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RESEARCH ARTICLE

EVALUATION of the TRANSMISSION LINE TOWER EXPOSED to ARTIFICIAL GROUND MOTIONS and WIND LOADS

Asuman Isil CARHOGLU*

*Suleyman Demirel University, Civil Engineering Department, Isparta, isilcarhoglu@sdu.edu.tr, ORCID:0000-0003-2325-1788

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ABSTRACT

Electricity transmission towers play an important role in the transmission of electricity. These buildings are very important to meet the many requirements related to electricity during natural disasters such as earthquakes and storms. Within the scope of this study, an electrical transmission line tower was analyzed and different wind velocities and different ground motion records were applied to the structure. In addition to it, the artificial earthquake acceleration records for different earthquake levels and soil classes were obtained for Istanbul by using Turkey Building Earthquake Regulation 2018. During the analysis, three wind speeds and the artificial earthquake acceleration records obtained by taking into account the different earthquake levels and ground classes were used. The wind pressure values acting on the structures are determined according to ASCE 7-10 standard. The ground motion data were carried out time history analysis. As a result of the analysis, displacement, stress and base shear force values were obtained and compared.

Keywords:*Steel towers, Wind analysis, Time history analysis.*

1. INTRODUCTION

Electricity Transmission towers are structures that provide electricity transmission. The requirement for transmission towers has increased with the rapid advance of technology. Transmission towers are generally tower type delicate structures having different geometrical features and are under the effect of forces such as earthquake and wind. In terms of structural engineering, it is of great importance to examine behavior under the earthquakes and wind effects of these towers. Since electricity transmission towers are structures providing electricity transmission, it is very important following the earthquake.

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Figure 1. The steel tower damaged by the strong wind in China [1].

Strong winds often occur in many regions of the earth. They occur in tropical regions especially and create destructive effects on coastal parts [2]. Storms such as earthquakes can have destructive effects in a number of regions of the world. The five towers were damaged during strong winds in China in 2010 [1;3]. The tower structures damaged in China are shown in Figure 1. These steel tower structures are under the effect of wind and earthquake loads. Examining the effect on the structures of wind loads is of great significance in terms of structural engineering. As the height of the structure increases, the wind load occurring on the structure will be greater.

Many studies investigating the behavior of the towers under the earthquake effect were performed. There are studies which take the wind effect as well as the earthquake effect into consideration. Liang et al. [4] examined the behavior of the towers under seismic loads by modeling two electric towers with different heights by SAP 2000 program. Bai et al. [5] investigated the behavior of the building under the earthquake effect by modeling an electrical tower with SAP 2000 program. Hadimani P. [6] modeled electrical tower structures with ANSYS program and performed static and dynamic analysis. They studied the behavior of the structure under the wind and earthquake effect. Partal [7] investigated the steel telecommunication tower structure which was exposed to the effect of wind and seismic forces. They modeled the tower with SAP 2000 program and examined the structural behavior of the tower under the effect of the earthquake and wind loads. Tuncer [8] examined in the behavior of PTT. Kars television transmitting tower. They compared the values obtained from test results by using SAP 90 program. They observed that the values were close. They carried out the static and dynamic analyzes. Furthermore, the comparisons were also made by performing the wind calculations. Rajasekharan et al. [9] dealt with 4 legged towers whose heights are 30m, 40m and 50m. They considered two different wind velocities in the course of the analysis. Additionally, the analysis was performed by using the modal analysis and response spectrum method. They determined displacement values for towers with different heights. Sharma et al. [10] discussed telecommunication towers with different heights and different bracing shapes. They carried out wind analysis for different wind zones in accordance with the regulation. They also carried out seismic analysis using the response spectrum analysis method. Long et al. [11] examined the collapse of transmission steel towers by using MATLAB and ANSYS programs. As a result of the performed analysis, it was seen that the finite particle method and the finite element method were compatible. In addition to this, it has been determined that the transmission tower is safe under the effect of earthquakes and resistant to collapse. Bhowmik et al. [12] performed the modal analysis of the transmission tower by using analytical and experimental studies. The transmission tower was designed as a prototype. In addition, the tower was modeled using the finite element program with ANSYS program.The first six frequency values were determined and compared experimentally and analytically. It was obtained the differences as a result of analytical and experimental studies. Asgarian et. al. [13] examined the progressive collapse of a tower structure. Load increase factor was determined by performing analysis. The ratios of capacity-demand was obtained by using different scenarios for element removal. This values was compared with overload factor obtained by performing pushdown analysis. Tas [14] carried out the time history analysis of the steel telecommunication towers having different bracing shapes by considering different ground motion data. In addition to this, the analysis of the response spectrum and wind analysis were made. As a result of the analysis, The steel tower structures were compared in terms of different heights, bracing shapes, wind speeds and earthquakes. Korkmaz et. al. [15] performed nonlinear pushover analysis to determine the curve of force displacement by dealing with a wind turbine tower. Time history analysis was made by using the six different earthquake records. It was evaluated results obtained from the time history and nonlinear pushover analysis. Yalciner et al. [16] analyzed RC structure by using the different corrosion effects. It was examined fragility curves of structures subjected to 20 different ground motion data. According to the analysis results, It was obtained that the corrosion of steel is of great importance. Kumbasaroglu [17] investigated three RC buildings considering 20 ground motion data for the purpose of determining the effects of anchor bars. It was observed that the possibility of exceeding the performance level is reduced with anchor bars.

