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Investigation of Wind Effects of Tall Buildings According to ASCE 7-16 Regulation and Comparison of Wind Simulation Program

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Abstract

Over time, developments in structural systems have increased the strength-to-weight ratio of load-bearing systems, the weight of the structure has decreased, and wind loads have begun to gain importance. Therefore, it has been understood that since the tall buildings built today are lighter and more flexible than their predecessors, their oscillations under wind load have become the most important problem faced by the designers of high buildings and have become the main parameter guiding the design. TSEN-1991-1-4 regulation excludes buildings with a maximum height of 200 meters from the scope of the regulation and recommends wind tunnel testing. However, there are various simulation programs for situations where wind tunnel testing is not possible. Within the scope of this article, the wind effect on the facade of the 72-storey building, which architectural plan is given, was examined according to the ASCE 7-16 regulation, and the results were compared with the wind simulation results in the Autodesk robot program. According to these results, it was concluded that the values were approximately similar. Although the process steps are long and laborious, it has been concluded that similar simulation results can be used as the first step in the absence of a wind testing or for preliminary design situations of critical structures.

1. Introduction

In the past, wind loads were ignored because the load-bearing systems of the first skyscrapers made vertical forces more critical than horizontal forces. Over time, with the developments in carrier systems and the increase in the strength-to-weight ratio of structural systems, the weight of the structure decreased and wind loads began to gain importance. In this way, it has been understood that the proportions of high-rise building units built today have become the main parameter that constantly guides the most important problems faced by building designers with high oscillations under wind load, as they are lighter and inflexible. In addition to the vertical loads that increase with the rise of the building, the main loads affecting the bearing system of the building are horizontal forces such as wind and earthquake, and the building is rigidified by various methods to meet these loads [1]. There are various studies on the static and dynamic behaviour of high-rise buildings under the influence of horizontal loads and calculation methods related to wind load in different regulations [2-4]. There are widely accepted wind tunnel techniques for obtaining wind loads on tall buildings. Hovewer, they are time-consuming and may be inconvenient in the pre-concept design process in terms of fast and economic methods to predict the wind loads [5]. For this reason, studies on the realistic determination of wind load by different methods are still ongoing today. Fouad et al. have been studied Computational Fluid Dynamics (CFD) techniques to facilitate winds required for flexible design such as permanent drag in pressure centers for some buildings. For some structures (such as single and double inclined single angle short cradle structures, trusses and domes) existing wind tunnel results and those used by CFD experts were investigated. Fundamental effects such as roof slopes and wind directions were not taken into account in the analysis of the gables. In addition, different roof zone pressure floors were evaluated for gable buildings with CFD experts' international wind standards and codes of practice [6]. Verma et al. is specified that wind code IS 875 (PART-3 rd) provides pressure coefficients (C_P) only at 0º and 90º wind incidence angles and only for a few standard cases. Therefore, experimental studies gain importance and measure wind loads on high-rise building models at different wind incidence angles. Wind tunnel experiments are carried out for CFD offers a very powerful alternative to predict wind-related events on buildings or different types of structures. CFD analysis was carried out by taking into account the same parameters used in the experimental study by FLUENT-14 (ANSYS 14.0) software, and the buildings selected were octagonal in plan. Also, to measure the average area-weighted average wind pressures on the surfaces of building models in order to examine the effect of changing wind incidence angles (0º, 15º and 30º) on the wind pressure distribution were aimed [7]. Esmaili et al. examines urban planning that causes an increase in the wind speed at ground level around a 56-storey high-rise building with a special architectural plan consisting of three wings of the same plan, approximately 48 meters by 22 meters, placed 120 degrees away from each other, around three other 36-storey high-rise buildings with a rectangular architectural plan. It addresses one of the most common situations. FLUENT program, was used to demonstrate the effectiveness of these building regulations in increasing wind speed and the associated disturbance level. Some design practices to avoid high wind speeds around buildings are derived from this analysis, which may be useful for engineers, architects and urban planners [8]. In Jeong and Choi's study, wind loads on two rectangular building models predicted using CFD were compared with those obtained by different international building design codes (KBC 2005, AIJ 2004, ASCE 7-05, Eurocode-2004) and wind tunnel tests. FLUENT program, was used to calculate wind loads on buildings. The CFD results for Model I (45 m high building) matched well with the wind tunnel test results. However, the results obtained with international design codes are approximately 2-3 times higher than the results obtained by experiment. The results of Model II (200 m high building) show that the values obtained by CFD are some between the design codes and the wind tunnel test. The results show that wind loads predicted on buildings using CFD are comparable to wind tunnel testing results and that building design codes are more conservative than CFD and wind tunnel testing [9].

In this study, variables against the wind forces of high-rise buildings have been researched and ASCE 7-16 (Minimum Design Loads and Associated Criteria for Buildings and Other Structures) standard have been examined [10]. According to this, the wind loads acting on the building and the building's response to this effect depends on variables such as the character of the wind, the geometry of the building dimensions, the building mass distribution and geometry, the building mass distribution and stiffness, the energy absorption capacity of load-bearing system and topoghraphic structure. Also within the scope of this study, for a high-rise building model, the wind loads obtained according to the ASCE 7-16 regulation are compared with the results obtained using a wind simulation programme.

Since wind speed pressure increases with height, wind loads acting on the building become more important as the height of the building increases. Generally, in buildings above 40 floors, structural design is controlled by wind loads in buildings [11]. In Figure 1, the movements that may occur in the building due to wind effect are shown. According to this, wind-induced building movements are as follows (Figure 1);

- Movement in the direction of the wind
- Movement perpendicular to the wind
- Torsional movement

Windward movement and torsional movement of most tall buildings are more critical than downwind movement. However, due to the complexity of directional movements perpendicular to the wind and torsional movements, many existing specifications include approaches that only address the response in the wind direction. In order to determine the wind behaviour of non-standard tall buildings due to their architecture, structural features or location (e.g. geometry, height, cross-section, material used, location or surrounding structures), wind tunnel tests are generally required [13]. Wind tunnel tests are recommended to determine the reactions occurring in the building as close to reality as possible. In the wind tunnel test, the building and the wind are modeled to a certain scale and air flow is sent to the model at various speeds and modes. In structural design, wind load is determined according to the results obtained from wind tunnel testing.

