear wall core systems. Three dimensional finite element method was used in the analysis of all models. Shear walls were meshed by 0.6 m x 0.6 m plate elements.

CP3 which is simple in it's approach for finding wind loading on structures, but made in 1970's and many advance knowledge gain about wind engineering in last few decades were not reflected in the code. The applied pressure on a building is depended on design wind speed (V_s) and the force coefficient C_f. All factors can be obtained from code tables. For a same building in different wind speeds, apart from numerical change in wind speed all other factors remain unchanged.

BS6399 included gust factor and mildly dynamic conditions. It produced almost similar wind pressures and subsequently induced forces to that of CP3. Code provide 2 methods for calculating design wind pressures and the standard method which does not use directional wind speed and directional method which is more complex and generally less conservative. The advance method, directional method needs directional wind speeds for accurate results. Both of these methods are not applicable to Sri Lankan conditions. The directional method is unique and code has unique features in relation to the calculation of design wind speed. But as discussed before they are more country specific and advance. The total external pressure coefficient for all models considered was 1.1 and values were changed with depth / height ratio (D/H). Internal pressure coefficient can be neglected for enclosed building. When overall loads are applied considering leeward and windward surfaces a reduction factor of 0.85 allows for the non simultaneous action.

AS/NZS contains procedure for calculation of dynamic response and classifies dynamic structures as those having first mode natural frequency less than 1 Hz. Among these codes, AS/NZS consider the dynamic along wind and cross wind responses of tall buildings. Cross wind force spectrum coefficients derived from wind tunnel data. Mendis *at el.*, (2007**)** noted that there are many examples of slender structures that are susceptible to dynamic motion perpendicular to the direction of wind. The external pressure on leeward face taken as a constant pressure equals to value at the top of the building. The effects of building height, depth and wind speeds were considered for calculation of design wind pressures. Cross wind effects have more influence on slender structures.

NBCI procedure has less calculation than AS/NZS procedure and use similar criteria to define dynamic situation. The code suggested that it does not included methods of calculating loads for across wind or other component due to non maturity of procedures fully for all types of structure at the time of drafting the code. This suggests that AS/NZS has more advance methods comparing to other codes. Force coefficient changed with the dimensions of the building and can be obtained from a graph. The gust factor changed for different heights and depth and also for different wind speeds.

From the pressure comparison of all wind loading codes, it can be seen that both British standards, CP3 and BS6399 used for comparison produced less wind pressure forces on buildings in all different conditions with respect to building dimensions and wind speeds. The graphs of changing pattern of wind pressure with relation to horizontal dimension of a building indicated that NBCI produced high change in applied pressure with respect to change in horizontal dimension of a building with same height. Similarly AS/NZS produced high change in applied crosswind pressures with respect to change in horizontal dimension of a building with same height.

Top displacements showed similar behavior to that of applied pressures. BS 8100 Part 2 1985 Structural use of concrete – Code of practice for special circumstances stated that excessive response to wind at service load , with respect to deflection has to be limited to $h_s/500$, where h_s is story height for single story. Allowable deflection of the whole structure under applied loads are 36 mm, 108 mm, 180 mm an 288 mm for 18m , 54 m , 90m high and 144 m height respectively. Any of the code values with respect to all codes except NBCI for Model No. 8 do not exceed the permitted values.

From comparison of support reactions, column forces and beam forces, beam absolute forces have the smallest change with respect to all codes. The change in average basis is less than 40% for all range of buildings. The biggest change is shown for supports and a maximum value is about 60% higher than CP3 value. Shear walls show similar pattern of behaviour while change in absolute maximum principle stress remain relatively low. Total base shear on shear walls are directly correlated to the applied pressures. For all range of buildings, effects are comparatively less for the wind zone 3 and reduced from wind zone 1 to wind zone 3, especially with respect to AS/NZS and NBCI.

All buildings higher than 15 stories are located at Capital city of Sri Lanka and according to Wikipedia, the free encyclopedia list, there are 25 buildings situated Colombo which falls under zone 3 of the wind zoning map of Sri Lanka. A well organized survey must be done with respect to design criteria used for all buildings higher than 10 stories through out the country to establish the present practice with respect wind loading on medium rise buildings. Simplified procedures from code and standard might lead to uneconomical or inadequate results. As the Sri Lankan construction industry of medium to high rise buildings is being in infant stage with only 25 buildings higher than 15 stories in capital city of Colombo, best option may be to adopt an advance method of wind force evaluation so design engineers will be fully equipped with knowledge for the future. Average maximum values at support shear force, axial force and bending moment for zone 3 by AS/NZS are 1.28, 1.02 and 1.48 times the CP3 values. For columns, average maximum for shear force, axial force and bending moment for zone 3 are 1.08, 1.02 and 1.18 times the CP3 values respectively. For beams average maximum shear force and bending moment are 1.28 and 1.1 times the CP3 values. If terrain height multiplier from CP3 used in conjunction with AS/NZS procedures the applied pressures as well as induced forces will be reduced.

CONCLUSION

In view of structural engineers, all buildings should be design to resist the worst wind loading applied during their life time. Hence it is necessary to predict wind loading more accurately. Often wind loading codes are consistent with the knowledge of the structure of the wind storms in their country of use. Codes based on extensive research. But they include simplified procedures for practical engineers. With the advancement of wind engineering, most unpredictable factors of natural wind phenomena can be predicted fairly and accurately.

The available data from the department of Meteorology of Sri Lanka were for a very short period of about 4 years and was found to be inadequate for a conclusive prediction of basic design wind speeds. The basic wind speeds provided by the existing wind Manual was used for further analysis. The basic gust wind speeds were taken as 53.4 m/s, 47 m/s and 38 m/s for zone 1, zone 2 and zone 3 respectively.

As BS 6399 and CP3 produced similar pressure pattern for all aspects with respect to width and height of a building, the adoption of the procedure provided by BS 6399 may be simply a change of procedure. Most of country specific factors can not be used in Sri Lanka. The evaluation of factors need extremely high quality data base with respect to location of the site. The availability of such advanced data base is questionable for a developing country. The average changes of pressures are 25% to 10% higher than CP3 for all range of buildings for all wind zones. The change of average pressures reduced with the height of the building.

NBCI produced high pressure intensities for dynamic structures and use mean wind speed and peak gust factor format. Two methods specified by the code indicate complete discontinuity of procedures. The gust factor procedure is mainly based on readings from figures of the code. Main disadvantage of this method is that the collective error of approximations may be high at times which will leads to uneconomical designs. Similarly the error may be low and which leads to under design of structures. The changes of average pressures are 90% to 55% higher than CP3, but do not indicate a pattern of change. The lowest value 55% is for the Model No.3.

AS/NZS uses the most elaborate method for the prediction of wind loads on structures. Code incorporated along wind and cross wind effects. Some structures particularly that tall or slender, response dynamically to the effect of wind. Structures may be wind sensitive in line with wind direction due to turbulence and cross wind response due to vortex shedding or galloping. For same height of buildings crosswind effects are more prominent for slender structures. The procedure is clear but need vigorous mathematical calculations. With the advanced computer systems, an accurately developed spreadsheet can be a useful technique to overcome this barrier. The average changes of pressures are 90% to 60% higher than CP3 for all range of buildings for all wind zones. The change of average pressures reduced with the height of the building.

BS 6399 has the minimum variation of top displacement and maximum value higher than CP3 is less than 10%. AS/NZS values are 42% to 84% higher than CP3 and NBCI values are 36% to 88% higher than CP3 values. Except for Model No. 1, AS/ NZS values are about 60% higher than CP3 values. NBCI procedure produces excessive deflection for slender buildings models for same height.

Induced forces due to applied loads follow similar pattern as top displacement but with reduced magnitude. BS 6399 procedure resulted with similar forces to that of CP3 and AS/NZS and NBCI procedures with higher resultant forces. Effects due to change of applied pressures are high at supports and less at beams. The maximum variations are for zone 1 and minimum variations are for zone 3 where most of medium to high rise buildings are located in Sri Lanka. Change in induced forces at supports are maximum from NBCI and for support moment, average value varied from 60% to 50% higher than CP3 from zone 1 to zone 3. For columns from same code, column moments are varied from 45% to 21% and for beam, beam shear forces are varied from 38% to 20% from zone 1 to zone 3. AS/NZS procedure has similar values to that of NBCI. But there are major differences between NBCI and AS/NZS induced forces with slender buildings. NBCI method produced much higher induced forces for buildings having higher height to breath ratio.

The natural frequency formulae from the BS 6399 can be adopted in new code as Sri Lanka use similar standard in building construction. Adoption of k factor 0.59, 0.57, 0.56 for 3 wind zones can be discarded and 0.6 can be used. The code must be a trade off between safety and economy with more emphasis on safety. Country specific factors can be excluded till more investigations done locally. The factors like shielding need special attention. Even though AS/NZS produced average 40% more induced forces, it is versatile in every aspect with clear procedures. AS/NZS included procedures for cross wind response analysis. Terrain height factor affected design wind speed and 10 ± % higher in AS/NZS. With careful investigation of local practice, the values for this factor can be determined. AS/NZS is a viable alternative especially with respect to high rise building design in Sri Lanka.

