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MANUSCRIPT TITLE: STRUCTURAL ASSESSMENT OF TELECOMMUNICATION TOWER UNDER SEISMIC EXCITATIONS

ABSTRACT

Uninterrupted service is an essential design criterion for utilities subjected to natural hazards. As one of the utilities, telecommunication lines play a significant role in the operation of a reliable telecommunication system. Recent earthquakes reveal that telecommunication towers are vital components since impacts of shaking to several telecommunication towers caused delays in the national communication systems through out the most critical rescue and recovery period, namely the hours immediately following the earthquake. Therefore, in order to minimize the disruption to telecommunication systems, the reliability and safety of these towers against natural forces should be assessed. In this study, an actually built steel telecommunication tower having a height of 40 m was selected in order to assess its structural response under the effect of earthquake. All computer simulations were conducted using finite element modeling software of SAP 2000. The structural analysis considered as acting vertical loads as well as wind effects over the steel towers. Moreover, four different natural ground motion records were utilized to identify the dynamic behavior of the tower under seismic excitations. As a result, the structural response of the telecommunication tower and its behavior under seismic and wind forces were discussed comparatively.
Keywords: Earthquake, Finite Element Modeling, Steel Tower, Structural Analysis

SİSMİK ETKİLER ALTINDAKİ TELEKOMÜNİKASYON KULESİNİN YAPISAL DEĞERLENDİRMESİ

ÖZET

Doğal afetlerde kesintisiz servis sağlanması kamu hizmetleri için temel bir kriterdir. Kamu hizmetlerinden biri olarak telekomünikasyon ağları, güvenli iletişim sistemlerinin işleyişinin sağlanmasında önemli bir rol oynamaktadır. Geçmiş yıllardaki depremlerde birçok çelik telekomünikasyon kulelerinde deprem sarsıntısının, özellikle depremden hemen sonra hayati önem taşıyan kurtarma ve iyileştirme sürecinde iletişimin sağlanmasında gecikmelere sebep olduğu görülmüş ve telekomünikasyon kulelerinin iletişim ağının önemli unsurları olduğunu ortaya çıkmıştır. Dolayısıyla, iletişim sistemindeki deprem etkisiyle oluşabilecek aksaklıkların en aza indirilebilmesi için, iletişim kulelerinin deprem etkilerine karşı da güvenilirliliğinin değerlendirilmesi gereklidir. Bu çalışmada, 40 m yüksekliği olan mevcut bir çelik telekomünikasyon kulesinin, rüzgar ve sismik etkiler altındaki yapısal davranışı incelenmiştir. Kulenin yapısal olarak modellenmesi ve analizleri sonlu eleman modelini kullanan SAP 2000 programı ile yapılmıştır. Kulenin analizlerinde hem dikey yükler hem de kule üzerindeki rüzgar yükleri dikkate alınmıştır. Diğer taraftan, kulenin sismik hareketler altındaki davranışlarını belirlemek için dört farklı doğal deprem ivme kaydından yararlanılmıştır. Sonuç olarak, bu çalışmada örnek olarak seçilen kulenin sismik ve rüzgar yükleri altındaki davranışı yapısal tepkisi de göz önüne alınarak karşılaştırmalı olarak incelenmiştir.
Anahtar Kelimeler: Deprem, Sonlu Elemanlar Yöntemiyle Modelleme, Çelik Kule, Yapısal Analiz

1. INTRODUCTION (GİRİŞ)

Necessity of uninterrupted communication is so effective for human life. In the current century, this field has become significantly important and has been named communication era. Telecommunication towers have essential role in this industry. They support radio, television, and telephone antennas to transmit telecommunication signals over long distances. In the case of emergency, these towers play an important role for transmitting news from damaged area to the rescue centers (medical services, fire fighting, and police stations). Therefore, damage to them can significantly increase loses due to natural disasters. Also, infrastructures such as dams, electricity power stations, gas and fuel stations, etc. for their operation need these towers for transmitting their data and these towers are very important for such facilities. Therefore, the protection of these towers during natural disasters is of major importance and accordingly the performance of such structures under these loadings should be properly evaluated [1].