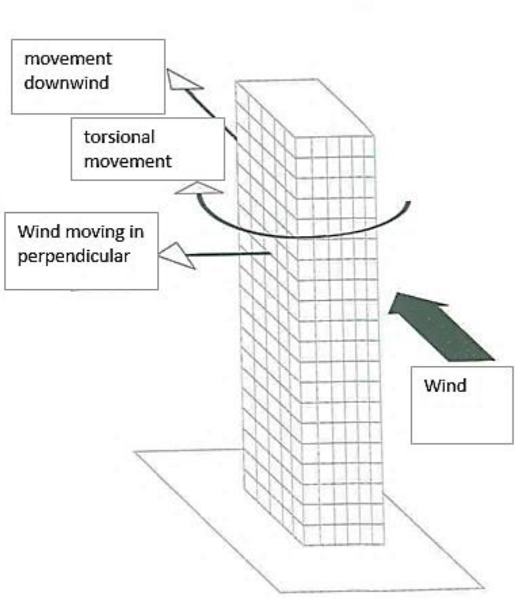


Figure 1. Wind-induced building movements [12]

The facade loads obtained in the wind tunnel experiment are generally smaller than the regulation values throughout the building. Therefore, significant economy can be achieved with the facade loads obtained from wind tunnel testing. Especially in the design of super-tall buildings and mega-tall buildings, it is necessary to work together with wind engineers from the idea project stage. The dynamic effects of the wind can be significantly reduced by making changes in the building architecture, such as rounding the corners, making the building facade twisted, tapering the building towards the upper floors, making changes to some floor plans, adding small wings that will disperse the vortex effects to a certain extent, and creating a gap in the building. Chicago Spire, Shanghai Tower, Taipei 101, Shanghai World Financial Center are examples of tall buildings shaped according to wind load [11]. Wind tunnel tests of Taipei 101 and Burj Khalifa can be seen from Figure 2 and Figure 3, respectively. Wind tests are very important in this respect before starting construction. Such tests are required in most high-rise buildings built in the world. As can be seen from Figure 2 and Figure 3, important structures such as skyscrapers are considered together with the surrounding structures in the wind analysis. The 1/500 scale version of the building model in Figure 3 is rotated around its axis and is subjected to the wind effect from the turbine.

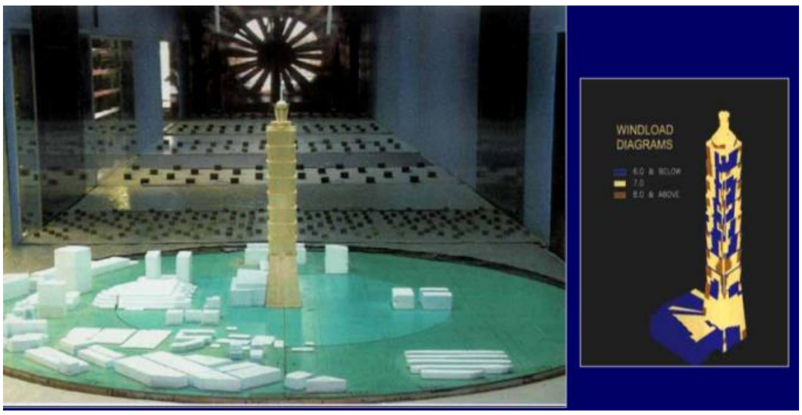


Figure 2. Taipei 101 wind tunnel test [14]

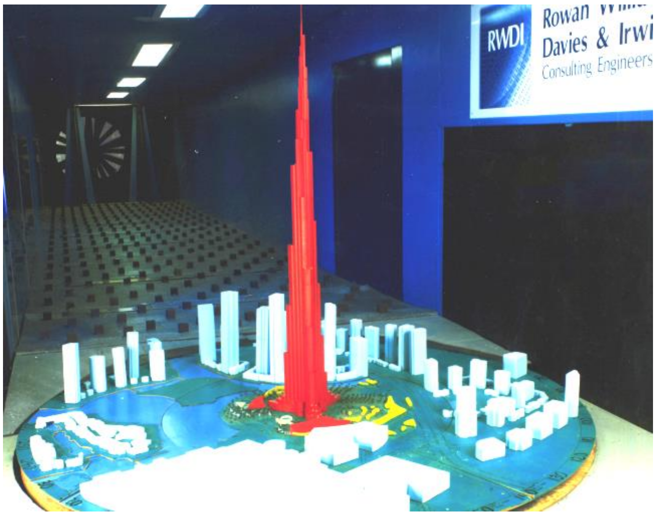


Figure 3. Burj Dubai wind tunnel test [15]

2. Material and Method

According to the Regulation on the Principles of Design, Calculation and Construction of Steel Structures, the conditions given in TS EN 1991-1-4 regulation will be taken into consideration for the wind loads to be taken as basis in the design of building systems [16]. TS-EN-1991-1-4 regulation excludes buildings with a maximum height of 200 meters from the scope of the regulation and recommends wind tunnel testing for these buildings [17]. However, there are various simulation programs for situations where wind tunnel testing is not possible. Within the scope of this study, the wind effect on the facade of the 72-storey tubular steel building, whose architectural plan is given in Figure 4 and Figure 5, was examined according to the ASCE 7-16 regulation, and the results were compared with the wind simulation results obtained from the Autodesk Robot Structural Analysis program [18].

In this study, it is assumed that the building is located in the central district of Akdeniz in Mersin and that the building will be designed as a 72 storey office building. The local soil class is determined as ZC. The floor height of the building is considered as 3.6 meters and the building is designed symmetrically with 6 spans in both directions. The axle distances are 6 meters and the total length is 36x36 meters.