Availability of wind data with other Sri Lankan authorities like Sri Lanka Electricity Board used for wind power generation for national grid may be a useful alternative for the prediction of extreme winds in Sri Lanka. Further investigation of other aspect of AS/NZS code is recommended for the implementation of full version of the code. Few models have to be designed with factored loads using CP3 and AS/NZS to evaluate cost implication from new code.

LITERATURE CITED

Asia Society. 2007. **Sri Lanka.** Available source. http://www.askasia.com. 2007.

AS/NZS 1170.2**.** 2002. **Australian/ New Zealand Standard: Structural design Actions Part 2: Wind Actions.** Standard Australia, Sydney.

AS/NZS 1170.2 Supplement 1**.** 2002. **Structural design –Action Commentary** Standard Australia, Sydney.

BS CP3**.** 1972. **Code of Basic data for the design of buildings Chapter V Loading - Part 2 Wind Loads** British Standard Institution, London.

BS 6399. 1997. **Loading for Buildings Part 2. Code of Practice for wind loads.** British Standard Institution, London.

Davenport, A.G. 1967. Gust loading factors. **Journal of structural engineering (ASCE)** June 11-34

Davenport, A.G. 1960. Wind load on structures**. Technical paper No 88**. Division of Building Research. Building Research Council. Canada

Dyrbye, C., S.O. Hansen. 1997. **Wind Loads on Structures**. John Wiley & Sons Ltd. West Sussex

IS 456. 2006. **National Building code of India Part 6 section 1 Clouse 6** Bureau of Indian Standard, New Dellie

Mendis, P., T. Ngo, N Haritos, A. Hira, B. Samali, J cheung. 2007. Wind loads on tall buildings. **E- journal Structural Engineering International(eJSE)** 41-45

Ministry of Local Government, Housing and Construction, Sri Lanka. 1980 **Design of buildings for high winds – Sri Lanka.** Colombo.

Newberry, C.W., K.J. Eaton. 1974. **Wind loading handbook.** Building Research Station, London

Sesma, J.S., J. Aguirre, M. Sen. 1998. Simple modelling Procedure for Estimation of Cyclone wind speeds. **Journal of structural engineering (ASCE**) February 352-370

Simu, E., R. Scanlan. 1996 **Wind effects on structures: Fundamentals and applications to design**. 3 rd edition. John Wiely & Sons, INC, NY

Solari, G. 1987. Turbulence Modelling for Gust Loading. **Journal of structural engineering (ASCE).** February 1550-1569

Vellozzi, J., E. Cohen. 1968. Gust response Factor **Journal of structural engineering (ASCE**) June 1295-1313

Weggel, R.G. 1999. Maximum daily wind gusts related to mean daily wind speed. **Journal of structural engineering (ASCE).** April 465-468

Woelwine-Moen Group. 2007. **Indian Sub Continent.** Available source. http://www.worldatlas.com. 2007.

Zhou, Y., A. Kareem. 2002. Definition of wind profiles in ASCE-7. **Journal of structural engineering (ASCE).** August 1082-1085

Zhou, Y., T. Kijewski, A. Kareem, 2002. Along-wind loads effects on tall buildings: Comparative study of major international codes and standards, **Journal of structural engineering (ASCE).** June 788-796

APPENDICES

Appendix A

Wind Speeds Data

Appendix Table A1 Monthly Basic Gust Wind Speed in Km/h (Trincomalee) -Wind Zone 1

	Year-1991	Year- 1992	Year-1993	Year - 1994	Year-1995
January		118.8	133.0	133.2	144.0
February		72.0	142.2	149.4	
March		97.2	109.8	163.8	
April		90.0	145.8	126.0	
May		97.2	158.4	158.4	
June		126.0	194.4	133.2	
July		115.2	162.0	162.0	
August		165.6	158.4	165.6	
September		165.6	158.4	187.2	
October		187.2	162.0	187.2	
November	136.8	176.4	153.0	162.0	
December	158.4	160.3	142.5	151.2	

Appendix Table A2 Monthly Basic Gust Wind Speed in Km/h (Colombo) - Wind Zone 3

	Year-1991	Year- 1992	Year-1993	Year - 1994	Year-1995
January		42.5	42.5	40.0	42.5
February		45.0	45.0	40.0	45.0
March		40.0	50.0	37.5	40.0
April		60.0	42.5	47.5	40.0
May		60.0	65.0	80.0	52.5
June		65,0	75.0	70.0	80.0
July	60.0	50.0	62.5	52.5	62.5
August	52,5	45.0	62.5	50.0	42.5
September	55.0	42.5	55.0	51.5	52.5
October	60.0	75.0	60.0	65.0	65.0
November	90.0	52.5	45.0	60.0	47.5
December	42.5	45.0	65.0	47.5	40.0

Appendix B

Sample Calculation

Calculation of pressure intensity applied on the building

Sample calculations for all 4 codes were given below.

Sample calculation CP 3 Chapter V Part 2

For zone 1 – Building model 7- 144mx54mx54m – Wind pressure at 144 m level

The dynamic pressure of wind is given by Equation (5).

$$q = kV_s^2$$

Where “k” is a constant and taken as 0.613 (common practice)

Design wind pressure is given by Equation (6)

$$V_s = V_b S_1 S_2 S_3$$

Where, V_b =basic wind speed – gust speed =53.5m/s

S_1 = Topography factor- normally taken as 1

S_2 =Ground roughness, building height and height above ground level factor taken from Table 3 of code

For open country with no obstructions with class C building category,

Class C- All buildings and structures whose greatest horizontal dimension or the greatest vertical dimensions exceeds 50 m.

140 m - 1.17

$\longrightarrow$ 144 m – 1.174

160 m – 1.19

S_3 =The factor based on statistical concepts and normally taken as 1 for permanent buildings

$V_s = 53.5 \times 1 \times 1 \times 1.174$ =62.81 m/s

Dynamic wind pressure

$q = kV_s^2 = .613 \times 62.81^2$ =2418..34N/m^2

Force applied on a building is given by Equation (7).

$$F = C_f q A_e$$

Force coefficient C_f from Table 10 – Force coefficient for rectangular building with flat roofs- 1.0167 (from interpolation)

$F = 1.0167 \times 2418.27$ /1000 per unit area = 2458.64 N/ m^2 = 2.46 KN/m^2

Sample calculation BS 6399

For zone 1 – Building model 7- 144x54x54m- Wind pressure at 144 m level

Building height is more than 100m. So the directional method was used.

Directional Method

The value of the dynamic pressure q_s is given by Equation (8).

$$q_s = 0.613V_e^2$$

0.613 is the “k” factor.

V_e = the effective wind speed in m/s and given by the Equation (9).

$$V_e = V_s S_b$$

Where S_b = the terrain and building factor which can be obtain from table of the code.

V_s = the site wind speed abstains for the range $\theta = \pm 45^0$ around the notional orthogonal wind directions define by the Equation (10).

$$V_s = V_b \times S_a \times S_d \times S_s \times S_p$$

Where, V_b = basic wind speed viz the mean hourly speed =53.5/1.78=30.06 m/s

S_a = altitude factor is the factor to adjust the basic wind speed for the altitude of the site above sea level- taken as 1

S_d = directional factor & taken as 1.00 for all directions

S_s = Seasonal factor and & taken as 1.00 for permanent structures

S_p = probability factor, for normal design applications taken as 1.00

Consider open country category

For country terrain S_b is given by the Equation (11).

$$S_b = S_c[1 + (g_t \times S_t) + S_h$$

S_c = the fetch factor obtained from the Table 22 of the code =1.648

S_t = the turbulent factor obtained from table of the code = 0.0897

For the calculation of gust factor – Building was divided according to code suggestion, Bottom part 54 m from ground (equal to cross wind breath) and 54 m from top of the building. Middle part was divided to 3.6 m lengths for more accuracy.

Reference height (H_e) = 144 m

Diagonal length $= \sqrt{(54^2 + 54^2)}$ =76.4 m

Appendix Table B1 Gust Factor from Table 24 of BS 6399

Effective height H_e -m	Diagonal length a -m	
	40	100
100	2.79	2.4
200	2.84	2.47

g_t = the gust peak factor – using diagonal length of 76.4 m = 2.65

S_h = the topographic increment = 0

$S_b = 1.648[1 + 3.44 \times 0.0897) + 0$ =2.04

Design wind speed = 2.04x 30.06 =61.3m/s

P_s -dynamic wind pressure $= 0.613 \times 61.3^2$ =2304.7 N/m^2

The overall horizontal load applied on a building is by the Equation (12) for both standard and directional methods

$$P = 0.85(\sum P_{front} - \sum P_{rear})(1 + C_r)$$

Where P_{front} = net pressure across the surface for front face

P_{rear} = net pressure across the surface for rear face

C_r =Dynamic augmentation factor C_r =1.1 from figure 8 of code

$$p_{front} = p_{rear} = (p_e - p_i)A$$

Where p_e is the external pressure and given by the Equation (14)

$$p_e = q_s C_{pe}$$

Where q_s = the dynamic pressure

C_{pe} = the external pressure coefficient

Where $p_i = q_s C_{pi}$ is the internal pressure

The internal pressure coefficient for enclosed buildings can be neglected. The net force can be determined using external pressure coefficient on front and rear faces. The factor of $(1 + C_r)$ for the mildly dynamic nature and 0.85 for the non simultaneous action between faces.