Among several types of towers, steel lattice towers are widely used in telecommunication industry. The need to design a lattice tower for resonant dynamic response due to wind load arises when the natural vibration frequency (fundamental frequency) of the structure is low enough to be excited by the turbulence in the natural wind [2]. Moreover, such towers are usually designed considering wind effects as the sole source of lateral loads with no attention given to earthquake [3]. However, in the recent work, Lefort [4] investigated the effects of wind and earthquake loads on the self-supporting antenna towers and it is reported that for towers, seismically induced member forces may exceed forces obtained from service and wind load calculations. Amiri and Booston [1] studied the dynamic response of antenna-supporting structures. In this regard, self-supporting steel telecommunication towers with different heights were evaluated considering the wind and earthquake loads. A comparison is made between the results of wind and earthquake loading. These comparisons resulted in the necessity of considering earthquake loads in tower analysis and design. In the study of Amiri et al. [5], the seismic response of 4-legged self-supporting telecommunication towers was examined. It is found that in the case of towers with rectangular cross section, the effect of simultaneous earthquake loading in two orthogonal directions is important. At the end, they proposed a number of empirical relations that can help designers to approximate the dynamic response of towers under seismic loadings. In the literature, it is also suggested that for towers located in high risk seismic regions, the effects of earthquake on towers may not be negligible compared to wind effects and should be taken into account as a design check at least in a simplified manner [3].

In this study, an actually built steel telecommunication tower having a height of 40 m was selected so as to assess its structural response under the effect of seismic loading. All computer simulations were performed using a finite element modeling software of SAP 2000. The structural analysis considered as acting vertical loads as well as wind effects over the steel towers. Moreover, different earthquake ground motion records were utilized to identify the behavior of the steel telecommunication tower under seismic excitations.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Telecommunication towers are vital components and the reliability and safety of these towers should be assessed to minimize the risk of disruption to telecommunication system that may result from failure under natural catastrophic events. In the current study, the structural behavior of an existing free standing steel lattice tower was investigated based on the detailed dynamic analysis under the effect of seismic loading and also wind loading.

3. ANALYTICAL STUDY (ANALİTİK ÇALIŞMA)

3.1. Description of Steel Lattice Tower (Çelik Kulenin Özellikleri)

Free-standing steel lattice towers are three-legged or four-legged space trussed structures with usual heights between 30 m and 160 m. In the current study, an actual free standing four-legged steel lattice tower with square transversal cross-sections was chosen as a case study tower. The structural members used in the tower are single equal leg angles, and the used steels are S235JR with a tensile yield strength of 235 MPa and S355JR with a tensile yield strength of 355 MPa. The modulus of elasticity and the unit weight of the steel materials used were 210 GPa and 7850 kg/m^3, respectively. The sample steel lattice tower possess a square cross section divided into two segments: the lower part is pyramidal while the upper part is trapezoidal, as shown in Figure 1. At the end of the analysis, in order to better present the results, the tower was divided into 7 panels and all diagonal, horizontal, and leg members particularly grouped according to these panels seen in Figure 1.