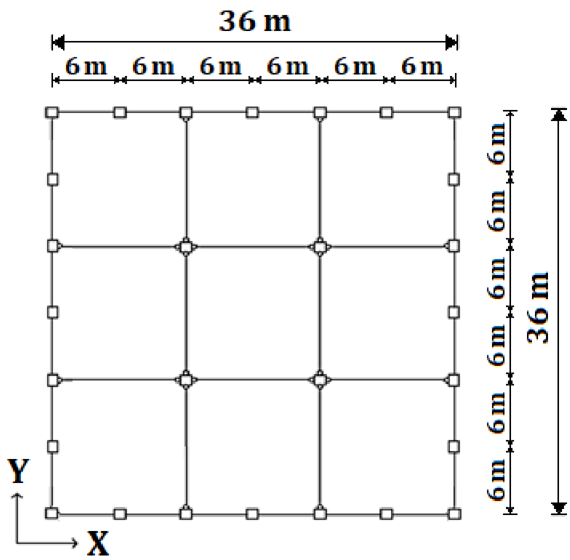


Figure 4. Floor plan of building model

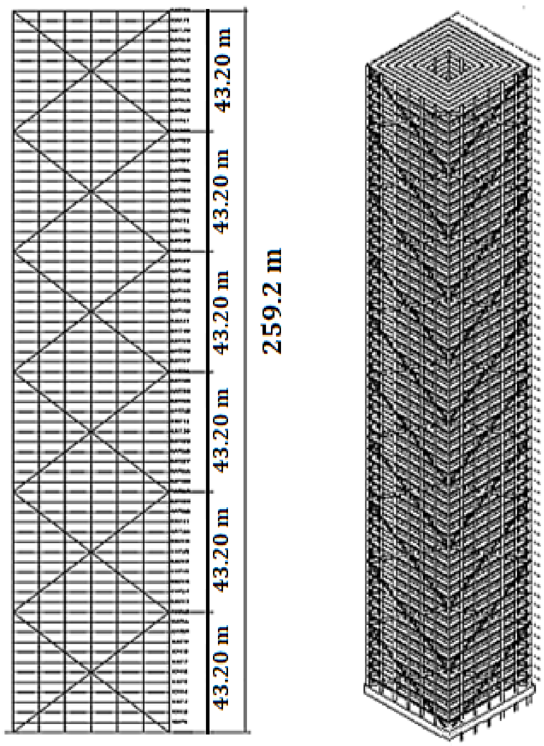


Figure 5. Structural system and three-dimensional view of building model

2.1. Wind Load according to ASCE 7-16 Regulation

This standard contains the principles on how wind loading will be applied to building type structures and other structures. Within the scope of this regulation, the wind pressure that will affect open and other structures should not be less than 0.42 kN/m^2 multiplied by the A_f area. Where A_f is area of open buildings and other structures either normal to the wind direction or projected on a plane normal to the wind direction.

In this study, the 3-second speed of the wind blowing at a height of 10 meters for category C was taken as the basic wind speed.

In the ASCE 7-16 regulation; there are three types of building descriptions namely low-rise buildings, open buildings and partially closed buildings.

Low-rise building: This type of buildings includes closed or partially closed buildings where the height does not exceed 18.3 meters or the roof height does not exceed the minimum building length.

Open buildings: In this type of buildings, 80% of each wall is open.

Partially closed buildings: Building where the total amount of opening on the building facade exceeds 10%. It is a building type consisting of walls where the opening on the building facade exceeds 0.37 m^2 or 1% of the gross area of the relevant wall.

ASCE 7-16 regulation also divides structures into rigid structures and flexible structures. Rigid structures are considered to be buildings where the building frequency equal or exceeds 1 Hz, and flexible structures are considered to be buildings whose building frequency is below 1 Hz.

2.1.1. Wind load design methods

There are three methods for calculating wind loads according to ASCE 7-16. These methods are:

Method 1: Simplified method (envelope procedure), is used in structures consisting of simple diaphragm buildings with low height.

Method 2: Analytical method (directional procedure) is a second method that is somewhat more complex than method 1 used in high-rise buildings with regular geometry.

<u>Method 3:</u> This method, called wind turbine (wind tunnel procedure), is an experimental method based mostly on small-scale real models of the building. This method is based on complex and geometrically irregular buildings.

In this study, method 2 (directional procedure) will be used first and then compared with the wind simulation results. The parameters of method 2 used in the calculation of wind loads are stated below.

2.1.1.1. Wind Directionality Factor(K_d)

The wind directionality factor K_d, which varies depending on the building type, is taken from the Table 1 [10]. In this study, the wind direction coefficient K_d of the building structural system (MWFRS) was determined as 0.85.

Table 1. Wind directionality factor, K_d values [10]

Structure Type	Wind Direction Coefficient K_d
Buildings	
Main Wind Force Resisting System(MWFRS)	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

[a]Directionality factor Kd =0.95 shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

2.1.1.2. Importance factor, (I)

The importance factor, which varies depending on the building category and speed, is taken from the Table 2 [10]. In this study, the importance factor was chosen as 1, based on category 2 and regions without hurricane effects.

Table 2. Importance factor, I values [10]

Risk Category	Hurricane affected and hurricane-prone areas	Areas affected by hurricanes
	V = 38-45 m/sn	V > 45 m/sn
I	0,87	0,77
II	1,00	1,00
III	1,15	1,15
IV	1,15	1,15

2.1.1.3. Velocity pressure exposure coefficients (K_h and K_z)

According to ASCE 7-16, surface roughness categories are divided into three classes: B, C and D.

<u>Ground surface roughness B:</u> Includes urban centers and their surroundings, frequently disabled lands, forest areas, single-storey buildings or lands with more residential buildings.

<u>Ground surface roughness C:</u> Open lands, scattered obstacles, land with structures lower than 9.1 meters and scattered around, open areas and pastures.

