GUFBD / *GUJS* (2022) 12(4): 1000-1011
DOI: 10.17714/gumusfenbil.1107506 Araştırma Makalesi / *Research Article*

The effect of local soil conditions on structure target displacements in different seismic zones

Farklı sismik bölgelerde yerel zemin koşullarının yapı hedef yerdeğiştirmelerine etkisi

Fatih AVCİL*[1,a], Ercan IŞIK[1,b], Aydın BÜYÜKSARAÇ[2,c]
[1]*Bitlis Eren Üniversitesi, Mühendislik-Mimarlık Fakültesi, İnşaat Mühendisliği Bölümü, 13100, Bitlis*
[2]*Çanakkale 18 Mart Üniversitesi, Çan Meslek Yüksekokulu, 17200, Çanakkale*

• Geliş tarihi / *Received*: 22.04.2022 • Düzeltilerek geliş tarihi / *Received in revised form*: 05.07.2022 • Kabul tarihi / *Accepted*: 25.07.2022

Abstract
The local soil conditions of the region where the structure is located are one of the important parameters taken into account in the evaluation and design of structures under the influence of earthquakes. In this study, the effect of different local soil conditions on target displacement values of reinforced-concrete (RC) structures in different seismic regions was investigated. For this purpose, four different settlements within each earthquake zone specified in the previous earthquake zone map were taken into account. Structural analyzes for a sample reinforced concrete structure using four different local soil conditions were performed for all residential units separately. The values predicted in the current earthquake hazard map for the considered locations were repeated for four different local soil classes. For the settlements, the predicted values in the last two maps were compared. As the soil properties improved as a result of the structural analysis, the displacement values predicted for the building performance level took lower values.

Keywords: Local soil, Performance level, Pushover analysis, Reinforced-concrete, Target displacement

Öz
Yapıların bulunduğu bölgeye ait yerel zemin koşulları, deprem etkisindeki yapıların değerlendirmesi ve tasarımında dikkate alınan önemli parametrelerden biridir. Bu çalışmada, farklı yerel zemin koşullarının farklı sismik bölgelerde betonarme yapılarda hedef yer değiştirme değerlerine etkisi incelenmiştir. Bu amaç doğrultusunda önceki deprem bölgeleri haritasında belirtilen her bir deprem bölgesi içerisinde yer alan dört farklı yerleşim birimi dikkate alınmıştır. Dört farklı yerel zemin koşulu kullanılarak örnek bir betonarme yapı için yapısal analizler tüm yerleşim birimleri için ayrı ayrı gerçekleştirilmiştir. Dikkate alınan konumlar için güncel deprem tehlike haritasında öngörülen değerler dört farklı yerel zemin sınıfı için tekrarlanmıştır. Yerleşim birimleri için son iki haritada öngörülen değerler karşılaştırılmıştır. Yapısal analizler sonucu zemin özelliklerini iyileştikçe yapı performans düzeyi için öngörülen yer değiştirme değerleri daha düşük değerler almıştır.

***Anahtar kelimeler**: Yerel zemin, Performans düzeyi, Statik itme analizi, Betonarme, Hedef yer değiştirme*

[*a] Fatih AVCİL; favcil@beu.edu.tr, Tel: (0506) 814 17 13, orcid.org/0000-0001-6550-550X
[b] orcid.org/0000-0001-8057-065X [c] orcid.org/0000-0002-4279-4158

1. Introduction

1. Giriş

Many different factors are considered when designing and evaluating earthquake-prone structures. Significant losses due to structural damage after each earthquake are enough to reveal the importance of these factors. Among these factors and structural characteristics, the seismicity of the region/geography and local soil conditions are also effective. The seismicity of any region is based on geological, tectonic, and statistical data. Among the most important parameters in determining the earthquake hazard of a region are the location, magnitude, and source parameters of the earthquake and the intensity distribution data. Earthquake activity in a region is an indicator of future earthquakes in that region. (Yunatçı & Çetin, 2007; Cornell, 1968; McGuirre, 2008; Kramer, 2003; Işık, 2010). In general, parameters such as seismicity, faults and fault groups in the region, characteristics of the faults, the distance of the structure to the faults, earthquake history of the region, and the characteristics of the earthquakes are taken into account. In countries with high earthquake hazards, earthquake hazard maps are created by conducting various seismic zones (Özmen, 2012; Işık et al., 2021). In Turkey, until the last earthquake hazard map, a regional-based earthquake zones map was used on different bases. With the current map, the term seismicity specific to geographical location has been used instead of regional basis. With the help of these maps, it is possible to have information about the earthquake hazard and risks of any region/location.