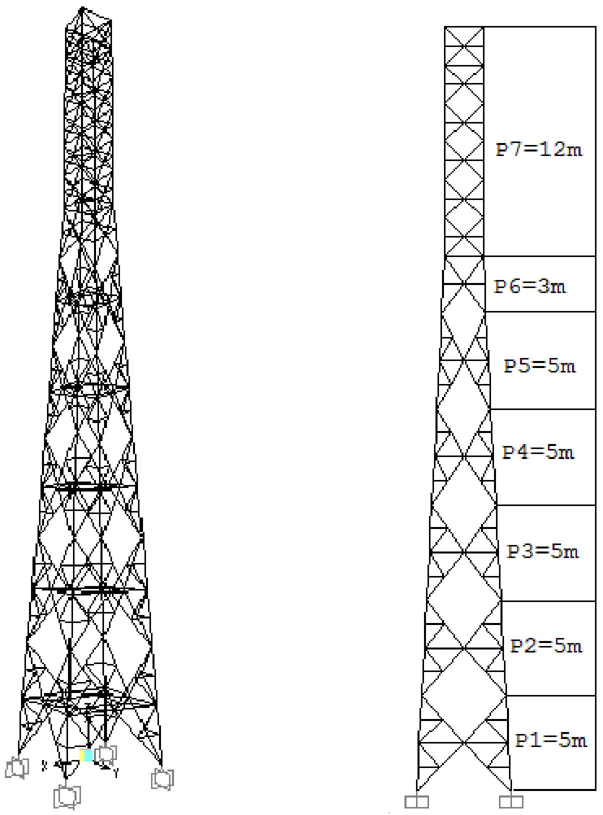


Figure 1. View of the steel lattice telecommunication tower
(Şekil 1. Çelik kafes telekomünikasyon kulesinin görünümü)

The finite element model of the selected lattice tower was conducted by using SAP 2000 Nonlinear version 14 which is a general purpose structural analysis program. This investigation considered as acting vertical loads: structure self-weight, stairs, internal platforms, vertical carriers, cables, etc. To account for the mass of ancillary components in the analysis, their mass was proportionally

distributed along the tower height by modifying the material properties. It is worthy to note that the weight of ancillary components is considerably high and its exclusion from the analysis can alter the results [5].
In addition to these vertical loads, the wind forces over the steel tower were the first type of horizontal load considered in the structural analysis of the tower. For determination of the wind forces and wind forces with ice, ANSI/TIA 222-G [6] was utilized. In the calculations of wind forces, the base wind velocity of 110 km/h was considered. Additionally, for the calculation of wind loads acting in conjunction with ice, an ice thickness equivalent to 1 mm was used.

3.2. Seismic Analysis (Sismik Analiz)

The responses of the tower under seismic forces were determined by using both response spectrum analysis and time history analysis methods. For response spectrum analysis, the design spectrum given in Turkish Seismic Code [7] for Z4 local site class was considered. The design spectrum was scaled by effective acceleration coefficient of 0.4 given for the highest seismicity level. As in the study of Amiri et al.[5], due to the stability and serviceability criteria required of such structures during and after the occurrence of an earthquake, the elastic behavior of the structure was considered and the seismic load reduction factor was taken as 1.

Four natural ground motion records [8] with a single criterion; the compatibility of the elastic spectra of these ground motions with the code spectrum used in the response spectrum analysis of the tower were selected. The comparison between the code spectrum and the elastic spectra of the selected ground motion records is given in Figure 2. The characteristics of the selected ground motion records are listed in Table 1 and the earthquake ground motion records are given in Figure 3.