<u>Ground surface roughness D:</u> Flat unobstructed areas and water surfaces mud layer salt pan.

According to ASCE 7-16, terrain is divided into three classes: B, C and D.

<u>Terrain class B:</u> Land class with land surface hardness of 20h > 792 along the wind direction, where h is the building height.
<u>Terrain class C:</u> Land type for which terrain classes B and D do not apply.
<u>Terrain class D:</u> Land class with a land surface hardness of 20h > 1585 along the wind direction, h being the building height (situation on smooth water surfaces), and also having a B and C class surface hardness of 20h> 154 m along the wind blow direction, h being the building height land.

In this study, the model building is located in the city center of Mersin and is classified as B land since it does not vary across 20 x 252 = 5040 meters. Velocity pressure exposure coefficients, K_h and K_z values are shown in Table 3 according to ASCE 7-16.

Table 3. Velocity Pressure Exposure Coefficients, K_h and K_z [10]

Height		Exposure			
		B		C	D
ft	**m**	**State 1**	**State 2**	**State 1,2**	**State 1,2**
0-15	0-4.6	0.7	0.57	0.85	1.03
20	6.1	0.7	0,62	0.9	1.08
25	7.6	0.7	0,66	0.94	1.12
30	9.1	0.7	0,7	0.98	1.16
40	12.2	0.76	0,76	1.04	1.22
50	15.2	0.81	0,81	1.09	1.27
60	18	0.85	0,85	1.13	1.31
70	21.3	0.89	0,89	1.17	1.34
80	24.4	0.93	0,93	1.21	1.38
90	27.4	0.96	0,96	1.24	1.4
100	30.5	0.99	0,99	1.26	1.43
120	36.6	1.04	1,04	1.31	1.48
140	42.7	1.09	1,09	1.36	1.52
160	48.8	1.13	1,13	1.39	1.55
180	54.9	1.17	1,17	1.43	1.58
200	61	1.2	1,2	1.46	1.61
250	76.2	1.28	1,28	1.53	1.68
300	91.4	1.35	1,35	1.59	1.73
350	106.7	1.41	1,41	1.64	1.78
400	121.9	1.47	1,47	1.69	1.82
450	137.2	1.52	1,52	1.73	1.86
500	152.4	1.56	1,56	1.77	1.89

The velocity pressure exposure coefficient K_z can also be determined using Equation (1) and Equation (2) according to ASCE 7-16. Table 4 shows the required values in these equations.

$$4{,}6\,m \le z \le z_g \quad K_z = 2{,}01\left(\frac{z}{z_g}\right)^{\frac{2}{a}} \tag{1}$$

$$\mathrm{z} \le 4{,}6 \quad \mathrm{K_z} = 2{,}01\left(\frac{15}{\mathrm{z_g}}\right)^{\frac{2}{\mathrm{a}}} \tag{2}$$

Table 4. Terrain exposure constants [10]

Exposure	α	z_g(m)	$\hat{\alpha}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	l(m)	$\bar{\epsilon}$	z_{min}(m)^a
B	7	365.76	1/7	0.84	1/4.0	0.45	0.30	97.54	1/3.0	9.14
C	9.5	274.32	1/9,5	1.00	1/6.5	0.65	0.20	152.4	1/5.0	4.57
D	11.5	213.36	1/11,5	1.07	1/9.0	0.80	0.15	198.12	1/8.0	2.13

$^a z_{min}$ = minimum height used to ensure that the equivalent height $\bar{z}$ is the greater of 0.6h or z_{min}.
For buildings or other structures with h ≤ z_{min}, $\bar{z}$ shall be taken as z_{min}.

In this study, Equation (1) and (2) were used to determine the structure velocity pressure exposure coefficient K_z, and for land class B, α = 7 and z_g = 366 values were taken for calculation.

2.1.1.4. Topographic factor, (K_{zt})

Topographic factor is the coefficient that allows taking into account factors that increase wind speed due to sudden changes on the land surface, such as hills and slopes. This coefficient is determined by Equation (3).

$$K_{zt} = (1 + K_1 K_2 K_3)^2 \tag{3}$$

Where K_1: Factor that takes into account the shape of topographic feature and maximum speed-up effect, K_2: Factor that takes into account the reduction in speed-up with distance upwind or downwind of crest, K_3: Factor that takes into account the reduction in speed-up with height above local terrain. K_1 factor can be taken from Table 5 [10].

Table 5. Speed–up over Hills and Escarpments parameters [10]

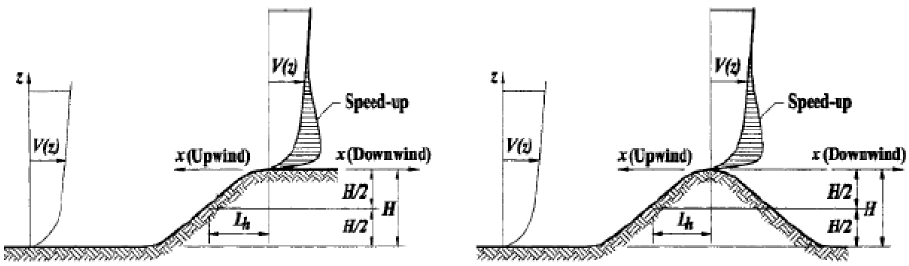
Hill shape	$K_1(H/L_b)$ Exposure B	C	D	γ	μ Upwind of crest	Downwind of crest
2 Dimensional ridges or valleys	1.3	1.45	1.55	3	1.5	1.5
2 Dimensional escarpments	0.75	0.85	0.95	2,5	1.5	4
3 Dimensional axisymmetrical hill	0.95	1.05	1.15	4	1.5	1.5

The other parameters K_2 , K_3 values must be taken from Equation (4) and Equation (5).

$$K_2 = \left(1 - \frac{|X|}{\mu L_h}\right) \tag{4}$$

$$K_3 = e^{-yz/L_h} \tag{5}$$

Speed increase representation for escarpment and slope can be seen in Figure 6. In cases where there are no sudden changes, K_{zt} = 1 can be taken. In this study, K_{zt} value was taken as 1.



