Wind Comfort Assessment of a Tall Building According to Various Structural Codes

Samet TOZAN [1], Kadir GÜLER [2], Barış ERKUŞ[3]

[1] M.S. Student, ITU, Faculty of Civil Eng. 34469 Maslak, Istanbul, Turkey, sametozan@itu.edu.tr
[2] Prof. Dr., ITU Faculty of Civil Eng. 34469 Maslak, Istanbul, Turkey, kguler@itu.edu.tr
[3] Assist. Prof. Dr., ITU Faculty of Civil Eng. 34469 Maslak, Istanbul, Turkey, Baris.Erkus@itu.edu.tr

ABSTRACT: In this study, comfort condition of a tall building under wind excitation is assessed using various structural codes. A 31-story and 116.6 m tall office building is considered in Istanbul, Turkey. Typical floor is approximately 30m-by-35m in dimensions and symmetrical in plan in both major directions. The lateral system of the building is a dual system of shear walls and moment frames, which typical for tall buildings in Turkey. First, the building is designed according to 2007 Turkish Seismic Code and verified against wind loads estimated using Istanbul Wind Code. Seismic loads govern the design since Istanbul is located in a highly seismic region of Turkey. Then, maximum top floor along-wind and across-wind accelerations are estimated using various structural codes and design guidelines. Comfort conditions are assessed considering maximum accelerations of the top floor of the building due to wind excitation. It is shown that while different codes give different values of maximum accelerations, same or similar comfort condition is achieved.

Keywords: tall building, comfort condition, wind loading

1 INTRODUCTION

Economic and social developments increase the need of dwelling. The need of dwelling makes tall building compulsory especially in crowded cities. Wind is an important parameter in the design of tall buildings. During the design of the structure, some problems may arise due to the wind. Comfort assessment due to wind excitation is an important problem in tall building design. Comfort in buildings is generally defined by occupants' reactions and perception of wind vibration of buildings. Comfort conditions are generally assessed by examining accelerations of the building during wind excitation. Various structural codes provide formulae for estimation of maximum wind accelerations of top floor of a tall building. There is generally no accepted international standard for comfort criteria in tall buildings even tough accelerations are to be estimated accurately, rather there are several studies and resulting recommendations for this purpose.

Wind is considered in the x-direction and along-wind acceleration and across-wind accelerations are estimated for the sample building. For this purpose, structural codes, ASCE7-10, AS/NZS 1170.2, IS875, EUROCODE1-04, NBCC, AIJ and EIT are used. The main reason of selecting a 31-storey building is that there are many approximately 30-storey buildings in Istanbul, Turkey. The aim of this study was to determine the acceleration of a tall building and assess comfort condition under wind loads.

2 WIND ACCELERATION AND COMFORT CRITERIA

2.1 Wind acceleration and code requirement

Important parameters for finding wind accelerations of tall buildings are as follows:

- ✓ The location of the building
- ✓ Dimensions of the building
- ✓ Height of the structure
- ✓ Wind speed
- ✓ Wind direction
- ✓ Structural weight
- ✓ Damping of the structure

There are various differences in the calculation of the wind accelerations in various structural codes. The reason for this is that different structural codes are applicable to different countries and regions. Vibration of tall buildings due to wind can be characterized by along-wind, across-wind and torsional vibration. Most of the structural codes provide along-wind and across-wind acceleration values. However, torsional acceleration can also be found in AIJ code. Structural damping ratio is important for the acceleration of the wind. This coefficient may differ between codes. Damping ratio values used in this study are shown in Table-1.

Table 1. Damping ratio values

Code	Damping ratio
ASCE7-10	0.005
AS/NZS 1170.2	0.005
IS875	0.002
EUROCODE 1-04	0.003
NBCC	0.005
AIJ	0.005
EIT	0.005

EUROCODES 1-04, AS/NZS 1170.2 codes are used for the buildings at a height of less than 200 m. Turbulence intensity coefficient is similar in all codes. This coefficient is related to terrain category and building height. Along-wind acceleration is related to displacements due to the wind according to NBCC2005 and EIT codes.