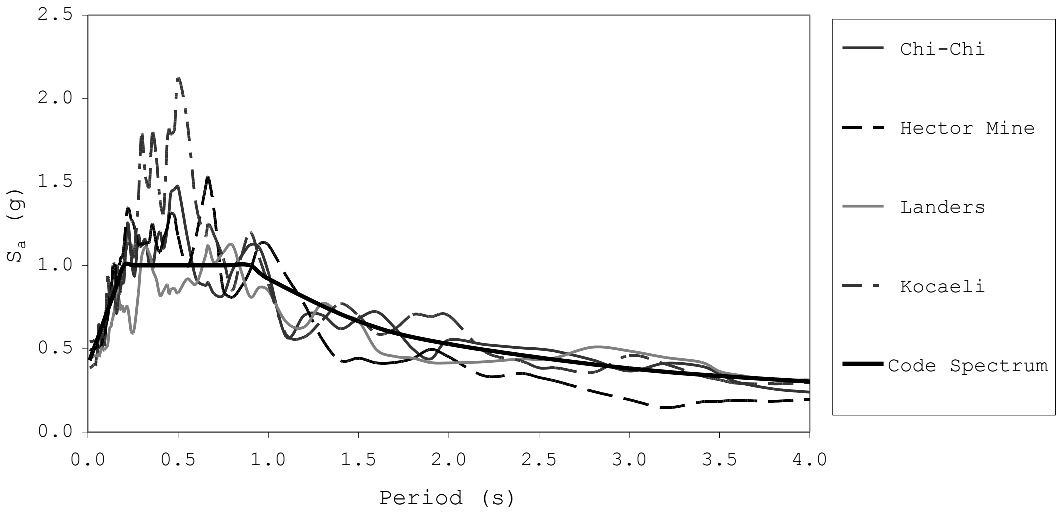


Figure 2. Comparison of the normalized elastic spectra of the natural ground motions with the code spectrum
(Şekil 2. Doğal deprem ivmelerinin elastic spektrumu ile yönetmelikte verilen spektrumun karşılaştırılması)

Table 1. Chracteristics of the selected natural ground motions
(Tablo 1. Seçilen doğal yer ivmelerinin özellikleri)

Earthquake Location	Recording Station	Date	Magnitude	Scale factor	PGA (g)	PGV (cm/s)	Soil (Vs30)(m/s)
Chi-Chi, Taiwan	TCU056	1999	7.62	3.05	0.39	132.81	440.2
Kocaeli, Turkey	Airport Station	1999	7.51	6.02	0.54	148.63	424.8
Landers, USA	Downey - Co Maint Bldg	1992	7.28	9.22	0.45	112.10	271.9
Hector Mine,USA	Whittier-Scott&Whittier	1999	7.13	12.53	0.49	66.99	338.5

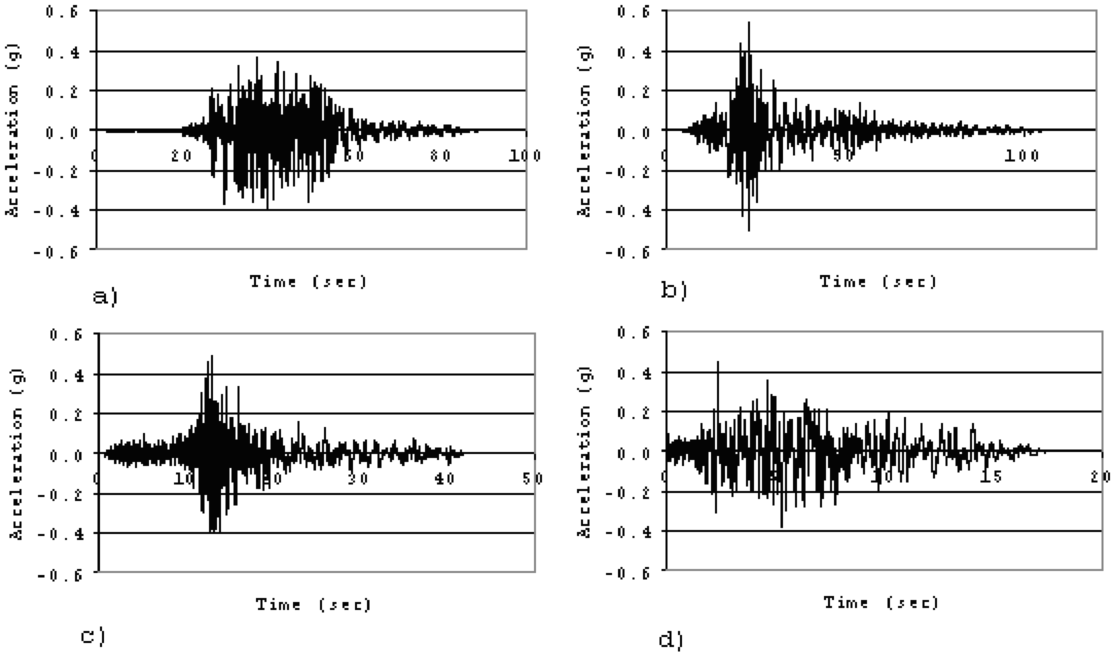


Figure 3. Ground motion acceleration records: a)Chi-Chi, b)Kocaeli, c)Hector Mine, and d)Landers
(Şekil 3. Deprem ivmesi kayıtları: a)Chi-Chi, b)Kocaeli, c)Hector Mine, ve d)Landers)