ESCARPMENT 2-D RIDGE OR 3-D AXISYMMETRICAL HILL

Figure 6. Speed increase representation for escarpment and slope [10]

2.1.1.5. Gust-effect factor, G

G factor is calculated differently for rigid and flexible structures. Within the scope of the ASCE 7-16 regulation, 0.85 can be taken for rigid structures or it can be calculated with the help of the Equation (6).

$$G = 0.925\left(\frac{1+0,7g_Q I_{\bar{z}} Q}{1+0,7g_v I_{\bar{z}}}\right) \quad (6)$$

The equivalent height of the structure $\bar{z}$ is defined as 60% of the height of the structure ($\bar{z}$ = 0.6h). This is not valid for structures where the height z_{min} is less than the building height. g_Q is the peak factor for ground response and g_v is recommended for the peak factor against the wind. The recommended value for g_v is 3.4. The turbulence intensity at height $\bar{z}$ is calculated using $I_{\bar{z}}$ formula (Equation 7). Q and $L_{\bar{z}}$ parameters can be obtained from Equation (8) and Equation (9), respectively.

$$I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{1/6} \quad (7)$$

$$Q = \sqrt{\frac{1}{1+0,63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0,63}}} \quad (8)$$

$$L_{\bar{z}} = l\left(\frac{\bar{z}}{10}\right)^{\bar{\varepsilon}} \quad (9)$$

Q parameter is the background response is given by Equation (8). $L_{\bar{z}}$ is integral length scale of turbulence at the equivalent height given by Equation (9). l and $\bar{\varepsilon}$ are constants determined from Table 4.

In this study, since the building is a rigid structure, the gust effect factor was taken as 0.85.

2.1.2. Wind pressure

According to ASCE 7-16 regulation, wind pressure at height z is calculated according to the Equation (10).

$$q_z = 0,631. K_z. K_{zt}. K_d. V^2. I\ (N/m^2) \quad (10)$$

2.1.3. Internal pressure coefficient

Internal pressure coefficients GC_{pi} of building classes are determined according to the Table 6 [10].

Table 6: Internal pressure coefficients of construction classes [10]

Enclosure classification	GC_{pi}
Enclosed buildings	+0.18 -0.18
Partially enclosed buildings	+0.55 -0.55
Partially open buildings	+0.18 -0.18
Open buildings	0.00

Since the building type within the scope of the study is a closed structure, the internal pressure coefficient GC_{pi} is determined as +0.18 and -0.18.

2.1.4. External pressure coefficient, C_p

Building classes external pressure coefficients C_p are determined according to Table 7 [10]. Wind distribution in plan and section on a building according to ASCE 7-16 are shown in Figure 7.

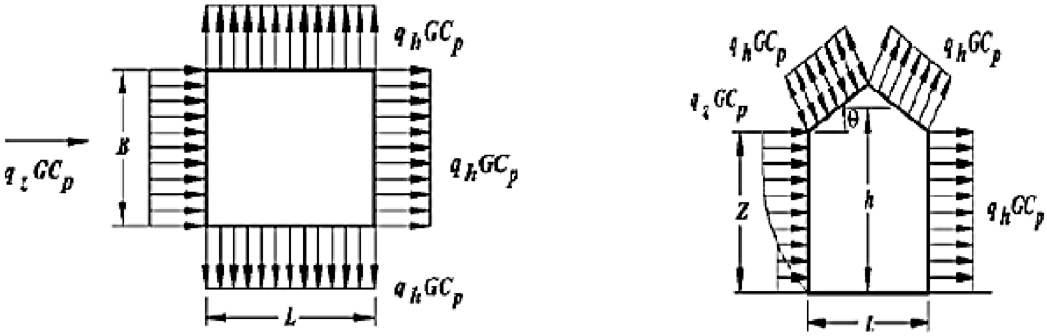


Figure 7. Wind distribution in plan and section [10]

Table 7: Wall Pressure Coefficients, C_p [10]

Surface	L/B	C_p	Velocity pressure
Windward wall	All values 0-1 2	0.8 -0.5	q_z
Leeward wall	2 ≥ 4	-0.3 -0.2	q_h
Side wall	All values	-0.7	q_h

Within the scope of this study, the external pressure coefficient C_p was determined as 0.8 for the front side, C_p=-0.5 for the rear side from L/B=36/36=1, and C_p= -0.7 for the side walls.

2.1.5. Design wind pressure

Design wind pressures for the main wind force resisting system of enclosed, partially enclosed rigid and flexible buildings can be obtained by Equation 11 according to ASCE 7-16.

$$p = q.G.C_p - q_i(GC_{pi}) \qquad N/m^2 \tag{11}$$

2.2. Autodesk Robot Structural Analysis

In this study, the wind effect on the facade of the 72-storey steel building, whose architectural plan and structural system are given in Figure 4 and Figure 5 was modeled in Autodesk Robot Structural wind simulation program. This program is a wind simulation tool to emulate wind tunnel testing to investigate building performance and structures can be subjected to simulated wind flows using computational fluid dynamics (CFD) analysis. The analysis can be customized and the results can be viewed or used to automatically generate wind loads on the structure [19]. The wind distribution simulator window in the Robot Structural Analysis program is shown in Figure 8.