In addition to the seismicity parameters, the local soil conditions of the area where the structures will be built directly affect both the level of feeling of the earthquake effect and the behavior of the structures under the influence of the earthquake. Local soil conditions cause the earthquake effect to be felt more strongly on both living things and structures. Seismic waves created by the energy released from a source at the bedrock level are affected by the properties of the environments they pass through during their propagation; There may be changes in duration, frequency, and amplitude (İyisan & Haşal, 2011). Although local soil conditions generally differ between countries, soil classifications are included in earthquake codes. Within the scope of this study, the interaction of different local soil conditions in different seismic zones was tried to be investigated. There are many studies on these subjects. Özşahin and Eroğlu (2019) examined the effect of local soil conditions on seismicity for Erzincan, which has high earthquake sensitivity. Akyıldız et al (2021) studied the cross-sectional effects of five different soil classes stipulated in the current earthquake code for a reinforced concrete building. Peker and Işık (2021) obtained displacement, period, and internal forces for an eight-storey steel structure model by choosing five different local soil classes in the current regulation as variables. Karaşin and Işık (2017) performed structural analyzes for a reinforced concrete building model in order to reveal the effects of different soil classes and building behavior coefficients on building performance. Sisman (2022), in his study local soil conditions of the Zeytinburnu district in İstanbul are analyzed concerning the Building and Earthquake Code of Turkey. Aykaç et al. (2021), in their study, revealed the damage-local soil condition relationships in the 2011 Van earthquakes for a district in Van city. Tohumcu et al. (2003) classified the local soil conditions obtained in field tests and laboratory experiments in two different ways and obtained the design spectra according to both methods. Işik et al. (2016) examined the effect of local soil conditions on earthquake damages. Becerra et al. (2016) performed comparisons between local soil conditions and observed damage from the 2014 Iquique earthquake. Yon et al. (2015) and Yon and Calayir (2015) tried to reveal the effect of different local soil conditions and seismic zones on a reinforced concrete building. Mwafy and Elnashai (2001) studied the comparisons of static pushover and dynamic collapse analysis of reinforced concrete buildings.

Within the scope of this study, settlements with different seismic hazards and four different cities were selected for four different earthquake zones in the previous earthquake zone map in Turkey. The cities of Manisa (Center), Ağrı (Center), Gümüşhane (Center), and Ankara (Center) were selected which are located in the first, second, third, and fourth-degree earthquake zones, respectively. The values in the last two seismic hazard maps and seismic design codes were compared for these settlements with different seismic risks in Turkey. Structural analyzes were carried out for a reinforced-concrete building selected as a model, using the peak ground acceleration predicted in the earthquake zone and earthquake hazard maps used in Turkey for these settlements. In the analyses, four different local soil classes (ZA, ZB, ZC, and ZD) in the Eurocode-8, which is more widely used in the world, were chosen as variables. Target displacements were calculated for three different performance levels in Eurocode-8. The part that distinguishes this study from other studies is the target displacements obtained for performance levels. One of the two different variables considered in this study is seismic risk variation. For this variable, settlements with different seismic risks in the last two maps and codes in Turkey were taken into account. For the local soil class, which is another variable taken into consideration, four different soil classes specified in Eurocode-8, which is used much more widely in the world, are taken into account.