4.DISCUSSION OF RESULTS (SONUÇLARIN DEĞERLENDİRİLMESİ)

Before conducting time history analyses and response spectrum analysis to evaluate the seismic response of the sample tower, the structural response characteristics were assessed by modal analyses. The first and second flexural mode and the first torsional mode were obtained as 0.32, 0.11, and 0.056 seconds, respectively. The mode shapes corresponding to these modes are given in Figure 4.

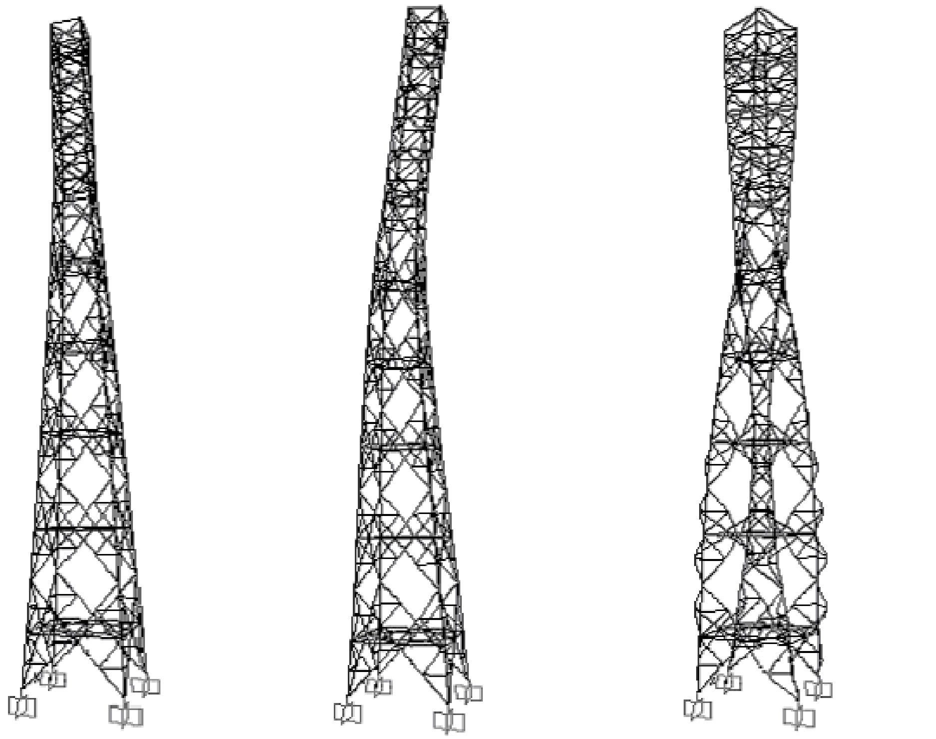
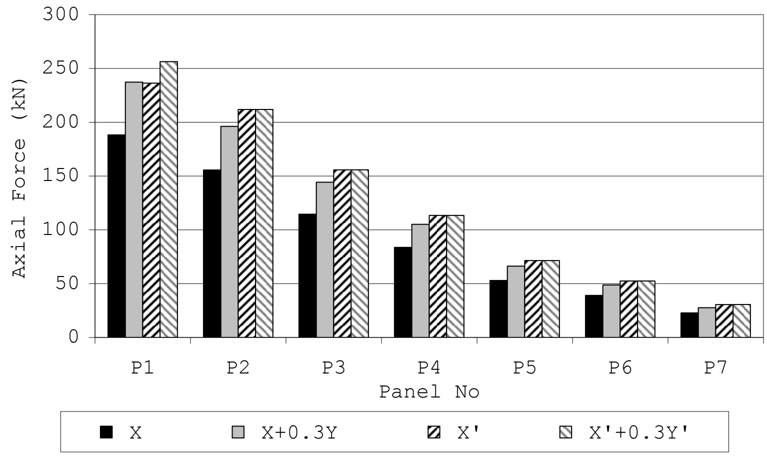