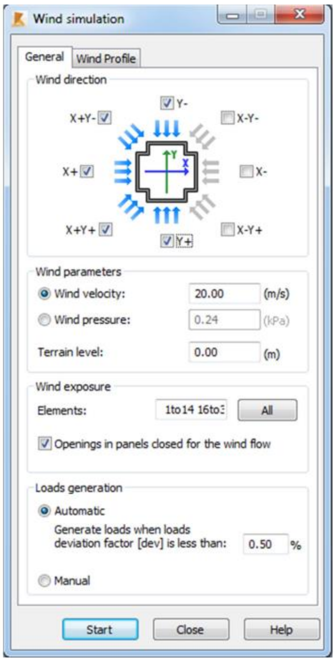


Figure 8. Wind distribution simulator window

Robot Structural Analyst's wind simulation analysis is based on structural analysis and design software and can be applied to all types of structures. Unlike code-based analysis methods, the program takes into account the actual geometry of the building and the interaction between wind flow and building response. If building parameters such as geometry, mass or stiffness change, the wind analysis can be updated and the results of these changes can be seen. Initial validation tests have shown that the wind simulation results of Robot Structural Analysis Professional closely match code-based analysis methods for regularly shaped low-rise structures and wind tunnel results for more complex structures. The wind distribution on the building model surface in the program is given in Figure 9. In the analysis, the stress distributions on the surface of the building can be seen on the color scale on the side.

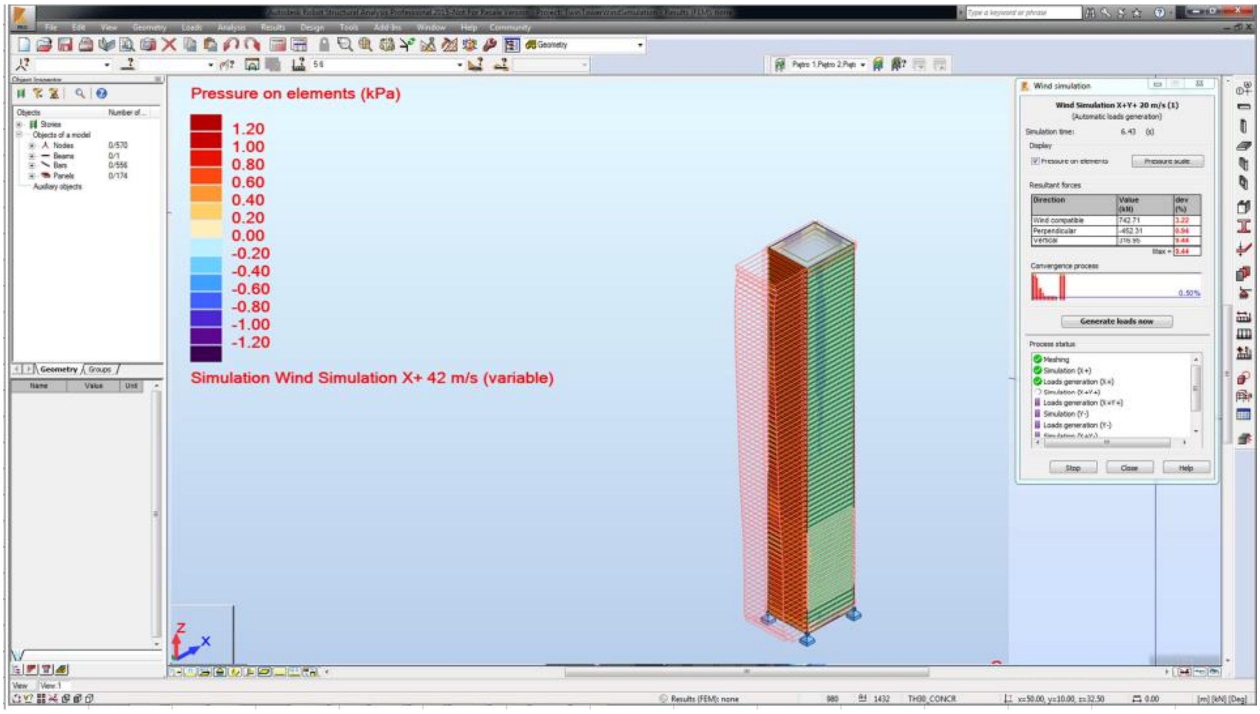


Figure 9. Wind distribution on the surface of the building model

3. Results

Design wind pressures can be obtained from Equation 11 according to ASCE 7-16. Accordingly, wind pressure values of examined building model were determined by using Table 8.