2. Settlements with different seismic hazard

2. Sismik tehlikenin farklı olduğu yerleşim birimleri

The threat posed by earthquakes to human activities in many parts of the world is sufficient reason for careful consideration of earthquakes in the design of structures and facilities. Considering some deficiencies in earthquake regulations in Turkey and uncertainties in earthquake source zones, necessary corrections were made and the earthquake zones map was finalized. The map was prepared by carrying out these mentioned studies; With the decision of the Council of Ministers dated 18.4.1996 and numbered 96/8109, it entered into force under the name of Turkey Earthquake Zones Map with a scale of 1/1.800.000 (Özmen, 2012; Özmen & Can, 2016; Işık, 2021). Within the scope of this study, four different settlements located in four different earthquake zones were selected using the earthquake zones map, which has different seismic risks, has been used in Turkey since 1996, and was retired in 2018 with the new earthquake map. The representation of the selected locations on the previous earthquake zones map is given in Figure 1.

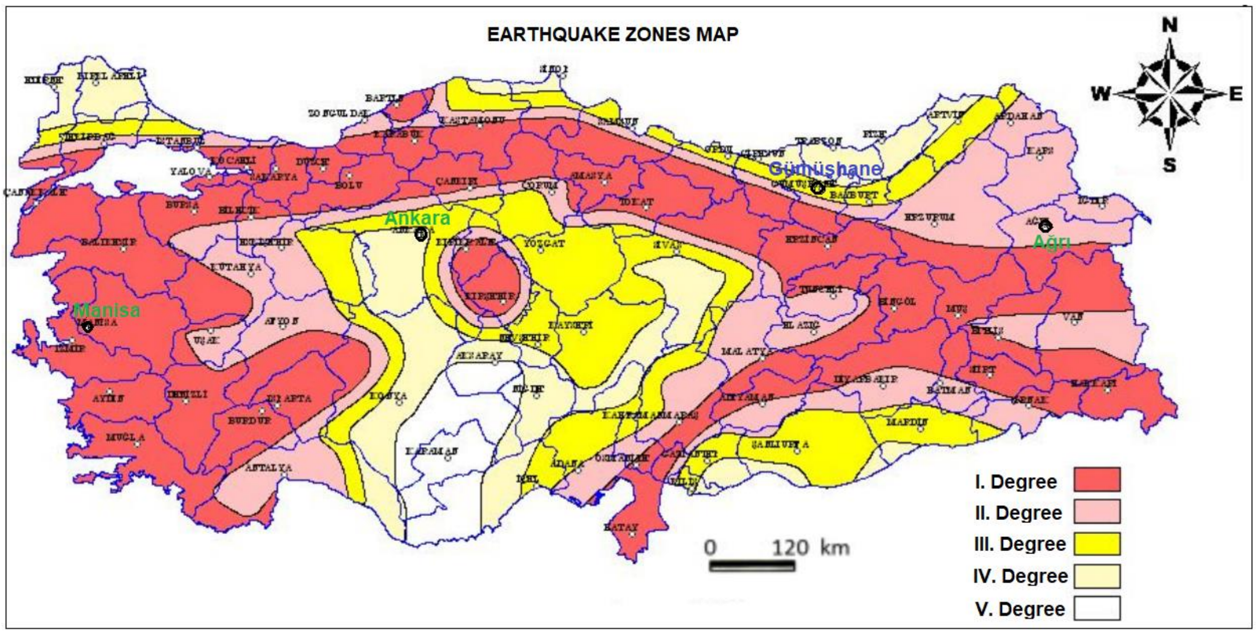

Figure 1. Earthquake zones map and selected geographic locations (Adopted from Özmen & Nurlu, 1999)
Şekil 1. *Deprem bölgeleri haritası ve seçilen coğrafi konumlar (Adopted from Özmen & Nurlu, 1999)*

In the map, regions, where ground acceleration is expected to be greater than 0.40 g, are 1st degree, regions expected to be between 0.30-0.40 g are 2nd regions, expected to be between 0.20-0.30 g 3rd, regions expected to be between 0.10-0.20 g 4th. degree and regions expected to be less than 0.1 g were determined as the 5th-degree earthquake zone. As can be seen on the map, the selected settlements are located in different degree earthquake zones in Turkey.