In this study, the electrical transmission tower structure, which can be damaged under the effects of loads such as wind and earthquake, is examined. Firstly, the behavior of an electrical transmission tower under the wind influence is investigated according to ASCE 7-10 regulation for different wind speeds [18]. Secondly, Considering Turkey Building Earthquake Regulation 2018, artificial acceleration records were obtained for earthquake level II and soil class C, and analyzes were performed using the time history method. The displacement, stress and base shear force values were obtained and the results were compared [19,20].

2. MATERIALS and METHODS

The structure modeled by using the finite element method is divided into a finite number of elements connected to each other at certain points. The elements and joints are shown in Figure 2. The displacements in the elements form the displacements at the joints. The unknown values are values at the nodal points. A set of the equation for the whole system is formed when the equations of the elements forming the system are combined. In this method, elements are classified by their dimensions and load forms. Elements can be modeled as bar, shell, solid and spring. The finite element model is shown in Figure 2 [21].

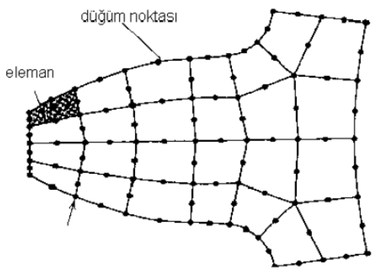

Figure 2. The finite element model [21].

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In this study, the steel tower being 32m in height was designed. Tower design, modeling and analysis were performed with SAP 2000 finite element program [22]. The tower structure consists of 390 elements and 140 points as a frame. L profiles are used in the steel tower design. L 45 5, L 45 5 at beams and diagonals and L 80 8 on columns of the top parts are used, L 70. 7 on beams, L 80.8 and L 90.9 profiles on diagonals and columns are used on the bottom parts. The steel electrical tower with 32m height is shown in Figure 3.