Total pressure coefficient on front and rear face- From table 26 of code =1.1

$P = 0.85(1+.1)(1.1)*\{2304.7\}$ /1000 per unit area =2.39 KN/m^2

Sample calculation AS/NZS

For zone 1 – Building model 7- 144 x54 x54m- Wind pressure at 144 m level

Check for Building type using natural frequency

Natural frequency n_o = 46/ height =46/144 =0.319 Hz

This is less than 1 Hz and the Building come under dynamic nature. C_{dyn} factor was calculated for dynamic effects

Gust loading factor method

The design wind pressure p is given by the Equation (16).

$$p = (0.5\rho_{air})(V_{des,\theta})^2 C_{fig} C_{dyn}$$

Where p = design wind pressure acting normal to a surface, in Pascal

ρ_{air} = density of air, which shall be taken as 1.2 Kg/m^3

$V_{des,\theta}$ = the maximum cardinal wind speed $V_{sit,\beta}$

C_{fig} = aerodynamic shape factor

C_{dyn} = dynamic response factor (the value is taken as 1.0 except where the structure is wind sensitive

$V_{sit,\beta}$, the site wind speed is for the 8 cardinal directions at reference height and given by the equation (17).

$$V_{sit,\beta} = V_R M_d M_{Z,cat} M_s M_t$$

Where V_R = regional 3 second gust speed in m/s for relevant annual probability of ascendance

M_d = Wind direction multiplier- taken as 1

$M_{cat,\phi}$ = terrain height multiplier- at 144 m height – From table 4.1(A)- category 1(open country) =1.308

M_s = shielding multiplier – taken as 1 for open country

M_t = topographic multiplier-taken as 1

$V_{sit,\beta}$ = 53.5x1x1.308x1x1 = 70 m/s

Along wind effect

C_{dyn} is given by the Equation (18)

$$C_{dyn} = \frac{1 + 2I_h \left[{g_v}^2 B_s + \frac{H_s {g_R}^2 S E_t}{\zeta} \right]^{0.5}}{(1 + 2 g_v I_h)}$$

Where S = height of the level at which action effected are calculated for the structure -144 m

H = average roof height of structure above ground -144 m

I_h = turbulence intensity from table 6.1 of the code for z=h =0.0966

g_v = peak factor for the upward velocity fluctuation (from code) =3.7

B_s = background factor

$$B_s = \frac{1}{1+\left[.26\left(h-s\right)^2+.46{b_{sh}}^2\right)\Big]^{0.5}/L_h}$$

Where b_{sh} =average breath = 54 m

L_h = 85 (h/10)$^{0.25}$ =165.58

H_s = height factor for the resonant response

$= 1+(s/h)^2$=1+(144/144)^2 =2

Substituting above values

B_s =0.8189

g_R = peak factor for resonant response (10 min period) is given as follows,

$$g_R = \sqrt{2\log_e}(600n_c)$$

Where n_c is natural frequency in cross wind direction = n_a = natural frequency in along wind direction = 46/144 = 0.3194

g_R = 3.242

S = size reduction factor is given as follows,

$$S = \frac{1}{\{1+\dfrac{3.5n_a h(1+g_v I_{h)}}{V_{des\theta}}\}\{1+\dfrac{4n_a b_{oh}(1+g_v I_{h)}}{V_{des\theta}}\}}$$

Where b_{0h} is average width = 54 m

Substituting values

S = 0.104

$E_t = \pi/4$ times the spectrum of turbulence in the approaching wind stream

Given by $= \dfrac{\pi N}{(1+70.8N^2)^{3/8}}$

Where N = reduced frequency and given by $= n_a L_h [1 + (\ g_v I_h)\ ] / \ V_{des\theta}$

Substituting values

N =1.0262

E_t =0.0877

ζ = ratio of structural damping to critical damping of the structure – from table 6. 2 of the code = 0.05 for concrete structures for ultimate design

Substituting above values in equation

C_{dyn} =1.02

C_{fig} = aerodynamic shape factor (external pressure coefficient of front and rear faces were taken from table 5.2(A) and 5.2(B) =1.3

Action combination factors for wind pressure contributing from two or more building surfaces to effects on major structural elements - K_a - form table 5.5

Considered a value between two cases below

Case (a) -where wind action from any single surface contribute 75% or more to an action effect =1.0

Case (b) – Pressure from windward and leeward walls in combination with positive or negative roof pressure =0.8

The K_a factor was taken as 0.9 for this case with force applied on two faces

Pressure intensity on the building at 144 m height

$$p = (0.5\rho_{air})(V_{des,\theta})^2 C_{fig} C_{dyn} = 0.5 \times 1.2 \times 70^2 \times 1.02 \times 1.3 \times .9 \quad =3504.28 \text{ N/ m}^2$$

Force intensity applied at height 144 m = 3504/1000 / unit area =3.504kN/ m^2

Cross wind effects

The equivalent cross wind static wind force per unit height as a function of height (Z) in Newton per metre is given as follows by Equation (19),

$$W_{eq} = 0.5\rho_{air}[V_{des,\theta}]^2 dC_{fig}C_{dyn}$$

Where $V_{des,\theta}$ is devalued at overall building height

d is the horizontal depth of structure parallel to the wind stream

$C_{fig}C_{dyn}$ as follows as for Equation (20)

$$C_{fig}C_{dyn} = 1.5 g_R (\frac{b}{d}) \frac{K_m}{(1+g_v I_h)^2} (\frac{z}{h})^k \sqrt{\pi C_{fs} / \varsigma}$$

Where K_m=m ode shape correction factor for crosswind acceleration and given by Equation (21),

$$K_m = 0.76 + 0.24k$$

Where k is mode shape power exponent for the fundamental mode -1 for building with central core and moment resisting facade.

C_{fs} is cross wind force spectrum coefficient generalized for a linear mode shape

$K_m = 0.76 + 0.24k = 76 + 0.24 \times 1.0$ =1.0

C_{fs} is cross wind force spectrum coefficient calculated using reduced velocity and reduced velocity(V_m) has to be calculated at z=h =144m

$$V_m = \frac{V_{des,\theta}}{n_c b(1 + g_v I_h)} = \frac{70}{0.3194 \times 54(1 + 0.0996 * 3.7)}$$ =2.98

Value of C_{fs} can be calculated from below equation for a square building type of 3:1:1(h:b:d) 144:54:54 = 2.67:1:1

For a turbulent intensity of 0.12 at 2h/3 height where the V_m range between 2 to 6 following equation can be used.

$$\log_{10} C_{fs} = 0.000353V_m^4 - 0.0134V_m^3 + 0.15V_m^2 - 0.345V_m - 3.109$$

$$\log_{10} C_{fs} = 0.000353 \times 2.98^4 - 0.0134 \times 2.98^3 + 0.15 \times 2.98^2 - 0.345 \times 2.98 - 3.109$$

=-3.1553 C_{fs} = 0.0006993

Substituting above value in equation (20)

$$C_{fig} C_{dyn} = 1.5 \times 3.242(\frac{54}{54})\frac{1.0}{(1 + 3.7 \times 0.0966)^2}(\frac{144}{144})^{1.0}\sqrt{\pi \times 0.000693 / 0.05}$$

=0.553

Substituting above values in Equation (19)

$W_{eq} = 0.5 \times 1.2[70]^2 \times 1 \times 0.553$ =1.63 KN/m^2

Considering load combinations using peak and mean values

The mean loads are obtained from dividing the peak loads by a gust factor given by:

$[C_{dyn}(1+2g_v I_h)]$=$[1.02(1+2\times 3.7\times 0.0966)]$ =1.75

1 [mean along wind load + 0.75 (peak- mean) along wind] with 0.75 [peak-mean] cross wind from 2 orthogonal directions =3.13 KN/m^2 and 0.52 KN/m^2

2 [mean along wind load + 1.0 (peak- mean) along wind] =3.50 KN/m^2

3 [1.0(peak-mean)]crosswind =1.62 KN/m^2

The pressure intensities for load case 1, 2 and 3 applied for the whole structure and the wind profile which produced maximum induced forces was consider for the comparison.

Sample calculation National Building code of India -2006

For zone 1 – Building model 7- 144x54x54m- Wind pressure at 144 m level

Check for Building type using natural frequency

Natural frequency n_o = 46/ height =1/T_n =1/1.763 =0.567Hz

Where T_n is fundamental natural period and given by following equation for building with infill walls.