2.2 Comfort Criteria for Tall Buildings

Previous studies investigated the effects of movements in the frequency range 0-1 Hz on humans. Human response to building vibration is generally very complicated. Various research show that psychology of people should be taken into account as an important parameter in building vibration assessment. There is no generally accepted international standard for comfort criteria in tall buildings. Furthermore, there are significant differences between the commonly accepted comfort criteria since these are adopted for different region and people from different cultures. Human perception levels and acceleration values used in this study are shown in Table-2 and Table-3.

Table 2. Human perception levels [11]

LEVEL	ACCELERATION (m/s^2)	EFFECT
1	<0.05	Humans cannot perceive motion
2	0.05 - 0.1	a) Sensitive people can perceive motion; b) Hanging objects may move slightly
3	0.1-0.25	a) Majority of people will perceive motion; b) Level of motion may affect desk work: c) Long - term exposure may produce motion sickness
4	0.25-0.4	a) Desk work becomes difficult or almost impossible; b) Ambulation still possible

Table 3. Human perception levels[12]

Peak Acceleration	Comfort Limit
<0.5%g	Not Perceptible
0.5 -1.5 %g	Threshold of Perceptibility
1.5 -5 %g	Annoying
5 -15 %g	Very Annoying
>15 %g	Intolerable

3 EXAMINATION OF REINFORCED CONCRETE BUILDING

The building used in this study has 31 stories, where floor height is 3.6 m and the total building height is 111.6 m. The layout dimensions of the RC tall building are 35.5 m by 28.9 m direction and it is symmetrical in plan in two directions with an approximately 1026 m^2 floor area. The structural system of building is a dual system of shear walls and moment frames. The thickness of core walls changes between 55 cm and 50 cm. The thickness of the floor slabs is 18cm. The material classes for concrete and reinforcement are C60 and S420, respectively. Live loads are assumed to be 5.0 kN/m^2 and 2.0 kN/m^2. Dead loads are assumed to be 6.50 kN/m^2.