Earthquake maps in Turkey were renewed on seven different dates, and the last map was implemented as Turkey Earthquake Hazard Map in 2018. All maps except the last map have been prepared based on regional risk. Scientific developments in the field of earthquake and civil engineering and experienced earthquakes reveal that there is a need for updates in earthquake hazard maps. After 20 years, this change has been made in Turkey, and the Turkey Earthquake Hazard Map has been put into effect since 2018. While the previous map is on a regional basis and predicts the same earthquake parameters for the settlements located in the same earthquake zone, the current map predicts earthquake parameters specific to each geographical location. The variation of the seismicity elements according to the geographical location also directly affects the structural parameters to be obtained from the earthquake data. With the current map, the concept of the earthquake zone has also been removed. The representation on the current earthquake hazard map is shown in Figure 2.

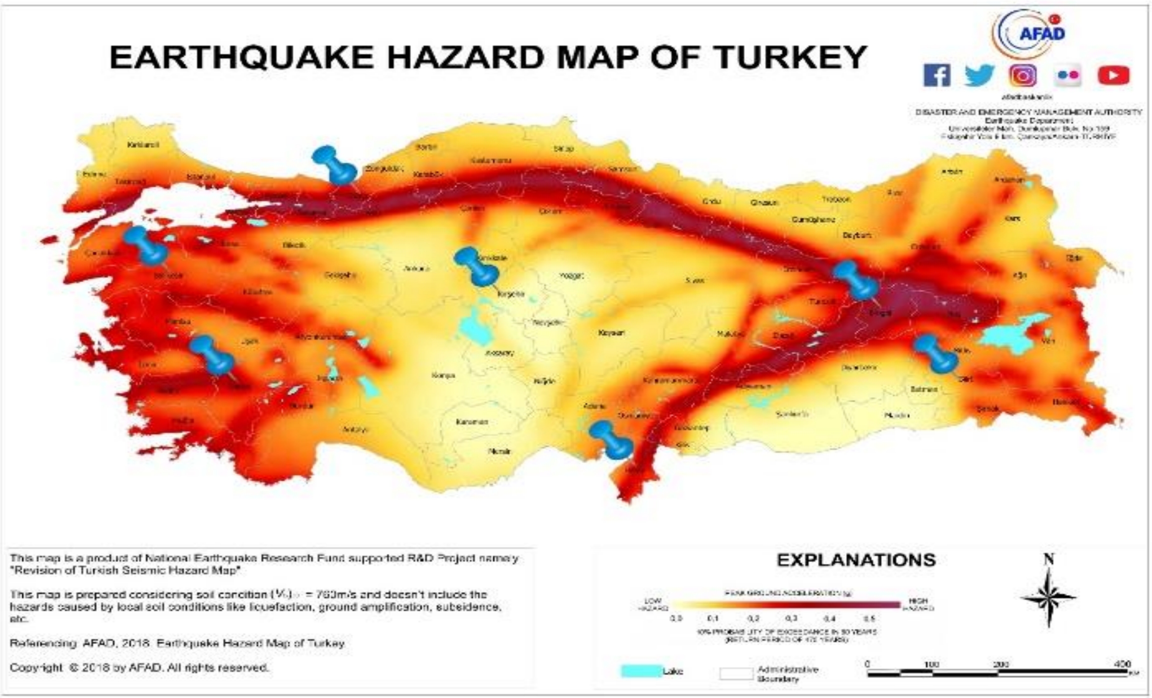

Figure 2. The current earthquake hazard map
Şekil 2. *Güncel deprem tehlike haritası üzerinde gösterimi*

Within the scope of this study, in the selection of settlements with different seismic risks, four different settlements located in four different earthquake zones were selected. The Peak Ground Acceleration (PGA) values predicted in the last two earthquake maps for randomly selected locations in four different city centers located in different seismic zones are shown in Table 1. While comparing the PGA values, the design with a 10% probability of exceedance in 50 years on both maps was carried out by taking into account the earthquake ground motion level.