$T_n = 0.09H/\sqrt{b}$ = 0.09x144/√54 \ =1.763 sec.

n_o is less than 1 Hz. Hence use gust factor method

Gust factor (GF) or Gust effective factor (GEF) method

Deign wind pressure p_z is given by the Equation (24).

$$p_z = 0.6V_z^2$$

Where V_z = Design hourly wind speed in m/s and given from the Equation (25).

$$\overline{V_z} = V_b k_1 \overline{k}_2 k_3$$

Where V_b =basic wind speed – gust speed

k_1 =Probability factor (risk coefficient) - taken as 1

$\vec{k}_2$ =Terrain, and height factor – (hourly mean wind speed factor)

For category 1 – Open country

100 m - 0.99

$\longrightarrow$ 144 m – 1.025

160 m – 1.03

k_3 = topography factor- from clause 4.4.3.3 =1

Design wind speed $\overline{V_z} = V_b k_1 \overline{k}_2 k_3$ =53.5x1.025 = 54.84m/s

Deign wind pressure $p_z = 0.6V_z^2 = 0.6 \times 54.84^2$ =1804.45N/m^2

The applied surface load F, the along wind load is given by the following equation

$$F_s = C_f A_e \overline{p}_z G$$

Where C_f = force coefficient for the building

A_e = effective frontal area considered for the structure at height Z

$\bar{p}_z$ = design pressure at height Z due to mean hourly wind

G = Gust factor $\frac{peakload}{meanload}$ and is given by

$$G = 1 + g_t r \sqrt{[B(1+\phi)^2} + \frac{SE}{\beta}]$$

Where g_t = peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuating load

r = a roughness factor which depend on the size of the structure in relation to the ground roughness

B = is the background factor

E = is the measure of the available energy in the stream at the natural frequency of the fluctuating wind

S = is size reduction factor

$\phi = \frac{g_r \sqrt{B}}{4}$ and accounted only for buildings and taken as 0

β = the damping coefficient and given as 0.016 for reinforced concrete (from table 26 of the code)

For terrain category 1 from figure 7 of code- values of $g_t r$ and L_h

$g_t r$ (approximate) =0.7

L_h - a measure of turbulence length scale =2000

To obtained back ground factor B from figure 8 from code, calculate

$\lambda = C_y b / C_z h$ and $C_z h / L_h$

$=10 \times 54 / 12 \times 144$ =0.31

Where C_y lateral correlation constant which may be taken as 10

C_z longitudinal correlation constant which may be taken as 12

b is the breath of the structure

h is the height of the structure

V_h hourly mean wind speed at height h

f_0 natural frequency of the structure in the fundamental mode =0.567

$\lambda = C_y b / C_z h$ =$10 \times 54 / 12 \times 144$ =0.31

$C_z h / L_h$ =$12 \times 144 / 2000$ =0.864

From the Figure 8 of code B (approximate) =0.6

To obtained E from figure 9 of code –gust energy factor calculate $f_0 L_h / V_h$

$f_0 L_h / V_h$ $= 0.567 \times 2000 / 54.8$ =20.7

From the Figure 9 of code E (approximate) =0.09

To obtained size reduction factor S calculate $F_0 = C_z f_0 h / V_h$

Where F_0 is reduced frequency

$F_0 = C_z f_0 h / V_h$=$12 \times 0.567 \times 144 / 54.8$ =17.88

From the Figure 10 of code S (approximate) =0.05

$$G = 1 + g_t r \sqrt{[B(1+\phi)^2} + \frac{SE}{\beta}] = 1 + 0.7\sqrt{[0.6(1+0)^2} + \frac{0.05 \times 0.09}{0.016}] \quad =1.66$$

C_f= force coefficient for the building (from figure 4) of code, force coefficient for rectangular clad building- if surface design pressure varies with height the force coefficient can be applied after sub divide the area and taking appropriate pressures.

C_f (approximate) =1.3

$F_s = C_f A_e \overline{p}_z G$ $=1.3 \times 1.66 \times 1804.45 / 1000$ per unit area =3.89KN/m^2

Appendix C

Wind Loading Data

Appendix Table C1 Along Wind Loading Data for Model No. 1 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	1.01	0.78	0.51	1.66	1.28	0.84	1.97	1.52	0.99	2.27	1.75	1.15
3.6	1.05	0.81	0.53	1.66	1.28	0.84	2.04	1.58	1.03	2.27	1.75	1.15
7.2	1.30	1.00	0.66	1.66	1.28	0.84	2.35	1.81	1.18	2.27	1.75	1.15
10.8	1.52	1.18	0.77	1.66	1.28	0.84	2.55	1.97	1.29	2.30	1.77	1.16
14.4	1.62	1.25	0.82	1.66	1.28	0.84	2.68	2.07	1.35	2.43	1.87	1.22
18.0	1.67	1.29	0.84	1.66	1.28	0.84	2.79	2.15	1.41	2.53	1.95	1.28

Appendix Table C2 Along Wind Loading Data for Model No. 2 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	1.04	0.80	0.53	1.57	1.21	0.79	2.28	1.76	1.15	2.37	1.83	1.19
3.6	1.08	0.83	0.55	1.57	1.21	0.79	2.33	1.8	1.17	2.37	1.83	1.19
7.2	1.33	1.03	0.67	1.57	1.21	0.79	2.52	1.94	1.27	2.37	1.83	1.19
10.8	1.56	1.21	0.79	1.57	1.21	0.79	2.64	2.04	1.33	2.40	1.85	1.21
14.4	1.66	1.28	0.84	1.76	1.35	1.03	2.72	2.1	1.37	2.53	1.95	1.28
18.0	1.72	1.33	0.87	1.76	1.35	1.03	2.79	2.15	1.41	2.64	2.03	1.33

Appendix Table C3 Along Wind Loading Data for Model No. 3 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	0.94	0.72	0.47	1.77	1.37	0.89	2.37	1.82	1.18	2.10	1.62	1.06
3.6	1.01	0.78	0.51	1.77	1.37	0.89	2.42	1.85	1.20	2.10	1.62	1.06
7.2	1.30	1.00	0.66	1.77	1.37	0.89	2.60	2.00	1.30	2.10	1.62	1.06
10.8	1.44	1.11	0.73	1.77	1.37	0.89	2.73	2.09	1.36	2.13	1.64	1.08

Appendix Table C3 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
14.4	1.53	1.18	0.77	1.77	1.37	0.89	2.81	2.16	1.40	2.26	1.74	1.14
18.0	1.59	1.23	0.80	1.77	1.37	0.89	2.88	2.21	1.43	2.36	1.82	1.19
21.6	1.64	1.26	0.83	1.77	1.37	0.89	2.93	2.25	1.46	2.43	1.88	1.23
25.2	1.69	1.30	0.85	1.77	1.37	0.89	2.97	2.28	1.48	2.48	1.92	1.25
28.8	1.74	1.34	0.88	1.77	1.37	0.89	3.00	2.30	1.50	2.53	1.96	1.28
32.4	1.78	1.37	0.90	1.95	1.5	0.98	3.03	2.33	1.51	2.58	1.99	1.30
36.0	1.82	1.40	0.92	1.95	1.5	0.98	3.06	2.35	1.52	2.62	2.02	1.32
39.6	1.86	1.43	0.94	1.95	1.5	0.98	3.09	2.37	1.54	2.66	2.06	1.34
43.2	1.90	1.46	0.96	1.95	1.5	0.98	3.10	2.38	1.54	2.71	2.09	1.37
46.8	1.94	1.49	0.98	1.95	1.5	0.98	3.12	2.39	1.55	2.75	2.12	1.39
50.4	1.97	1.52	1.00	1.95	1.5	0.98	3.13	2.40	1.56	2.79	2.15	1.41
54.0	2.00	1.54	1.01	1.95	1.5	0.98	3.15	2.41	1.56	2.81	2.17	1.42

Appendix Table C4 Along Wind Loading Data for Model No. 4 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	0.96	0.74	0.48	1.70	1.31	0.86	2.41	1.85	1.20	2.59	1.96	1.27
3.6	1.04	0.80	0.52	1.70	1.31	0.86	2.46	1.88	1.22	2.59	1.96	1.27
7.2	1.33	1.03	0.67	1.70	1.31	0.86	2.65	2.03	1.32	2.59	1.96	1.27
10.8	1.48	1.14	0.75	1.70	1.31	0.86	2.77	2.13	1.38	2.64	1.99	1.29
14.4	1.57	1.21	0.79	1.70	1.31	0.86	2.86	2.19	1.42	2.83	2.14	1.38
18.0	1.63	1.26	0.82	1.70	1.31	0.86	2.93	2.24	1.46	2.99	2.26	1.46
21.6	1.68	1.30	0.85	1.79	1.38	0.90	2.98	2.29	1.49	3.12	2.35	1.52
25.2	1.73	1.34	0.87	1.83	1.41	0.92	3.02	2.32	1.50	3.19	2.41	1.56
28.8	1.78	1.37	0.90	1.87	1.45	0.94	3.06	2.35	1.52	3.28	2.47	1.60
32.4	1.82	1.41	0.92	1.91	1.47	0.96	3.09	2.37	1.54	3.35	2.53	1.64
36.0	1.86	1.44	0.94	2.01	1.55	1.02	3.12	2.39	1.55	3.42	2.58	1.67
39.6	1.90	1.47	0.96	2.01	1.55	1.02	3.15	2.41	1.57	3.48	2.63	1.70