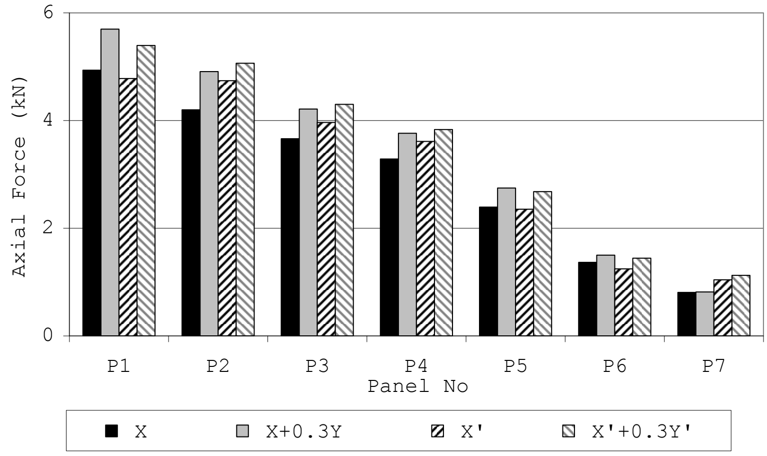
Figure 4. Mode shapes of 40 m tower
(Şekil 4. 40 m'lik kulenin mod şekilleri)

Firstly, the earthquake ground motions were considered to act in one orthogonal direction (X) and simultaneously in two orthogonal directions (both X and Y directions) with load factors of 1 and 0.3, respectively. Secondly, the earthquake ground motions were applied in one diagonal direction (X') and simultaneously in two diagonal directions (both X' and Y' directions) with the same load factors of 1 and 0.3, respectively. Therefore, for four different loading combinations, the maximum axial forces seen in the leg members, horizontal and diagonal members were evaluated by performing time history analysis. The results obtained from the time history analysis of the tower under Hector Mine acceleration record for the loading combinations mentioned are illustrated in Figure 5.

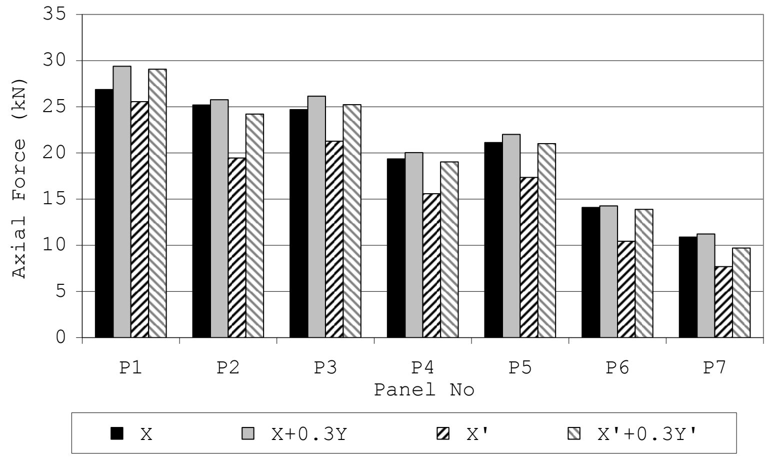
As seen in Figure 5, the axial forces obtained in the leg members under the effect of seismic load in diagonal direction were greater than the axial forces obtained under the effect of seismic load in orthogonal direction. It was also observed that axial forces in the leg members attained the highest value for the load combination of X'+0.3Y' in which the seismic loads were applied in two orthogonal direction simultaneously by using factors of 1 and 0.3 for two diagonal directions. However, when the axial forces in the horizontal and the diagonal members were compared, it was evident that results obtained from four different loading conditions changed among each other. Since the values of the axial force obtained in these members were small, also the differences in the loading combinations were small.