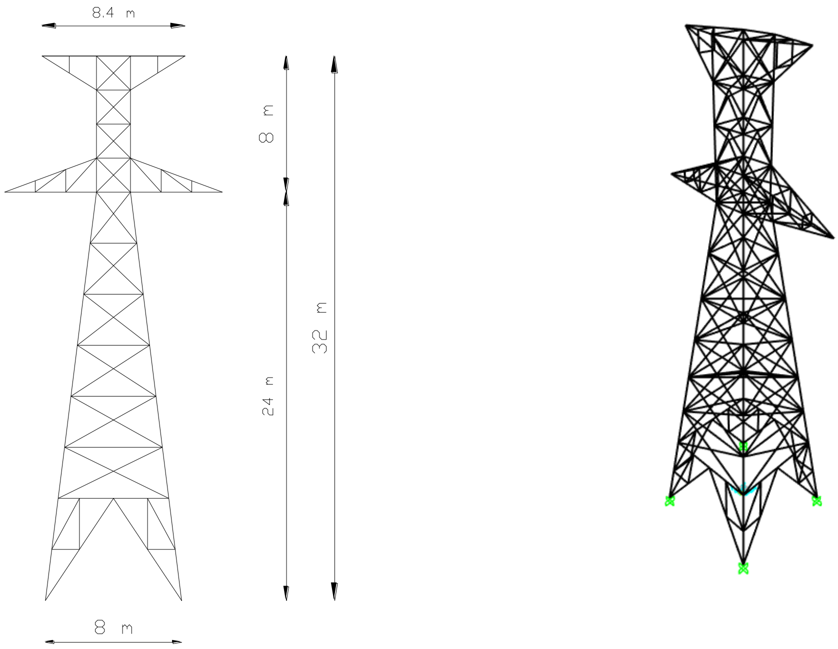

Figure 3. The view of the electrical tower structure.

Tower structures are under the effect of many loads. These loads are snow, wind and earthquake loads. The earthquake is very important in our country since it is located in the seismic zone. So far, most of the earthquakes in our country have been destructive and caused great loss of life and property. Wind load is another important load as well as earthquakes all over the world. In this study, the behavior of the tower structure under the wind and earthquake loads effect is examined. The behavior that tower type delicate structures, being very high will show against wind and earthquake forces is quite important. Time history method is used for earthquake calculations. The calculation of the wind loads is determined in accordance with ASCE 7-10 [18].

In this study, firstly the behavior of the tower structure under the earthquake effect is examined. Time history analysis is used during the earthquake analysis. The artificial acceleration values were obtained by taking into account of the earthquake level 2 and soil class C. 11 earthquake records selected according to the Turkey Building Earthquake Regulations 2018 [19]. The values for spectrum curves were obtained according to Kocaeli province Gebze district [20]. Graphics including time-

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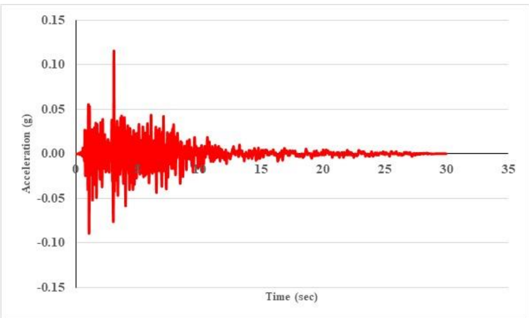
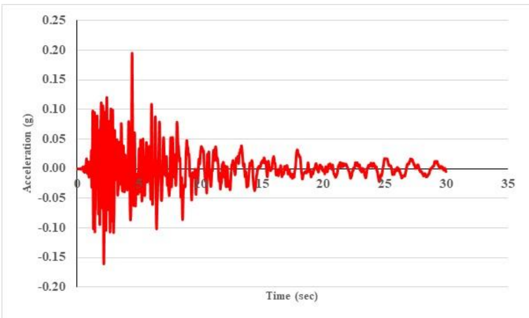
dependent acceleration values of artificial earthquakes are presented in Figure 4. The properties of the selected earthquakes are shown in Table 1 [23].

Table 1. The properties of the selected earthquakes [23].

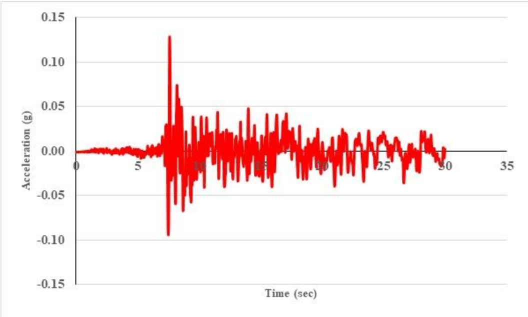
Earthquake Number	Earthquake Name	Station Name	V_s (m/s)	Focus Depth	Magnitude
1	Morgan Hill	Gilroy - Gavilan Coll	729.65	14.84	6.19
2	Morgan Hill	Gilroy Array #3	349.85	13.02	6.19
3	Imperial Valley-06	Calipatria Fire Station	205.78	24.6	6.53
4	Darfield, New Zealand	RKAC	295.74	16.47	7
5	Anza-02	Idyllwild - Kenworthy Fire Sta	382.44	20.34	4.92
6	Coyote Lake	Coyote Lake Dam - Southwest Abutment	561.43	6.13	5.74
7	Northridge -01	LA - UCLA Grounds	398.42	22.49	6.69
8	Imperial Valley-06	Bonds Corner	223.03	2.66	6.53
9	Coalinga-01	Slack Canyon	648.09	27.46	6.36
10	Chi-Chi Taiwan	TCU079	363.99	10.97	7.62
11	Duzce, Turkey	Duzce	281.86	6.58	7.14