Appendix Table C4 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
43.2	1.94	1.50	0.98	2.01	1.55	1.02	3.17	2.43	1.57	3.55	2.69	1.74
46.8	1.98	1.53	1.00	2.01	1.55	1.02	3.19	2.44	1.58	3.62	2.74	1.77
50.4	2.02	1.56	1.02	2.01	1.55	1.02	3.21	2.45	1.59	3.69	2.79	1.80
54.0	2.05	1.58	1.03	2.01	1.55	1.02	3.22	2.46	1.60	3.73	2.82	1.82

Appendix Table C5 Along Wind Loading Data for Model No. 5 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	0.94	0.72	0.47	1.87	1.45	0.95	2.43	1.86	1.22	2.29	1.75	1.14
3.6	1.02	0.78	0.51	1.87	1.45	0.95	2.47	1.89	1.27	2.29	1.75	1.14
7.2	1.30	1.01	0.66	1.87	1.45	0.95	2.66	2.04	1.37	2.29	1.75	1.14
10.8	1.45	1.12	0.73	1.87	1.45	0.95	2.78	2.13	1.43	2.33	1.78	1.15
14.4	1.54	1.19	0.78	1.87	1.45	0.95	2.86	2.19	1.47	2.50	1.91	1.24
18.0	1.60	1.23	0.81	1.87	1.45	0.95	2.93	2.24	1.51	2.64	2.02	1.31
21.6	1.64	1.27	0.83	1.87	1.45	0.95	2.98	2.28	1.53	2.75	2.10	1.36
25.2	1.69	1.31	0.85	1.87	1.45	0.95	3.02	2.31	1.55	2.82	2.15	1.40
28.8	1.74	1.35	0.88	1.87	1.45	0.95	3.05	2.34	1.56	2.89	2.21	1.43
32.4	1.79	1.38	0.90	1.87	1.45	0.95	3.08	2.36	1.58	2.96	2.26	1.47
36.0	1.82	1.41	0.92	1.87	1.45	0.95	3.11	2.38	1.59	3.02	2.30	1.50
39.6	1.86	1.44	0.94	1.87	1.45	0.95	3.13	2.40	1.60	3.08	2.35	1.53
43.2	1.90	1.47	0.96	1.91	1.48	0.96	3.15	2.41	1.60	3.14	2.39	1.56
46.8	1.94	1.50	0.98	1.94	1.5	0.98	3.16	2.42	1.61	3.20	2.44	1.59
50.4	1.98	1.53	1.00	2.05	1.58	1.05	3.18	2.43	1.62	3.26	2.49	1.62
54.0	2.01	1.55	1.01	2.05	1.58	1.05	3.19	2.44	1.62	3.29	2.51	1.63
57.6	2.04	1.57	1.03	2.05	1.58	1.05	3.20	2.45	1.62	3.32	2.53	1.65
61.2	2.06	1.59	1.04	2.05	1.58	1.05	3.22	2.46	1.63	3.35	2.56	1.66
64.8	2.08	1.61	1.05	2.05	1.58	1.05	3.23	2.47	1.63	3.38	2.58	1.68

Appendix Table C5 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
68.4	2.10	1.62	1.06	2.05	1.58	1.05	3.24	2.48	1.64	3.41	2.60	1.69
72.0	2.12	1.64	1.07	2.05	1.58	1.05	3.26	2.49	1.64	3.44	2.63	1.71
75.6	2.14	1.65	1.08	2.05	1.58	1.05	3.27	2.50	1.65	3.48	2.65	1.72
79.2	2.16	1.67	1.09	2.05	1.58	1.05	3.28	2.51	1.65	3.51	2.68	1.74
82.8	2.18	1.68	1.10	2.05	1.58	1.05	3.29	2.52	1.66	3.54	2.70	1.75
86.4	2.19	1.69	1.11	2.05	1.58	1.05	3.31	2.53	1.66	3.57	2.72	1.77
90.0	2.21	1.70	1.11	2.05	1.58	1.05	3.32	2.54	1.67	3.60	2.75	1.79

Appendix Table C6 Along Wind Loading Data for Model No. 6 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	1.01	0.78	0.51	1.74	1.35	0.88	2.50	1.91	1.23	2.69	2.04	1.31
3.6	1.09	0.84	0.55	1.74	1.35	0.88	2.54	1.95	1.26	2.69	2.04	1.31
7.2	1.40	1.08	0.71	1.74	1.35	0.88	2.73	2.09	1.35	2.69	2.04	1.31
10.8	1.55	1.20	0.78	1.74	1.35	0.88	2.86	2.19	1.41	2.74	2.08	1.34
14.4	1.65	1.27	0.83	1.74	1.35	0.88	2.95	2.25	1.45	2.94	2.23	1.43
18.0	1.71	1.32	0.86	1.74	1.35	0.88	3.02	2.30	1.49	3.11	2.36	1.52
21.6	1.76	1.36	0.89	1.84	1.42	0.93	3.07	2.35	1.51	3.23	2.45	1.58
25.2	1.81	1.40	0.92	1.88	1.45	0.95	3.11	2.37	1.53	3.31	2.52	1.62
28.8	1.87	1.44	0.94	1.92	1.48	0.97	3.14	2.40	1.55	3.40	2.58	1.66
32.4	1.91	1.48	0.97	1.95	1.51	0.99	3.17	2.43	1.57	3.47	2.64	1.69
36.0	1.95	1.51	0.99	1.98	1.53	1.00	3.20	2.45	1.58	3.54	2.69	1.73
39.6	2.00	1.54	1.01	2.01	1.55	1.01	3.23	2.47	1.59	3.62	2.74	1.76
43.2	2.04	1.57	1.03	2.04	1.58	1.02	3.25	2.48	1.60	3.69	2.80	1.80
46.8	2.08	1.61	1.05	2.07	1.60	1.03	3.27	2.49	1.61	3.76	2.86	1.84
50.4	2.12	1.64	1.07	2.10	1.62	1.04	3.28	2.51	1.62	3.83	2.91	1.87
54.0	2.15	1.66	1.09	2.11	1.63	1.06	3.30	2.52	1.62	3.87	2.93	1.89

Appendix Table C6 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
57.6	2.18	1.68	1.10	2.12	1.64	1.06	3.31	2.53	1.63	3.90	2.96	1.90
61.2	2.21	1.70	1.11	2.13	1.65	1.07	3.33	2.54	1.64	3.94	2.99	1.92
64.8	2.23	1.72	1.12	2.15	1.66	1.08	3.35	2.55	1.65	3.97	3.02	1.94
68.4	2.25	1.74	1.14	2.16	1.67	1.09	3.36	2.57	1.65	4.01	3.04	1.96
72.0	2.27	1.75	1.15	2.20	1.69	1.10	3.38	2.58	1.66	4.05	3.07	1.97
75.6	2.30	1.77	1.16	2.20	1.69	1.10	3.40	2.59	1.67	4.08	3.10	1.99
79.2	2.32	1.79	1.17	2.20	1.69	1.10	3.41	2.60	1.67	4.12	3.13	2.01
82.8	2.34	1.80	1.18	2.20	1.69	1.10	3.43	2.61	1.68	4.16	3.16	2.03
86.4	2.35	1.81	1.19	2.20	1.69	1.10	3.44	2.62	1.69	4.19	3.18	2.05
90.0	2.37	1.83	1.19	2.20	1.69	1.10	3.46	2.63	1.69	4.23	3.21	2.07

Appendix Table C7 Along Wind Loading Data for Model No. 7 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	0.95	0.73	0.48	1.12	0.86	0.56	2.49	1.91	1.28	2.25	1.72	1.11
3.6	1.03	0.80	0.52	1.35	1.03	0.68	2.54	1.94	1.30	2.25	1.72	1.11
7.2	1.32	1.02	0.67	1.67	1.28	0.84	2.72	2.08	1.40	2.25	1.72	1.11
10.8	1.47	1.13	0.74	1.84	1.41	0.92	2.84	2.17	1.46	2.29	1.75	1.13
14.4	1.56	1.20	0.79	1.97	1.50	0.98	2.92	2.24	1.50	2.46	1.88	1.21
18.0	1.62	1.25	0.82	2.04	1.56	1.02	2.99	2.29	1.53	2.60	1.98	1.28
21.6	1.67	1.29	0.84	2.10	1.60	1.05	3.04	2.33	1.56	2.71	2.06	1.33
25.2	1.72	1.32	0.87	2.15	1.64	1.07	3.08	2.35	1.57	2.78	2.12	1.37
28.8	1.77	1.36	0.89	2.20	1.68	1.10	3.11	2.38	1.59	2.85	2.17	1.40
32.4	1.81	1.40	0.91	2.24	1.71	1.12	3.14	2.40	1.60	2.91	2.22	1.43
36.0	1.85	1.43	0.93	2.27	1.74	1.14	3.16	2.42	1.61	2.97	2.26	1.46
39.6	1.89	1.46	0.95	2.30	1.76	1.15	3.19	2.44	1.62	3.03	2.31	1.49
43.2	1.93	1.49	0.97	2.33	1.78	1.17	3.20	2.45	1.63	3.09	2.36	1.52