Table 1. Comparison of PGAs of selected locations
Tablo1. Seçilen yerleşim birimleri için PGA değerlerinin karşılaştırılması

City	Earthquake Zone(1996 Map)	TBEC-2007 PGA (g)	TBEC-2018 PGA (g)	PGA Ratio 2007/2018
Manisa (Center)	I	0.400	0.470	0.85
Ağrı (Center)	II	0.300	0.235	1.28
Gümüşhane (Center)	III	0.200	0.185	1.08
Ankara (Center)	IV	0.100	0.150	0.67

With the current map, the concept of earthquake zone has been removed and the concept of earthquake hazard specific to each location has been started to be used. This situation caused an increase in PGA values for some settlements and a decrease for others. While it caused an increase in Manisa (central) and Ankara (Center) settlements considered in the study, it caused a decrease in the other two settlements.

Table 2. Soil classes considered in the study (Eurocode-8)

3. Local soil classes considered in the study

3. Çalışmada dikkate alınan yerel zemin sınıfları

It is known that local soil conditions directly affect the seismic behavior of structures (Borcherdt, 1970; Işık et al. 2016). In this study, while considering local soil conditions, four different soil classes in the more widely used Eurocode-8 were taken into account. Considered soil classes and properties are shown in Table 2.

Tablo 2. *Çalışmada dikkate alınan zemin sınıfları (Eurocode-8)*

Ground-type	Description of stratigraphic profile	Parameters $V_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	C_u (kPa)
A	Rock or other rock-like geological formation, including at most 5m of weaker material at the surface	>800	---	---
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth	360-800	>50	>250
C	Deep deposits of dense or medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of meters.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70

It is seen that the soil properties and strengths decrease as the soil class goes from A to D.

4. Structural analysis and results

4. Yapısal Analizler ve Sonuçları

For the calculation and design of today's modern engineering structures, many computer programs have been developed that enable the transfer of results to application projects in an integrated manner and facilitate data transfer. In this study, Seismostruct software was used (Seismosoft, 2022). While determining the effect of local soil conditions on structural performance, an 8-storey reinforced concrete structure was chosen. As an example, the floor plan of a reinforced concrete building is shown in Figure 3. There are four spans in both the X and Y directions and each span is chosen as 4 m.

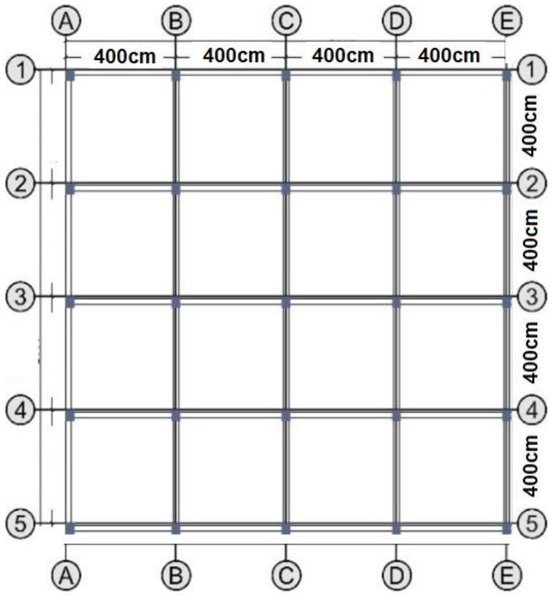

Figure 3. Floor plan of the RC building model
Şekil 3. *Örnek BA bina için kat kalıp planı*

The structural property considered for the RC building selected as an example is shown in Table 3. In the sample RC building model, force-based plastic hinged frame members (infrmFBPH) are used for columns and beams. These elements model the spread inelasticity based on force and only limit the plasticity to a finite length. In total, 100 fiber elements are defined for the selected sections. This value is sufficient for such sections. Plastic-hinge length (Lp/L) was chosen as 16.67%.