Earthquake Number 1



Earthquake Number 2



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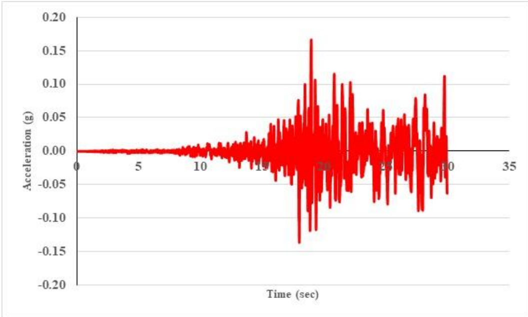

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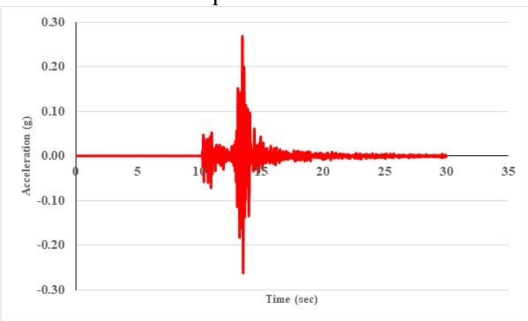

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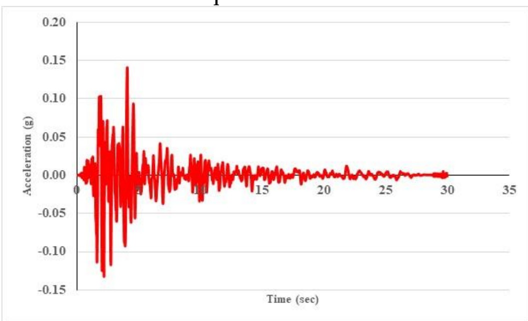

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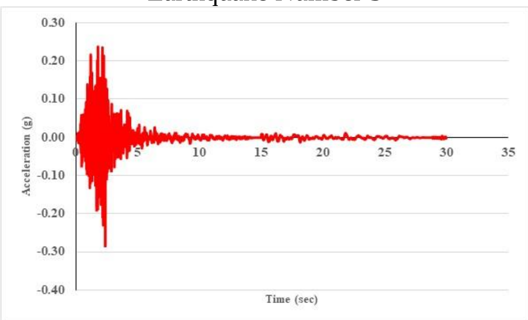

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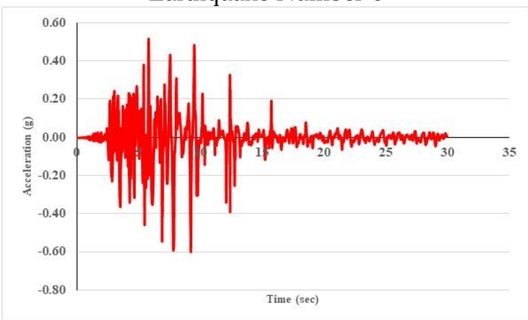

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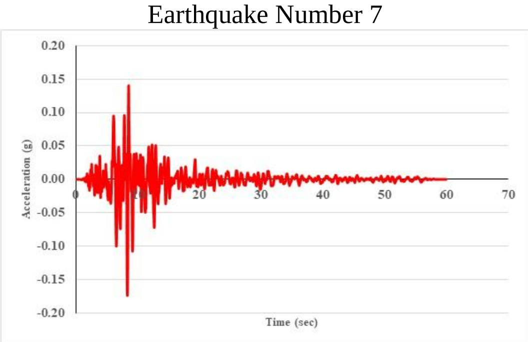
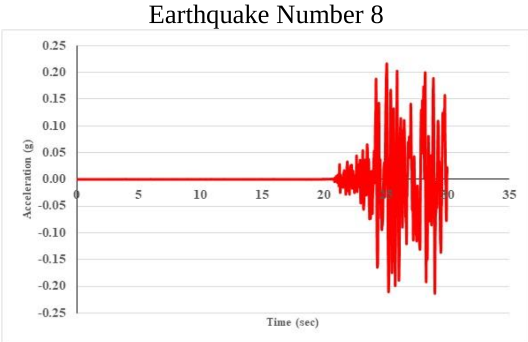