Appendix Table C7 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
46.8	1.97	1.52	0.99	2.36	1.81	1.18	3.22	2.46	1.64	3.15	2.40	1.55
50.4	2.01	1.55	1.01	2.39	1.83	1.20	3.23	2.47	1.64	3.21	2.45	1.58
54.0	2.03	1.57	1.03	2.41	1.84	1.20	3.24	2.48	1.65	3.24	2.47	1.59
57.6	2.06	1.59	1.04	2.42	1.85	1.21	3.25	2.49	1.65	3.27	2.49	1.61
61.2	2.09	1.61	1.05	2.44	1.86	1.22	3.27	2.50	1.66	3.30	2.52	1.62
64.8	2.11	1.63	1.06	2.45	1.88	1.23	3.28	2.50	1.66	3.33	2.54	1.64
68.4	2.13	1.64	1.07	2.47	1.89	1.23	3.29	2.51	1.66	3.36	2.56	1.65
72.0	2.15	1.66	1.08	2.48	1.90	1.24	3.30	2.52	1.67	3.39	2.58	1.67
75.6	2.17	1.68	1.10	2.50	1.91	1.25	3.32	2.53	1.67	3.42	2.61	1.68
79.2	2.19	1.69	1.11	2.51	1.92	1.26	3.33	2.54	1.68	3.45	2.63	1.70
82.8	2.21	1.70	1.11	2.53	1.93	1.26	3.34	2.55	1.68	3.48	2.66	1.71
86.4	2.22	1.72	1.12	2.54	1.94	1.27	3.35	2.56	1.69	3.51	2.68	1.73
90.0	2.24	1.73	1.13	2.56	1.95	1.28	3.37	2.57	1.69	3.54	2.70	1.75
93.6	2.25	1.74	1.14	2.57	1.96	1.28	3.38	2.58	1.70	3.58	2.73	1.76
97.2	2.27	1.75	1.14	2.58	1.97	1.29	3.39	2.59	1.70	3.61	2.75	1.78
100.8	2.28	1.76	1.15	2.59	1.98	1.30	3.41	2.60	1.71	3.64	2.77	1.79
104.4	2.30	1.77	1.16	2.60	1.99	1.30	3.41	2.61	1.71	3.66	2.79	1.80
108.0	2.31	1.78	1.17	2.61	1.99	1.30	3.42	2.61	1.71	3.68	2.81	1.81
111.6	2.32	1.79	1.17	2.61	2.00	1.31	3.43	2.62	1.71	3.70	2.82	1.82
115.2	2.34	1.81	1.18	2.62	2.00	1.31	3.44	2.62	1.71	3.72	2.84	1.83
118.8	2.35	1.82	1.19	2.63	2.01	1.31	3.45	2.63	1.72	3.74	2.85	1.84
122.4	2.37	1.83	1.20	2.64	2.01	1.32	3.46	2.64	1.72	3.76	2.87	1.85
126.0	2.38	1.84	1.20	2.64	2.02	1.32	3.46	2.64	1.72	3.79	2.89	1.86
129.6	2.40	1.85	1.21	2.65	2.02	1.32	3.47	2.65	1.72	3.81	2.90	1.87
133.2	2.41	1.86	1.22	2.65	2.03	1.33	3.48	2.65	1.73	3.83	2.92	1.89
136.8	2.43	1.87	1.23	2.66	2.03	1.33	3.49	2.66	1.73	3.85	2.94	1.90
140.4	2.44	1.89	1.23	2.67	2.04	1.33	3.50	2.66	1.73	3.87	2.95	1.91
144.0	2.46	1.90	1.24	2.67	2.04	1.34	3.50	2.67	1.73	3.90	2.97	1.92

Appendix Table C8 Along Wind Loading Data for Model No. 8 – as an Intensity kN/ m^2 with Height

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
0.0	1.00	0.77	0.50	1.12	0.86	0.56	2.60	1.99	1.29	2.55	1.93	1.23
3.6	1.08	0.84	0.55	1.35	1.03	0.68	2.65	2.03	1.31	2.55	1.93	1.23
7.2	1.39	1.07	0.70	1.67	1.28	0.84	2.83	2.17	1.41	2.55	1.93	1.23
10.8	1.54	1.19	0.78	1.84	1.41	0.92	2.96	2.27	1.47	2.59	1.96	1.25
14.4	1.64	1.27	0.83	1.97	1.50	0.98	3.04	2.33	1.51	2.78	2.11	1.34
18.0	1.70	1.31	0.86	2.04	1.56	1.02	3.11	2.38	1.54	2.94	2.23	1.41
21.6	1.75	1.35	0.88	2.10	1.60	1.05	3.16	2.42	1.57	3.06	2.32	1.47
25.2	1.81	1.39	0.91	2.15	1.64	1.07	3.19	2.44	1.58	3.13	2.38	1.51
28.8	1.86	1.44	0.94	2.20	1.68	1.10	3.22	2.47	1.60	3.21	2.44	1.55
32.4	1.90	1.47	0.96	2.24	1.71	1.12	3.25	2.49	1.61	3.28	2.49	1.58
36.0	1.95	1.50	0.98	2.27	1.74	1.14	3.27	2.51	1.63	3.35	2.54	1.61
39.6	1.99	1.53	1.00	2.30	1.76	1.15	3.29	2.52	1.64	3.42	2.59	1.65
43.2	2.03	1.57	1.02	2.33	1.78	1.17	3.30	2.53	1.64	3.49	2.64	1.68
46.8	2.07	1.60	1.05	2.36	1.81	1.18	3.31	2.54	1.65	3.56	2.70	1.71
50.4	2.11	1.63	1.07	2.39	1.83	1.20	3.32	2.55	1.65	3.62	2.75	1.74
54.0	2.14	1.65	1.08	2.41	1.84	1.20	3.33	2.56	1.66	3.66	2.77	1.76
57.6	2.17	1.68	1.09	2.42	1.85	1.21	3.34	2.56	1.66	3.69	2.80	1.78
61.2	2.20	1.70	1.11	2.44	1.86	1.22	3.35	2.57	1.67	3.72	2.82	1.79
64.8	2.22	1.71	1.12	2.45	1.88	1.23	3.36	2.58	1.67	3.76	2.85	1.81
68.4	2.24	1.73	1.13	2.47	1.89	1.23	3.37	2.58	1.68	3.79	2.88	1.83
72.0	2.26	1.75	1.14	2.48	1.90	1.24	3.38	2.59	1.68	3.83	2.90	1.84
75.6	2.29	1.76	1.15	2.50	1.91	1.25	3.40	2.60	1.69	3.86	2.93	1.86
79.2	2.31	1.78	1.16	2.51	1.92	1.26	3.41	2.60	1.69	3.90	2.96	1.88
82.8	2.32	1.79	1.17	2.53	1.93	1.26	3.43	2.61	1.69	3.93	2.98	1.89
86.4	2.34	1.81	1.18	2.54	1.94	1.27	3.44	2.62	1.70	3.97	3.01	1.91
90.0	2.35	1.82	1.19	2.56	1.95	1.28	3.46	2.63	1.70	4.00	3.03	1.93
93.6	2.37	1.83	1.20	2.57	1.96	1.28	3.47	2.65	1.71	4.04	3.06	1.94
97.2	2.39	1.84	1.20	2.58	1.97	1.29	3.48	2.66	1.71	4.07	3.09	1.96
100.8	2.40	1.85	1.21	2.59	1.98	1.30	3.50	2.67	1.72	4.11	3.11	1.98

Appendix Table C8 (Continued)

Height (m)	CP3/ SL Manual			BS 6399			AS/NZS			NBCI		
	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3	Z-1	Z-2	Z-3
104.4	2.42	1.86	1.22	2.60	1.99	1.30	3.51	2.67	1.72	4.13	3.13	1.99
108.0	2.43	1.88	1.23	2.61	1.99	1.30	3.52	2.68	1.72	4.15	3.15	2.00
111.6	2.45	1.89	1.23	2.61	2.00	1.31	3.53	2.69	1.73	4.18	3.17	2.01
115.2	2.46	1.90	1.24	2.62	2.00	1.31	3.54	2.69	1.73	4.20	3.19	2.02
118.8	2.48	1.91	1.25	2.63	2.01	1.31	3.55	2.70	1.74	4.23	3.21	2.03
122.4	2.49	1.92	1.26	2.64	2.01	1.32	3.56	2.71	1.74	4.25	3.22	2.05
126.0	2.51	1.94	1.27	2.64	2.02	1.32	3.57	2.72	1.74	4.27	3.24	2.06
129.6	2.52	1.95	1.27	2.65	2.02	1.32	3.58	2.72	1.75	4.30	3.26	2.07
133.2	2.54	1.96	1.28	2.65	2.03	1.33	3.59	2.73	1.75	4.32	3.28	2.08
136.8	2.56	1.97	1.29	2.66	2.03	1.33	3.60	2.74	1.76	4.35	3.30	2.09
140.4	2.57	1.98	1.30	2.67	2.04	1.33	3.61	2.74	1.76	4.37	3.32	2.10
144.0	2.59	2.00	1.31	2.67	2.04	1.34	3.61	2.75	1.76	4.40	3.33	2.12