Table 8: Wind pressure values of examined building model according to ASCE 7-16

Front surface weenwerd																
z (m)	K_z	0.613	K_{zt}	K_d	V^2	I	q_z (N/m^2)	C_p -	G -	q*G.C_p (N/m^2)	q_i=q_{hmax}	G	C_{pi}	q_i*(G.C_{pi}) (N/m^2)	p (N/m^2)	p (kPa)
0	0.81	0.613	1.00	0.85	1764	1	741.6	0.80	0.85	5.042.964	1129.2	0.85	0.18	172.77	331.53	0.33
3.6	0.81	0.613	1.00	0.85	1764	1	741.6	0.80	0.85	5.042.964	1129.2	0.85	0.18	172.77	331.53	0.33
7.2	0.65	0.613	1.00	0.85	1764	1	601.3	0.80	0.85	4.088.951	1129.2	0.85	0.18	172.77	236.13	0.23
14.4	0.80	0.613	1.00	0.85	1764	1	733.0	0.80	0.85	4.984.487	1129.2	0.85	0.18	172.77	325.68	0.32
21.6	0.90	0.613	1.00	0.85	1764	1	823.0	0.80	0.85	5.596.703	1129.2	0.85	0.18	172.77	386.90	0.38
28.8	0.97	0.613	1.00	0.85	1764	1	893.6	0.80	0.85	6.076.158	1129.2	0.85	0.18	172.77	434.85	0.43
36	1.04	0.613	1.00	0.85	1764	1	952.4	0.80	0.85	6.476.161	1129.2	0.85	0.18	172.77	474.85	0.47
43.2	1.09	0.613	1.00	0.85	1764	1	1003.3	0.80	0.85	6.822.458	1129.2	0.85	0.18	172.77	509.48	0.50
50.4	1.14	0.613	1.00	0.85	1764	1	1048.5	0.80	0.85	7.129.655	1129.2	0.85	0.18	172.77	540.20	0.54
57.6	1.19	0.613	1.00	0.85	1764	1	1089.3	0.80	0.85	740.692	1129.2	0.85	0.18	172.77	567.92	0.56
64.8	1.23	0.613	1.00	0.85	1764	1	1126.5	0.80	0.85	7.660.421	1129.2	0.85	0.18	172.77	593.27	0.59
72	1.26	0.613	1.00	0.85	1764	1	1161.0	0.80	0.85	7.894.529	1129.2	0.85	0.18	172.77	616.68	0.61
79.2	1.30	0.613	1.00	0.85	1764	1	1193.0	0.80	0.85	8.112.462	1129.2	0.85	0.18	172.77	638.48	0.63
86.4	1.33	0.613	1.00	0.85	1764	1	1223.0	0.80	0.85	8.316.669	1129.2	0.85	0.18	172.77	658.90	0.65
93.6	1.36	0.613	1.00	0.85	1764	1	1251.3	0.80	0.85	8.509.057	1129.2	0.85	0.18	172.77	678.14	0.67
100.8	1.39	0.613	1.00	0.85	1764	1	1278.1	0.80	0.85	8.691.147	1129.2	0.85	0.18	172.77	696.35	0.69
108	1.42	0.613	1.00	0.85	1764	1	1303.6	0.80	0.85	8.864.168	1129.2	0.85	0.18	172.77	713.65	0.71
115.2	1.44	0.613	1.00	0.85	1764	1	1327.8	0.80	0.85	9.029.136	1129.2	0.85	0.18	172.77	730.14	0.73
122.4	1.47	0.613	1.00	0.85	1764	1	1351.0	0.80	0.85	9.186.895	1129.2	0.85	0.18	172.77	745.92	0.74
129.6	1.49	0.613	1.00	0.85	1764	1	1373.3	0.80	0.85	9.338.158	1129.2	0.85	0.18	172.77	761.05	0.76
136.8	1.52	0.613	1.00	0.85	1764	1	1394.6	0.80	0.85	9.483.532	1129.2	0.85	0.18	172.77	775.58	0.77
144	1.54	0.613	1.00	0.85	1764	1	1415.2	0.80	0.85	9.623.538	1129.2	0.85	0.18	172.77	789.58	0.78
151.2	1.56	0.613	1.00	0.85	1764	1	1435.1	0.80	0.85	975.863	1129.2	0.85	0.18	172.77	803.09	0.80
158.4	1.58	0.613	1.00	0.85	1764	1	1454.3	0.80	0.85	9.889.202	1129.2	0.85	0.18	172.77	816.15	0.81
165.6	1.60	0.613	1.00	0.85	1764	1	1472.9	0.80	0.85	1001.56	1129.2	0.85	0.18	172.77	828.79	0.82
172.8	1.62	0.613	1.00	0.85	1764	1	1490.9	0.80	0.85	1.013.813	1129.2	0.85	0.18	172.77	841.04	0.84
180	1.64	0.613	1.00	0.85	1764	1	1508.4	0.80	0.85	1.025.707	1129.2	0.85	0.18	172.77	852.94	0.85
187.2	1.66	0.613	1.00	0.85	1764	1	1525.4	0.80	0.85	1.037.266	1129.2	0.85	0.18	172.77	864.50	0.86
194.4	1.68	0.613	1.00	0.85	1764	1	1541.9	0.80	0.85	1.048.511	1129.2	0.85	0.18	172.77	875.74	0.87
201.6	1.70	0.613	1.00	0.85	1764	1	1558.0	0.80	0.85	1.059.463	1129.2	0.85	0.18	172.77	886.69	0.88
208.8	1.71	0.613	1.00	0.85	1764	1	1573.7	0.80	0.85	1.070.138	1129.2	0.85	0.18	172.77	897.37	0.89
216	1.73	0.613	1.00	0.85	1764	1	1589.1	0.80	0.85	1.080.554	1129.2	0.85	0.18	172.77	907.79	0.90
223.2	1.75	0.613	1.00	0.85	1764	1	1604.0	0.80	0.85	1.090.725	1129.2	0.85	0.18	172.77	917.96	0.91
230.4	1.76	0.613	1.00	0.85	1764	1	1618.6	0.80	0.85	1.100.664	1129.2	0.85	0.18	172.77	927.90	0.92
237.6	1.78	0.613	1.00	0.85	1764	1	1632.9	0.80	0.85	1.110.384	1129.2	0.85	0.18	172.77	937.61	0.93
244.8	1.79	0.613	1.00	0.85	1764	1	1646.9	0.80	0.85	1.119.895	1129.2	0.85	0.18	172.77	947.13	0.94
252	1.81	0.613	1.00	0.85	1764	1	1660.6	0.80	0.85	1.129.209	1129.2	0.85	0.18	172.77	956.44	0.95
504	2.20	0.613	1.00	0.85	1764	1	2024.3	0.80	0.85	1.376.521	1129.2	0.85	0.18	172.77	1203.75	1.20

Table 8 shows the pressure forces on the floors depending on height. In Figure 10 the pressure graph on the surface depending on altitude based is given. As can be seen form Figure 10, wind pressures surface tensions increase with height.

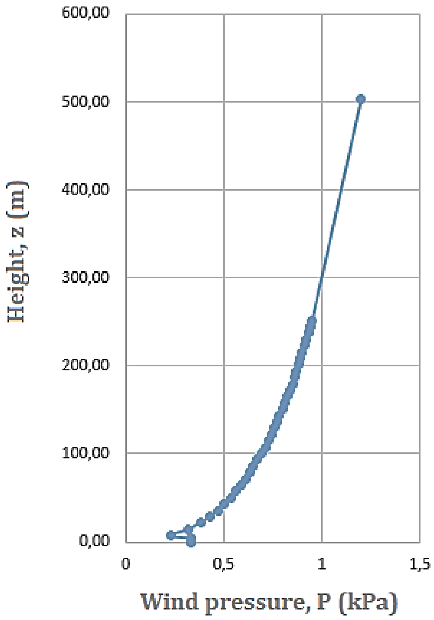


Figure 10*:* Wind pressure depending on altitude

Surface tension pressures as a result of wind simulations made with the Autodesk robot structural analysis program are given in Figure 11. When the wind effect on the three-dimensional model of the building is examined with the Autodesk Robot Structural program, the tension and compression stresses obtained on the building model facades are seen.