Table 3. Analysis of input data considered for the RC building model
Tablo 3. *Örnek betonarme bina için dikkate alınan analiz verileri*

Parameter		Value
Concrete grade		C25
Reinforcement grade		S420
Beams		250x600mm
Height of floor		120 mm
Cover thickness		25 mm
Columns		400x500mm
Longitudinal Reinforcement	Corners	4Φ20
	Top-bottom side	4Φ16
	Left-right side	4Φ16
Transverse reinforcement		Φ10/100
Steel material Model		Menegotto-Pinto (1973)
Concrete material model		Mander et al. (1998) nonlinear
Constraint type		Rigid diaphragm
Incremental load		2,50 kN
Permanent Load		5 kN/m
Target Displacement		0.48m
Importance Class		II
Damping		5%

Pushover analysis was used in structural analysis. The values given in Table 1 were taken into account as the PGA value in the analyses. For each settlement, four different local soil classes were selected as variables, and analyzes were carried out. The 2 and 3-dimensional models obtained from the software for the selected RC building as an example are shown in Figure 4.

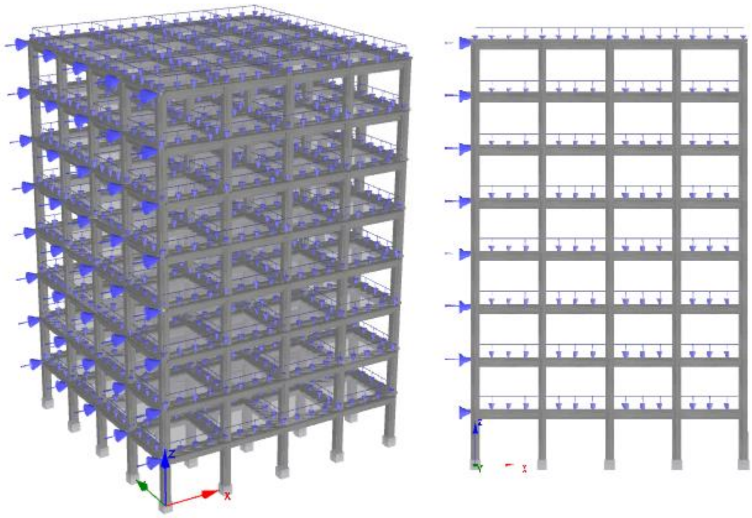

Figure 4. 2D and 3D structural model for the RC building
Şekil 4. *Örnek BA binası için elde edilen 2 ve 3 boyutlu yapısal model*

Elastic stiffness ($K_{elastik}$) and effective stiffness ($K_{effective}$) values, natural period, and base shear forces were calculated separately for all settlements. For the target displacement values, the levels specified in Eurocode-8 (Part 3), which is also more commonly used, were taken into account. Three different states of damage are specified for performance levels. These; are near collapse (NC), significant damage (SD), and damage limitation (DL). These considered levels and their explanations are shown in Table 4.

Table 4. Limit states in Eurocode 8 (Part 3) (EN 1998, 2005; Pinto & Franchin, 2011)
Tablo 4. *Eurocode 8'deki sınır durumları (Bölüm 3) (EN 1998, 2005; Pinto & Franchin, 2011)*

Limit State	Description	Return Period (year)	Probability of exceedance (in 50 years)
Limit state of damage limitation (DL)	Only lightly damaged, damage to non-structural components is economically repairable	225	0.20
Limit state of significant damage (SD)	Significantly damaged, some residual strength and stiffness, non-structural components damaged, uneconomic to repair	475	0.10
Limit state of near collapse (NC)	Heavily damaged, very low residual strength & stiffness, large permanent drift but still standing	2475	0.02

The representation of the considered limit states on an example pushover curve is shown in Figure 5.