Appendix D

Top Displacement

Appendix Table D1 Top Displacement of Building Models in mm

	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 2
	Model No. 1			Model No. 2		
CP3	12.2	8.5	6.1	15.7	11.0	7.1
BS	12.7	10.0	6.5	15.8	12.8	8.3
AS/NZS	21.0	16.2	11.2	26.4	20.3	13.3
NBCI	18.6	14.5	9.4	24.3	18.8	10.2
	Model No. 3			Model No. 4		
CP	43.4	33.4	23.1	67.4	52.1	34
BS	44.9	34.5	22.8	69.7	53.8	35.3
AS/NZS	72.2	54.3	35.3	111.0	85.5	55.5
NBCI	62.3	48	31.4	123.6	93.4	54.5
	Model No. 5			Model No. 6		
CP	54.7	42.2	27.9	81.4	59	40.2
BS	53.9	41.7	27.5	82.4	63.5	41.3
AS/NZS	86	65.8	43.5	129.3	98.6	63.5
NBCI	89.4	68.1	44.3	152.7	112.5	74.0
	Model No. 7			Model No. 8		
CP	106.3	82.0	53.6	184	142.3	93.0
BS	108.2	83.4	54.3	183.2	141.1	92.6
AS/NZS	159.3	121.5	78.6	269.3	209.9	131.7
NBCI	168.9	128.8	83.1	310.0	238.0	151.0

Appendix E

Wind Induced Forces

Appendix Table E1 Induced Forces – Model No.1- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	41.6	43.9	58.6	55.46	33.7	38.2	48.2	47	29.4	31.0	39.6	36.6
		Fx occurred at Supports 2D and 3D											
	Max Fy	2603	2604.0	2610	2608	2600	2601.5	2606	2605	2597.8	2598.4	2602	2600.9
		Fy occurred at supports 2B and 3B											
	Max Mz	72.8	77.4	109.3	103.4	55.6	65.2	89	84.3	48.8	49.8	68.5	62.3
		Mz occurred at Supports 2D and 3D											
Column	Max Fx	50.9	51.6	62.5	59.6	49.4	49.5	58	53.4	48.8	48.9	49.9	49.5
		4th to roof , 2D & 3D		2nd to 3rd floor2D&3D		4th to roof , 2D & 3D		2nd to 3rd 2D & 3D	--------------------4th to roof , 2D & 3D----------------				
	Max Fy	2603	2604.0	2610	2608	2600	2601.5	2606	2605	2597.8	2598.4	2602	2600.9
		Fy occurred at ground floor columns 2B and 3B											
	Max Mz	101.7	102.2	109.3	103.4	98.7	98.8	103	101.1	97.5	97.6	99.8	100.1
		4th to roof , 2D & 3D		2nd to 3rd floor2D&3D		4th to roof , 2D & 3D		2nd to 3rd 2D & 3D	------------------4th to roof , 2D & 3D------------------				
Beam	Max Fy	151.8	153.3	165.6	163	145.8	148.8	158	155.7	141	143.1	150.4	147.6
		Occurred at first floor beams along grid 2 & 3 between grid A & B											
	Max Mz	201.2	205.2	238.6	231.5	184.7	192.9	218	212.4	171.7	177.6	197.3	189.7
		Occurred at first floor beams along grid 2 & 3 between grid A & B											

Appendix Table E2 Induced Forces – Model No. 2- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	45.4	46.6	70.6	65.11	37.5	42.2	55.6	54.1	30.2	32.9	42.3	36.7
		Fx occurred at support 2C											
	Max Fy	2493.3	2593.3	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4
		Fy occurred at support 2B											
	Max Mz	79.6	84.3	128.4	124	64.6	74.4	103.8	100.4	48.8	54.6	74.9	62.3
		Mz occurred at support 2C											
Column	Max Fx	53.7	55.3	69.5	67.1	50	51.0	63.5	59.3	49.2	49.4	51.9	50.3
		Fx at 1^{st} to 2^{nd} floor, column 2C				4^{th} to roof , 2C		1^{st} 2^{nd} , 2C		--------4^{th} to roof , column 2C---------			
	Max Fy	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4	2593.4
		Fy occurred at ground floor column 2B											
	Max Mz	101.7	102.2	128	124	99.8	100.3	112.3	109	97.5	98.2	100.5	100.1
		4^{th} to roof , 2C		Ground to 1^{st} , 2C		4^{th} to roof , 2C		1^{st} 2^{nd} , 2C		---------4^{th} to roof , column 2C---------			
Beam	Max Fy	155.9	156.9	172.0	170.6	149.5	152.7	163.8	162.2	143.4	145.6	153	148.4
		Occurred at first floor beams along grid 2 between grid A & B											
	Max Mz	210.3	215.0	258	252.2	192.5	203.8	233	229.1	179.3	184.8	204	192.5
		Occurred at first floor beams along grid 2 between grid A & B											

Appendix Table E3 Induced Forces – Model No. 3- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	89.6	95.5	138.8	119.6	74.8	79.5	110.8	98.2	59.4	60.7	80.9	73
		At 3F & 4F		3E &4E		--At support 3F & 4F---------------------------------------							
	Max Fy	8159	8159	8160.4	8160	8156.6	8159	8159.5	8160	8158	8158	8159	8158.6
		Fy occurred at supports 3D and 4D											
	Max Mz	290	311	481.2	410.4	229.9	246.5	374.1	323.4	167	170.7	252.8	221.5
		At 3F & 4F		3E &4E		--At support 3F & 4F---------------------------------------							
Column	Max Fx	109.4	110.1	145.1	123.8	108.9	108.9	112.6	112	108.4	108.4	109.0	108.7
		3A& 4A top flr		3E&4E 1st to 2nd		------------------------------Occurred at 3A & 4A top floor-------------------------------							
	Max Fy	8159	8159	8160.4	8160	8156.6	8159	8159.5	8160	8158	8158	8159	8158.6
		Fy occurred at columns 3D and 4D in ground floor											
	Max Mz	290	301.1	481.2	410.4	229.9	246.5	374.1	323.4	235.9	236	252.8	236
		----------------------Occurred at columns 3E & 4E at ground floor---------------------											
Beam	Max Fy	183.9	184.7	211.3	201.3	174.9	175.9	195	187	167.7	167.5	176.8	173
	Floor level	5th	4th	4th	4th	6th	5th	4th	4th	9th	8th	5th	5th
		Both Fy and Mz occurred at Beams along grid 3 and 4 between grid E and F											
	Max Mz	318	322.5	402.9	372.6	292.1	294.8	353.5	323	270.3	269	298.2	287
		5th	5th	4th	4th	6th	6th	4th	4th	9th	9th	5th	5th

Appendix Table E4 Induced Forces – Model No. 4- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	116.7	123.4	197.2	211.4	95.9	101.0	151.4	160.1	71.5	75.0	103.8	108
		2D&3D	At supports 2C & 3C			--At 2D & 3D--		--At 2C & 3C--		----------At supports 2D & 3D----------			
	Max Fy	7565	7566	7586	7592	7565	7558	7573	7578	7550	7550	7559	7561
		Fy occurred at supports 2C and 3C											
	Max Mz	409.1	433.5	697.3	749.4	322.6	340.9	534.6	566.6	220.7	233.4	353.2	371.5
		2D&3D	At supports 2C & 3C			--At 2D & 3D--		--At 2C & 3C--		----------At supports 2D & 3D----------			
Column	Max Fx	127.6	133.4	212.7	229.3	105.3	107.0	164.0	173.8	105	105	109.5	114.8
		2C&2C 2^{nd} to 3^{rd}	--2C & 3C 1^{st} to 2^{nd} floor --			2A&2A top floor	2D&3D 1^{st} to 2^{nd}	2C & 3C 1^{st} to 2^{nd}		2A & 3A top floor		2D&3D 1^{st} to 2^{nd}	2C&3C 2^{nd} to 3^{rd}
	Max Fy	7565	7566	7586	7592	7565	7558	7573	7578	7550	7550	7559	7561
		Fy occurred at columns 2C and 3C in ground floor											
	Max Mz	409.1	433.5	697.4	749.4	322.6	340.9	534.6	566.6	232	233.4	353.2	371.5
		2D&3D ground flr	Columns 2C & 3C ground flr			2D&3D ground flr		2C&3C ground flr		2D&3D top floor	Columns 2D & 3D ground flr		
Beam	Max Fy	204.6	206.9	248.8	258.5	190	192	222.6	229	174.1	175.1	193.7	197.7
	Floor level	4^{th}	4^{th}	3^{rd}	3^{rd}	4^{th}	4^{th}	4^{th}	4^{th}	6^{th}	5^{th}	4^{th}	4^{th}
		Both Fy and Mz occurred at Beams along grid 2 and 3 between grid C and D											
	Max Mz	381.9	389.7	516.7	546.4	338	343.6	437.7	457.6	290	293.0	348.6	362
		4^{th}	4^{th}	3^{rd}	3^{rd}	4^{th}	4^{th}	4^{th}	4^{th}	6^{th}	5^{th}	4^{th}	4^{th}