Earthquake Number 9



Earthquake Number 10

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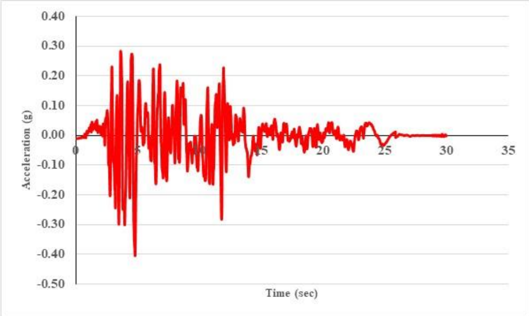

Earthquake Number 11

Figure 4.The artificial acceleration value for all the earthquake levels and soil classes.

Wind loads are also very important for tower type structures. In Table 2, the values obtained from the measurement of wind speed in three seconds and ten minute periods in ASCE 7-10 Regulation are presented by the risk categories [18;24]. In this study, 15 m/sec, 25 m/sec and 35 m/sec wind speeds were examined in accordance with the measurements carried out in 3-second periods.

Table 2. Wind velocities [18;24].

Risk Category	Wind Speed	
	T= 3 secPeriod	T= 10 minutePeriod
I	<35	<22
II	35-45	22-30
III	45-55	30-35
IV	55-65	35-40
V	>65	>40

Wind velocity pressure;

$q_z,q_h=0.613.K_zK_{zt}K_d.I.V^2$ (1)

V: Basic wind speed
Kd: Wind Direction Coefficient
Kz: Wind pressure exposure coefficient
Kzt: Topographic factor
I: Importance coefficient

Wind direction coefficient (K_d) is 0.85 for tower structures, topographic factor (K_{zt}) is 1. Exposure category is obtained according to surface roughness and is taken as B. K_z values are determined according to the standard depending on the height [18,24].

Design Wind Pressures;

$$P = q\ G\ C_P - q_i\ (GC)_{pi} \tag{2}$$

q_i: internal pressure
$(GC)_{pi}$: Internal pressure coefficients
C_P: It is calculated by external pressure coefficient.
C_P is 0.8 perpendicular wall to the wind and -0.5 on the back wall.
The storm effect factor (G) should be determined for the design wind pressure calculation

$$G = 0.925\left(\frac{1 + 1.7 g_Q I_{\overline{z}} Q}{1 + 1.7 g_v I_{\overline{z}}}\right) \tag{3}$$

$$I_z = c\left(\frac{10}{\overline{z}}\right)^{1/6} \tag{4}$$

$$L_{\overline{z}} = l\left(\frac{\overline{z}}{10}\right)^{\bar{\epsilon}} \tag{5}$$

$$Q = \sqrt{\frac{1}{1 + 0.63\left(\frac{B+h}{L_{\overline{z}}}\right)}\varepsilon} \tag{6}$$

Wind velocity pressure and design wind pressures are respectively determined by using Eq. (1) and Eq. (2). Q; Ground response factor is calculated by Eq. (6). The values of G were calculated as 0.82 by using Eq. (3), g_v; Peak factor for wind response, g_Q; Peak factor for ground response, B; Horizontal length of the building (in the direction perpendicular to the wind direction), h; Average building height [18,24]. The wind was applied perpendicular in the +X direction to the structure.

3. RESULTS AND DISCUSSION

In this study, the behavior of the steel electrical transmission tower height of which was 32m under the earthquake and wind effect was examined. 3 wind speeds and 11 artificial ground motion records were applied to the structure. In addition, the acceleration spectra were applied by considering all soil classes and earthquake levels. Period values and mode shapes occurring in the structure as a result of modal analyses are shown in Figure 5.