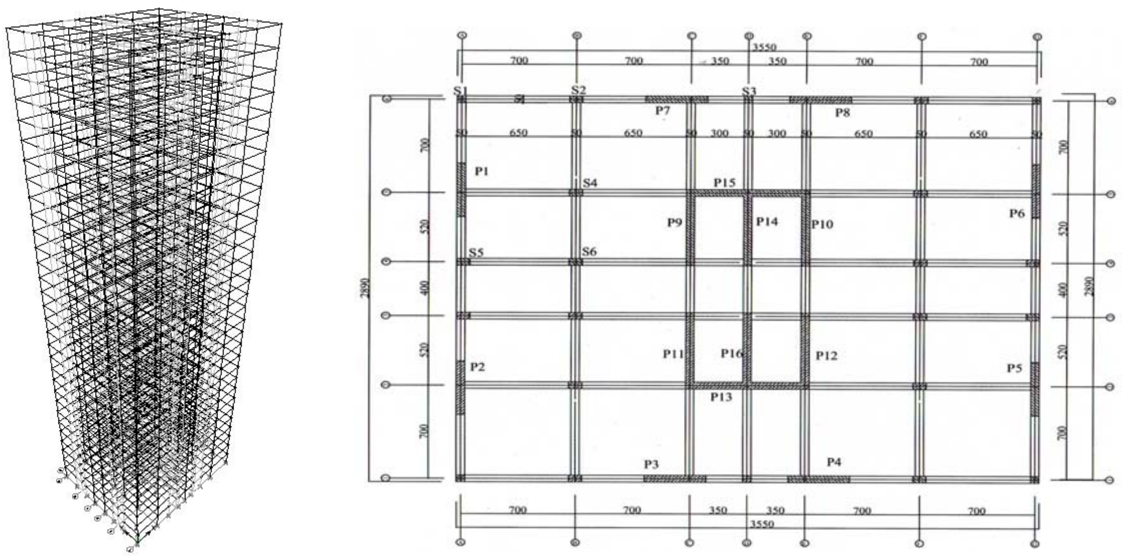


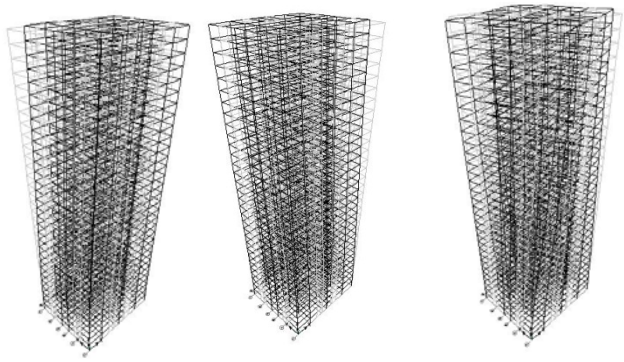
Figure 1. 3D model and typical storey layout of the tall building considered

3.1 Modal and Earthquake Analysis

The building is analyzed by using software of ETABS. The first mode period T_x = 2.4663 s and the second period T_y = 2.3781 s. The first six period and mode shape direction of the structure are given in Table 3. First three mode shape of structure are given in Figure2.

Table 4. The first six modes

Mode	Period	Direction
1	2.4663	X
2	2.3781	Y
3	1.9239	Torsional
4	0.7002	Y
5	0.6822	X
6	0.6137	Torsional



1.mode 2.mode 3. mode

Figure 2. The first three mode shapes of building

The design of the building is carried out by considering requirements of Turkish Seismic Code 2007. The following parameters are used to calculate the equivalent static seismic loads: The effective ground acceleration coefficient A_o=0.40 (first seismic zone), the building importance factor I = 1.0, the spectrum characteristic periods T_A = 0.10s and T_B = 0.30s (local site class Z1), the live load participation factor n = 0.3, and the structural behavior factor R=7. According to the equivalent seismic load method given in 2007 Turkish Seismic Code, the base shear forces are in x and y-directions, V_{tx} =13488.84 kN and V_{ty}=13926.32 kN, respectively. Minimum base shear force is $V_{t,min}$=20415.5 kN. Therefore, $V_{t,min}$ is used in both directions. By using the mode superposition method, the base shear forces are obtained as V_{tx} =12991.97 kN and V_{ty}=13765.83 kN, in x and y-directions, respectively. It should be clarified that no structural analysis is performed when estimating the accelerations. Accelerations are estimated from the formulas given in the codes. However, analysis is performed to estimate roof displacements under wind loads, which is required for estimation of accelerations in some of the codes. Also, modal analysis is performed for estimation of periods.

3.2 Wind analysis

Wind is considered in the x-direction (Figure 3).

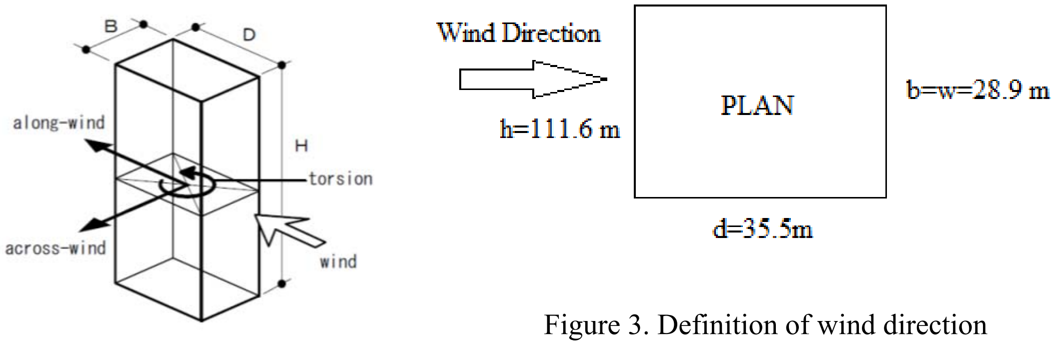


Figure 3. Definition of wind direction

The following expression has been proposed for wind frequency applications. (Zhou and Kareem 2001, Zhou, Kijewski, and Kareem 2002);

$$f_{n1} = \frac{150}{H} = 0.41 \text{ Hz} \qquad \text{where H is the height of the structure (feet)} \qquad (1)$$

The values obtained from analysis and the formulae are consistent. The frequency values obtained from the formula are used in the numerical calculations. The time duration and return periods for various codes are given in Table 6. As it is seen, the return period is generally 50 year. The wind speeds, peak accelerations and displacement limits are given in Table 7 for a number of codes, where H is the height of the structure (m) and h_i is the story height (m). The peak acceleration and comfort criteria are shown in Table 8. Estimation of accelerations are based on wind speeds with a return period of 10 years. Conversion of values from 50 years return period to 10 years return period is based on the formulas given by the codes respectively.