Appendix Table E5 Induced Forces – Model No. 5- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	627	636	816.2	816.7	559.1	568.8	702.9	707	483.4	488.7	579.0	573
		Fx occurred at supports 4E & 5E											
	Max Fy	13409	13407	14024	14100	13391.2	13390	13425	13432	13370.6	13370.2	13393	13394
		---At 3F & 6F---		---At 4E & 5E---		----------------------------Fy occurred at supports 3F & 6F--------------------------							
	Max Mz	327	338	524.8	525	256	265.7	406.2	405	176.3	181.9	276.3	269
		Mz occurred at supports 4E & 5E											
Column	Max Fx	380	380	475.6	475.7	374	374	404.9	404.3	366.8	366.5	374.0	372.5
		4D & 5D top flr		4E & 5E ground		4D & 5D top flr		4E & 5E ground		---------4D & 5D top floor level---------			
	Max Fy	13409	13407	13452	13458	13391.2	13390	13428	13432	13370.6	13370.2	13393	13394
		Fy occurred at columns 3F and 6F in ground floor											
	Max Mz	437	435	612.3	613.4	423	422	491	490.6	415.4	414.6	423.3	423.3
		4D & 5D top flr		4E & 5E ground		4D & 5D top flr		4E & 5E ground		---------4D & 5D top floor level---------			
Beam	Max Fy	620	620.1	989.8	995.7	480.5	492	765	765	324	333.5	516	507
		3^{rd} floor beams , along grid 4 and 5, between grid D and E											
	Max Mz	627	625.4	703.0	715.6	601.9	599	650.8	659	578.3	578.4	602.3	605
		Mz occurred at Beams along grid 4 and 5 between grid C and D											
		17^{th}	16^{th}	13^{th}	13^{th}	18^{th}	19^{th}	15^{th}	15^{th}	24^{th}	24^{th}	18^{th}	18^{th}

Appendix Table E6 Induced Forces – Model No. 6- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	561	560	725	787	496.6	500.3	619.5	665	411.8	420.1	498.5	527
		Fx occurred at supports 2C & 3C											
	Max Fy	11075	11012	13290*	13683	10326	10351	11889*	12265	9340	9410	10351*	10670
		Fy occurred at supports 2C & 3C											
	Max Mz	303.1	302.1	470.7	533	237.9	241.1	363	409	151.1	159.7	239.7	268.8
		Mz occurred at supports 2C & 3C											
Column	Max Fx	319.5	320	420	459	279	282.3	355.8	384	229.1	233.0	281.2	299
		Fx occurred at Columns 2C & 3C at ground floor											
	Max Fy	8850	8800.5	10633*	10948	8410	8417	9506*	9808	8022	8040	8375	8540
		Fy occurred at Columns 2C & 3C at ground floor											
	Max Mz	378.5	377	552	618	310	314	440.5	488	220.5	229	312.2	342.6
		Mz occurred at Columns 2C & 3C at ground floor											
Beam	Max Fy	603	595.5	931.0	1063	471	475	717.3	803	307.8	311.0	472	532
		3rd floor beams , along grid 4 and 5, between grid D and E											
	Max Mz	417.8	420.5	545	624	369	370.3	450.6	493	297.8	310	363.5	390
		10th flr along grid 2 ,3 , bt n grid A,B		3rd flr along grid 2 ,3 , bt n grid B,C		11th flr along grid 2 ,3 , bt n grid A,B		9th flr along grid 2 ,3 , bt n grid A,B		12th flr along grid 2 ,3 , bt n grid A,B		10th flr along grid 2 ,3 , bt n grid A,B	

Appendix Table E7 Induced Forces – Model No. 7- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	1115.8	1140.5	1377	1390	1010	1029.4	1206	1215	887	897.5	1011	1016
		Fx occurred at supports 5F and 6F											
	Max Fy	23267	23447	25823	26032	22658	22661	24110	24264	22601	22602	22650	22660
		Occurred at supports 5F & 6F				3H&7H	at supports 5F & 6F			Occurred at supports 3H & 6H			
	Max Mz	697.8	731	1048	1084.1	557	582.6	819	830.5	392	406.5	559	565
		Mz occurred at supports 5F and 6F											
Column	Max Fx	572	587.5	729	738.3	510	521	627	631	448	449.0	510.2	512
		------------------Occurred at column 5F & 6F ground floor-----------------------------								5E, 6E 6^{th} to 7^{th}		5F , 6F ground flr	
	Max Fy	22707.6	22710.5	22811	22834	22658	22661	22735	22734	22601	22602	22650	22660
		Occurred at column 3H & 6H at ground floor											
	Max Mz	811	845	1161	1178	752	762	933	944	730	730.5	748	753
		Occurred at column 5F & 6F ground flr				5D & 6D top flr		5F ,6F ground flr		---------5D & 6D at Top floor---------			
Beam	Max Fy	904.7	944	1406.0	1432	701	731	1077	1095	463	479	701	711
		3^{rd} floor beams , along grid 3 and 4, between grid C and D											
	Max Mz	907	910.6	1029	1057	859	861	937	958	815	815	850.5	861
	Floor level	23^{rd}	22^{nd}	18^{th}	18^{th}	26^{th}	24^{th}	22^{nd}	21^{st}	30^{th}	30^{th}	26^{th}	26^{th}
		Along grid 3 and 4, Between grid B and C											

Appendix Table E8 Induced Forces – Model No. 8- Fx and Fy in kN and Mz in kNm

		Zone 1				Zone 2				Zone 3			
		CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI	CP3	BS	AS/NZ	NBCI
Support	Max Fx	1129	1207.7	1385	1519	1004	1041	1197	1293	856.6	882.0	980.2	1031.7
		Fx occurred at supports 3D & 4D											
	Max Fy	23503	23729	26336*	27920	22072	22471	24206*	25347	20398	20660	21751*	22381
		Fy occurred at supports 3D & 4D											
	Max Mz	820	900	1171	1354	647.7	700.6	913.5	1043	446	481	616	686.2
		Mz occurred at supports 3D & 4D											
Column	Max Fx	693	743	864	954	609	635	738	802	510	528	594.0	637
		Fx occurred at columns 3D & 4D in ground floor											
	Max Fy	19919	20406	21746*	23064	19627	19689	20033*	20921	19284	19325	19540	19688
		2E&3E ground flr	3D & 4D in ground floor			3E & 4E in ground floor			2D&3D ground flr	columns 3E & 4E in ground floor			
	Max Mz	958	1044	1317	1503	782.3	838	1053	1186	570	612	749.2	822
		Mz occurred at columns 3D & 4D in ground floor											
Beam	Max Fy	1098.4	1213	1397.0	1597	854	929	1230	1414	567	616.0	808	907.2
		3rd floor beams , along grid 5 and 6, between grid E and F											
	Max Mz	893.2	902.0	1058	1088	793	814	933.5	1025	683	694	763	813
		16th	15th	14th	14th	13th	17th	16th	15th	20th	20th	17th	17th
		Along grid 5 and 6, Between grid D and E											

Appendix Table E9 Shear Walls- Total Base shear in Global X Direction in kN and Maximum Absolute Principal Stress in N/mm²

	Zone 1				Zone 2				Zone 3			
	CP3	BS 6399	AS/NZS	NBCI	CP3	BS 6399	AS/NZS	NBCI	CP3	BS 6399	AS/NZS	NBCI
	Model No. 5											
Total base shear	2773.6	2890.7	4589.4	4573.1	2142.5	2240.5	3512.2	3488.2	1417.9	1477.8	2333.5	2266.9
Max Absolute principal stress (S max)	15.1	15.3	18.0	18.0	14.1	14.3	16.3	16.3	13.0	13.1	14.4	14.3
	S max occurred at ground floor level along grid 4 and 5											
	Model No. 6											
Total base shear	2485.1	2491.6	3957.34	4490.0	1917.5	1923.5	3026.05	3408.6	1170.2	1251.6	1950.73	2191.3
S max	13.2	13.1	15.8	16.7	12.2	12.2	14.0	14.8	11.0	11.0	12.1	12.6
	S max occurred at ground floor level along grid B and C. S max produced by along wind and cross wind combination											
	Model No. 7											
Total base shear	3779.52	4002.98	5954.76	6028.85	2917.13	3090.2	4548.13	4596.78	1906.73	2005.68	2944.54	2968.48
S max	20.5	20.7	23.1	23.2	19.4	19.1	21.4	21.5	18.2	18.3	19.5	19.5
	S max occurred at ground floor level along grid 5 and 6											
	Model No. 8											
Total base shear	4487.63	4602.14	6922.74	7680	3463.18	3546.98	5253.32	5825	2263.81	2322.5	3379.98	3696.5
S max	21.1	21.7	24.3	25.6	19.6	19.7	22	23.0	18.0	18.1	19.4	20.0
	S max occurred at ground floor level along grid C and D. S max produced by along wind and cross wind combination											

CIRRICULUM VITAE

NAME : Miss. Wannaku Ralalage Nilanthi Rupika Premachandra

BIRTH DATE : November 02, 1967

BIRTH PLACE : Kaluthara, Sri Lanka.

EDUCATION :

YEAR	**INSTITUTE**	**DEGREE/DIPLOMA**
1994	Univ. of Moratuwa Sri Lanka.	B.Sc.Eng. (Civil Engineering)
2008	Kasetsart Univ.	M.Eng. (Civil Engineering)

POSITION/TITLE : Structural Engineer

WORK PLACE : Department of Building, Sethsiripaya, Battaramulla, Sri Lanka.