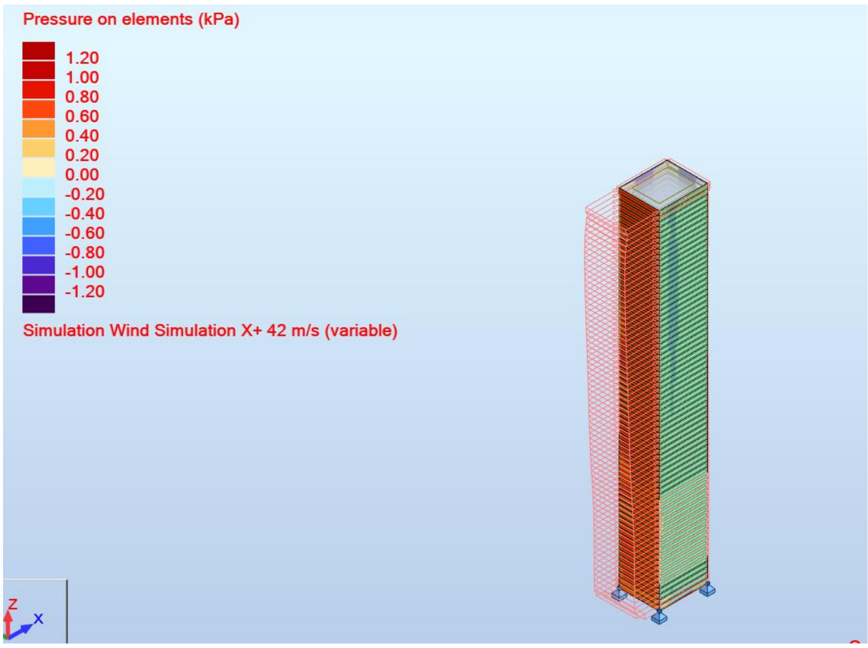


Figure 11: Robot structural analysis wind simulation results

The effect of wind on the facade was examined in Figure 12. According to the results obtained, it can be seen how the wind affects the side surfaces. As a result of these analyzes, it is seen that the largest stress value on the front surface of the building is 1.20 kPA as a result of simulation. As a result of the manual analysis, it was observed that although 1.20 kPA was the largest value, it was not observed in similar places in terms of distribution. Although they differ in terms of location, it is seen that the results are similar in terms of max min values. When the calculation is made for one floor below the top floor, it can be seen that a ratio of 0.95 / 1.20 = 0.80 is obtained.

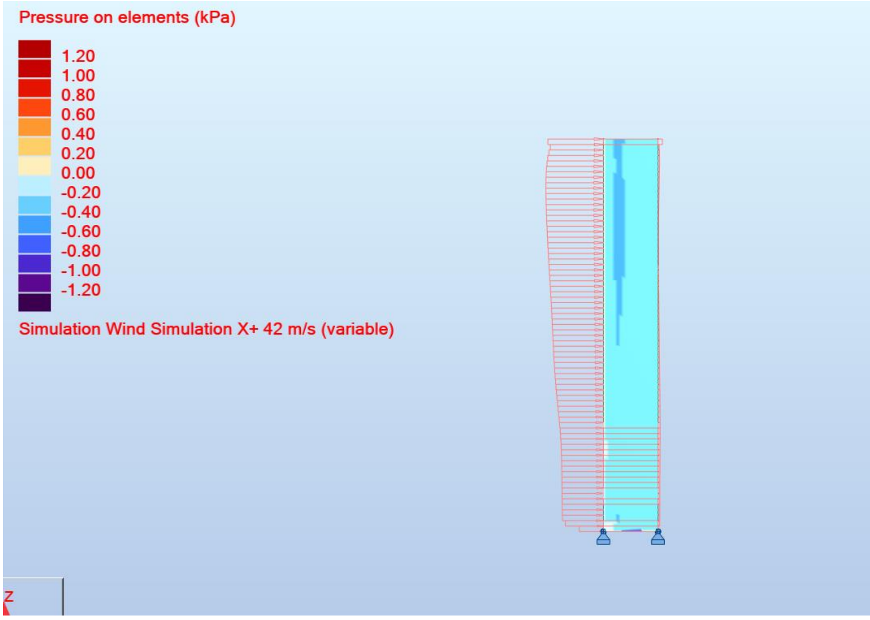


Figure 12: Wind affects on the side surfaces as wind simulation results

4. Conclusion

As a result of the calculations, the wind effect on the facade was examined according to the American wind regulation ASCE 7-16 and the results were compared with the wind consumption results found in the Autodesk robot program. According to these results, it was concluded that the values found in the simulation program and the results obtained in the ASCE 7-16 regulation are similar. When the result scale in the simulation program was examined, it was seen that the maximum and minimum values on the front of the building and the values in Table 8 remained in a similar range. Here, it should not be overlooked that the stresses that a phenomenon such as wind, which combines many complexities, will create on the building can not be fully determined neither by the formulas in the regulations nor by the simulation program. The process is long and laborious, similar simulation results are arranged in such a way that the first step can be used in the absence of wind tests or for preliminary design situations of critical structures. The wind simulation analysis programs may be used to validate or supplement analytical method results, and to identify potential wind design issues that require special consideration earlier in the design process. Also, this is important for validating analytical method results. Wind calculation is a critical issue that should be taken into consideration at the first stage of design. CFD softwares can be used in the initial stages of design to determine wind forces, which is an expensive and costly issue.

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Author contributions:

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Conflicts of interest

The authors declare no conflicts of interest.

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