a) Leg members



b) Horizontal members



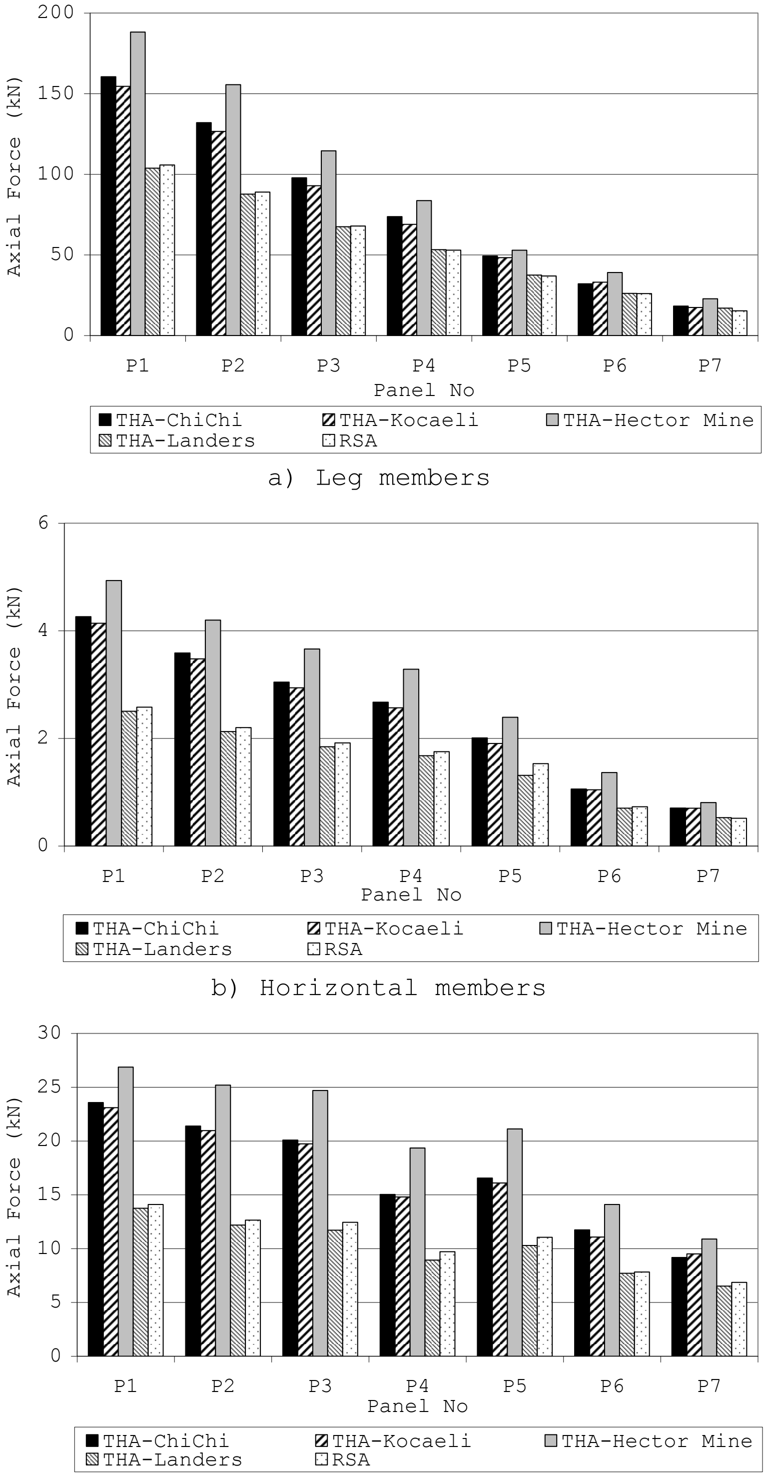
c) Diagonal members

Figure 5. Axial member forces under four different loading combinations for Hector Mine acceleration record
(Şekil 5. Dört farklı yükleme kombinasyonuna göre elemanlardaki eksenel yükler)

The tower was analyzed under different seismic loads by using response spectrum analysis (RSA) and by using time history analysis (THA) which utilizes four different natural ground motions, namely, Chi-Chi, Kocaeli, Hector Mine, Landers earthquake acceleration records and the results of the axial forces of the leg, horizontal and diagonal members obtained for seismic loading in one orthogonal direction (X) are given in Figure 6.