Table 5.Basic wind speed in Istanbul

Time Duration	Basic Wind Speed in Istanbul (m/s)
3 second	36.19
10 minute	25
1 hours	23.83

Table 6. Time duration and return period

CODE	Time Duration	RP (year)
İYBRY	10 minute	50
ASCE7-10	3 second	50
AS/NZS 1170.2	3 second	50
IS875	3 second	50
EUROCODE 1-04	10 minute	50
NBCC	1 hour	50
AIJ	10 minute	50-100
EIT	1 hour	50

Table 7.Peak acceleration, maximum displacement and lateral drift on the structure

CODE	Basic Wind Speed	Design Wind Speed	Wind Speed for Acc.	Along Wind Peak Acc.	Across Wind Peak Acc.	Max. Disp.	Disp. Limit	$(\delta_i)_{maks}/h_i$	Drift limit
	(m/s)	(m/s)	(m/s)	(m/s^2)	(m/s^2)	(m)	(m)	------	--------
ASCE7-10	36.19	31.53	28.43	0.025	-	0.012	H/1000=0.11	0.0001	0.002
AS/NZS 1170.2	36.19	38.57	34.79	0.022	0.121	0.015	H/1000=0.11	0.0002	0.002
NBCC	23.81	24.08	39.49	0.018	0.095	0.019	H/1000=0.11	0.0002	0.002
IS875	36.19	45.98	22.19	0.043	-				
EUROCODE 1-04	25	24.59	21.40	0.034	0.027				
AIJ	26.73	22.97		0.031	0.049				
EIT	23.81	24.16	21.80	0.032	0.048				

Table 8. Peak acceleration and comfort criteria

CODE	Peak Acc. (m/s^2)	According to Table 2	Acc. to Table3
ASCE7-10	0.025	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Not Perceptable
AS/NZS 1170.2	0.121	a) Majority of people will perceive motion; b) Level of motion may affect desk work: c) Long - term exposure may produce motion sickness	Threshold of Perceptibility
IS875	0.095	a) Majority of people will perceive motion; b) Level of motion may affect desk work: c) Long - term exposure may produce motion sickness	Threshold of Perceptibility
EUROCODE 1-04	0.043	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Not Perceptible
NBCC	0.034	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Not Perceptible
AIJ	0.049	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Not Perceptible
EIT	0.048	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Not Perceptible
MEAN	0.059	a) Sensitive people can perceive motion; b) Hanging objects may move slightly	Threshold of Perceptibility

4 CONCLUSION AND OBSERVATIONS

This paper has focused on serviceability limit states of tall buildings due to wind acceleration. Wind acceleration was investigated according to the different codes. The results obtained are summarized below:

- There are no single occupant comfort serviceability criteria that is accepted internationally and enforced in various codes. Structural codes of different countries have different methods of assessing serviceability, and each these codes may yield significantly different results.
- It has been determined that the wind acceleration in the along-wind direction is less than the acceleration in the across-wind direction of the wind for almost all codes
- It is observed that accelerations of the building is inversely proportional with the damping ratio of the structure according to the formulas given in all codes. This is important in the sense improving the damping may directly reduce the accelerations and may be a convenient solution for mitigation of the accelerations.
- It is observed that an increase in the weight of the structure will reduce the displacement caused by the wind and may result in a reduction in the acceleration of the structure according to the formulas given in the codes. On the other hand, if increase in the mass changes the period of the structure significantly, then above conclusion may not be true.
- Human psychology, culture and other social characteristics are very important for comfort criteria. It is considered that criteria given in one country may not be directly applicable in another country due to differences in social conditions.

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