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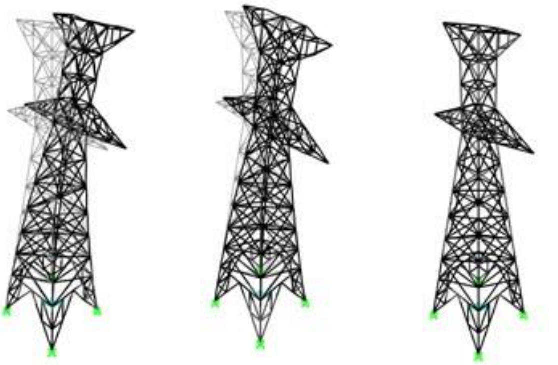
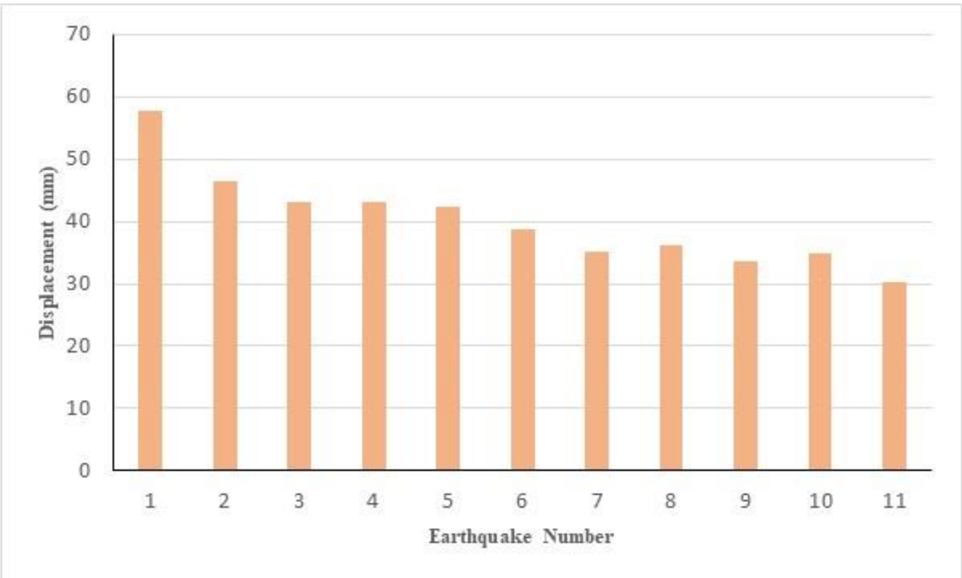


Figure 5. The values of the period and mode shapes of the electrical tower structure.

11 acceleration values dependent to time were selected in accordance with Turkish Earthquake Code 2018 and artificial acceleration records were obtained by considering Gebze district of Kocaeli province for the earthquake level 2 and the soil class C [19,20]. The values obtained from the results of the time history analysis performed with the artificial acceleration records obtained are shown in Figure 6.