From the results of the response spectrum analysis and the time history analysis, for the leg members, the highest values of the maximum axial forces were obtained under Hector Mine earthquake. The results of time history analysis by using Landers ground motion and the results of response spectrum analysis obtained were similar to each other. Nevertheless, similar to behaviour seen under different loading combinations, when the axial forces of the horizontal and diagonal members were compared, the resultant values showed insignificant difference.

To compare the effect of wind and earthquake loads on tower, the axial forces in the leg members attained under only wind loads, wind load with ice, and the earthquake loads are shown in Figure 7. From the figure, it was found that higher values for the axial forces of leg members were observed under wind load in comparison to seismic loads in some of the panel groups and in some of panels the trend was reverse. In addition to this, it was observed that the results due to seismic loads were close to those results from wind loads.



a) Leg members

b) Horizontal members

c) Diagonal members

Figure 6. Axial member forces obtained using response spectrum analysis (RSA) and time history analysis (THA)
(Şekil 6. Davranış spektrumu analizi ve zaman tanım alanında analiz sonucunda elde edilen eksenel yükler)

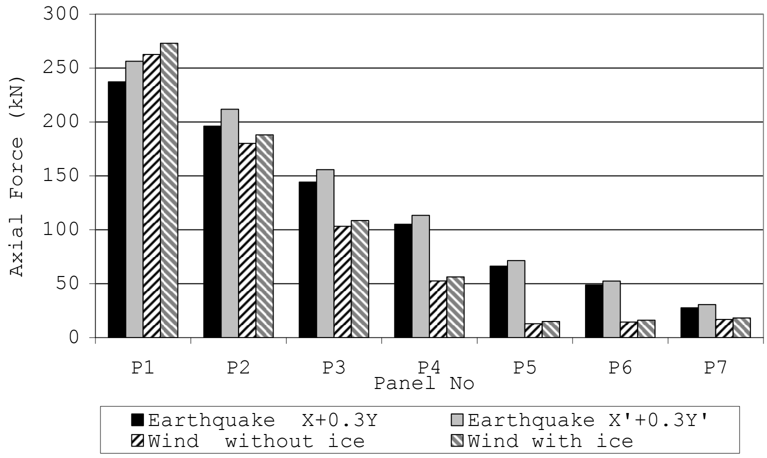


Figure 7. Maksimum axial forces attained in the leg members under wind, wind with ice and earthquake loads
(Şekil 7. Rüzgar, buz ve rüzgar, ve deprem yükleri altında elemanlarda görülen maksimum eksenel kuvvet)

7. CONCLUSION (SONUÇ)

In this study, an existing 40 m four legged steel lattice tower was selected as a case. This tower was modeled by using SAP 2000 structural analysis program and the response of the tower under seismic and wind loads were investigated. For the seismic analysis of the tower, the response spectrum analysis and time history analysis were performed. Firstly, the effect of seismic loading direction was investigated and it was observed that application of the seismic loads from the diagonal directions results in greater axial forces in the leg members. Secondly, the axial forces in structural members under seismic loads were attained by using response spectrum analysis and time history analysis methods. It was pointed out that depending on the selection of the natural earthquake record, both methods provided similar results. Finally, the axial forces in the structural members under the effect of wind and earthquake loads were compared. It was observed that the dominant force in the design of the tower might be seismic forces or the wind forces, depending on the magnitude of the wind and seismic load. Therefore, both types of lateral forces should be criticized in the design of the towers to improve the reliability of the tower structures.

NOT (NOTICE)

Bu makale, 28-30 Eylül 2011 tarihleri arasında Elazig Fırat Üniversitesinde "Inetnational Participated Construction Congress" IPCC11'de sözlü sunum olarak sunulmuştur.

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