a) The values of displacement

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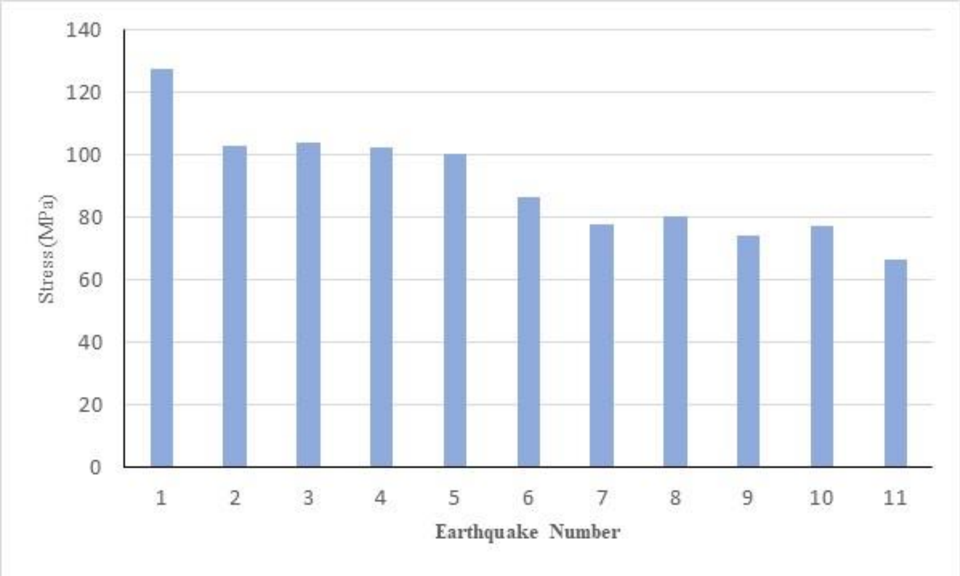
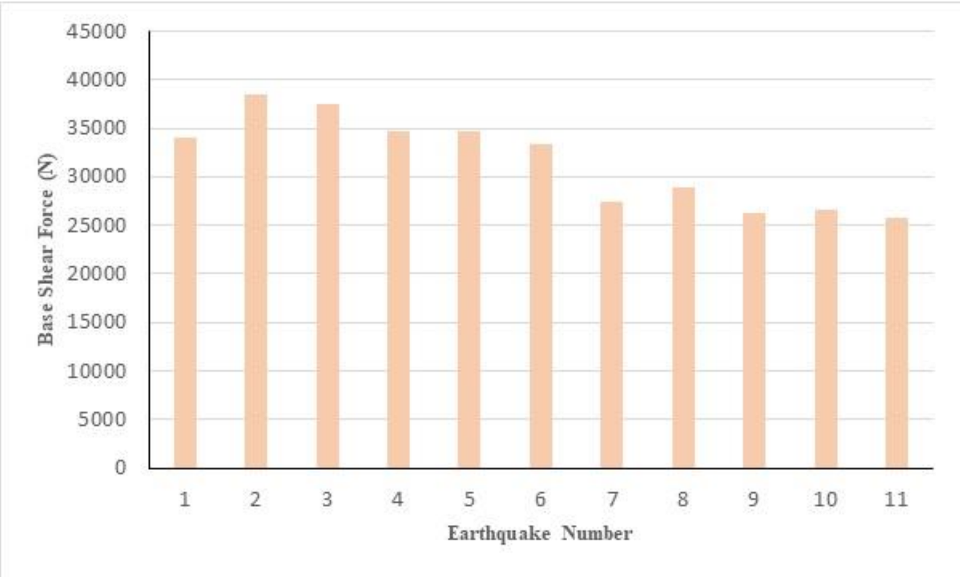


b) The values of stress

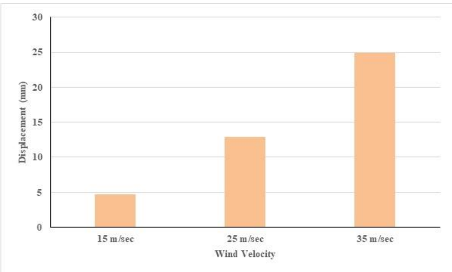


c) The values of base shear force

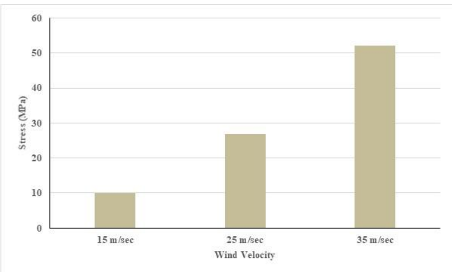
Figure 6. The values obtained as a result of the time history analysis.

In the case of earthquake level 2 and soil class C, the biggest displacement value is found as 57.69 mm, base shear force value is found as 34076.45 N and stress value is found as 127.64 N/mm^2 for 1 numbered Morgan Hill Earthquake. The smallest values were obtained in the case of the 11 numbered Duzce, Turkey Earthquake and the value of displacement is 30.34 mm, the value of base shear force is 25751.06 N and the value of stress is 66.47 N/mm^2. The effective ground acceleration values of 1 and 11 numbered earthquakes obtained as the artificial are respectively 0.81g and 0.47g. When the ground velocity of 1 numbered earthquakes is 729.65 m/s, the ground velocity of 11 numbered earthquake is 281.86 m/s. When the values are viewed from the largest to the smallest; It is seen that the 2 numbered Morgan Hill earthquake which has an effective ground acceleration of 0.70 g is in the second place. It is seen that the displacement value obtained as a result of the application of the 2 numbered Morgan Hill earthquake to the structure is 46.44 mm, the base shear force value is 38395.69 N and the stress value is 103.08 N/mm^2. The biggest displacement values were obtained in the upper parts of the tower, and the values of the biggest stress were obtained in the wings of the tower.

The values of the effective ground acceleration of 4 and 5 numbered artificially produced earthquakes are very close to each other. While the magnitude of the 4 numbered earthquake is 7, the magnitude of 5 numbered earthquake is 4.92. However, the ground velocity of 4 and 5 numbered earthquakes were 295.75 m/s, 382.44 m/s respectively. The displacement values obtained from 4 and 5 numbered earthquakes are 43.00 mm, 43.12 mm, base shear force values are 37411.65 N, 34703.36 N, stress values are 103.94 N/mm^2 and 102.42 N/mm^2, respectively. Although the magnitudes of the earthquakes are quite different, the values obtained due to other factors are quite close.



a) The values of displacement



b) The values of stress

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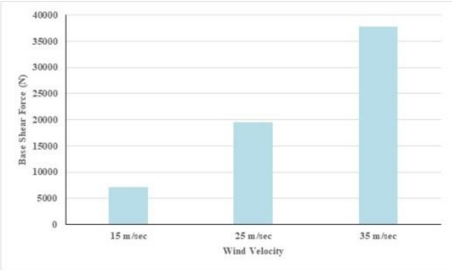

c) The values of base shear force

Figure 7. The values obtained under the wind loading effect.

The values of the pressure of the wind velocities of which were 15m/sec, 25 m/sec ve 35 m/sec were applied to the building. The values of the displacements, stresses, base shear forces obtained depending on the height occurred in the building because of the effect of these winds are presented in Figure 7. When the wind velocity is 25 m/sec, while the displacement values of the first floor occur 0.4 mm, the displacement value of the top floor occurs 12.86mm. While the displacement value of the first and the top of the floor are respectively 0.80 mm and 24.95 mm at 35 m/sec wind speed, the displacement value is 4.7 mm in the case of 15 m/sec wind speed. As the wind speeds were 15 m/sec, 25 m/sec and 35 m/sec, the stress values occurred as respectively 9.9 MPa, 26.82 MPa and 52.04 Mpa. However, the values of base shear force were obtained as 7172 N, 19456.22 N and 37746.06 N.

4. CONCLUSION

In this study, the structural behavior of an electric transmission tower under the effect of the earthquake and wind loads was investigated. Wind analysis was carried out according to the ASCE 7-10 standard, it was used to the time history analysis method for earthquake analysis. Wind analysis were performed for wind speeds of 15 m/sec, 25 m/sec, and 35 m/sec. In earthquake analysis, 11 earthquakes with different characteristics produced artificially were used. It was observed that the behavior of the structure under the wind effect was important as well as the earthquake effect.

The artificial acceleration records were obtained by taking into account of the earthquake level 2 and soil class C for Gebze Kocaeli. Considering the values obtained, it is seen that 11 artificial acceleration records were created by taking 11 time-dependent acceleration values and the values of the displacement, base shear force and stress were found. While the biggest values were obtained at 1 numbered Morgan Hill earthquake, the smallest values were obtained in the 11 numbered Duzce Earthquake. The smallest values were found in 11 numbered Morgan Hill Earthquake. It is seen that the values obtained changed depending on the effective ground acceleration, earthquake velocity and focus depth values.

Considering the results of the wind load analysis; it is seen that as the wind speed increases, the values of displacement, shear force and stress occurring at the building increase. The wind load acting on the structure increases as the height of the structure increases, and it is seen that the values obtained increases depending on the height.

Slender tower-type structures are structures that can be highly affected by the effects of earthquakes and winds. In future studies, the collapse status of tower structures can be examined. While performing the failure analysis, probability analysis can be done by considering the effect of wind and earthquake loads. In addition, different regulations and methods can be used while performing wind analysis.

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The author declares that there are no conflict of interests.

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