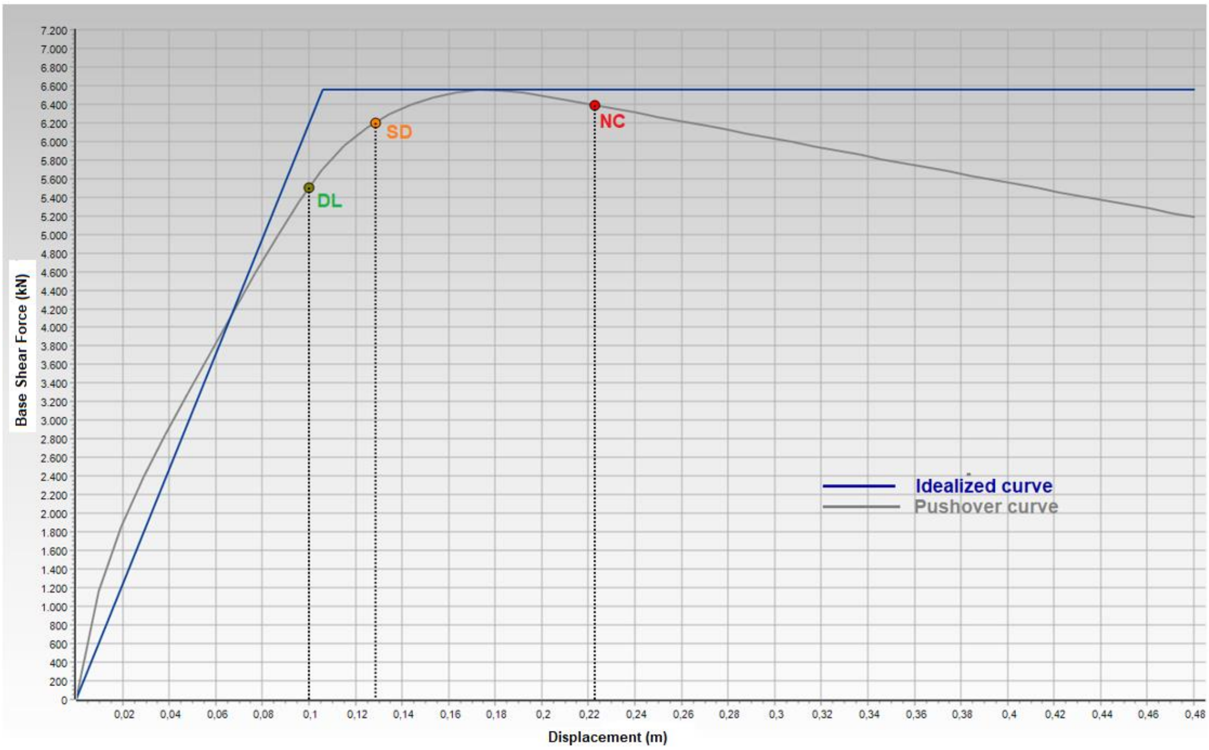

Figure 5. Representation of the considered limit states on the pushover curve
Şekil 5. *Dikkate alınan sınır durumlarının statik itme eğrisi üzerinde gösterimi*

Since the RC structural properties taken into account in the study are not variable, the natural vibration period of the building is the same for all settlements and is obtained as 0.704 sec. Since the structural characteristics did not change, the seismic capacity of the same shape structure was obtained as 6553.74 kN, elastic stiffness 120490.50 kN/m, and effective stiffness as 61955.62 kN/m in all settlements. The target displacement obtained for settlements with different soil and seismic risks by using the PGA values predicted in the previous earthquake zone map is shown in Table 5.

Table 5. Comparison of target displacements (TBEC-2007)
Tablo 5. *Hedef yerdeğiştirme değerlerinin karşılaştırılması (TBEC-2007)*

Local Soil Class	Limit State	Manisa (Center) (m)	Ağrı (Center) (m)	Gümüşhane (Center) (m)	Ankara (Center) (m)
	DL	0.085	0.064	0.043	0.021
ZA	SD	0.109	0.082	0.055	0.027
	NC	0.190	0.142	0.095	0.047
	DL	0.128	0.096	0.064	0.032
ZB	SD	0.164	0.123	0.082	0.041
	NC	0.284	0.213	0.142	0.071
	DL	0.147	0.110	0.074	0.037
ZC	SD	0.189	0.141	0.094	0.047
	NC	0.327	0.245	0.163	0.082
	DL	0.230	0.173	0.115	0.058
ZD	SD	0.295	0.221	0.148	0.074
	NC	0.512	0.384	0.256	0.128

The comparison of the values obtained for the limited damage (DL) condition in order to reveal the difference between the different soil classes is shown in Figure 6.

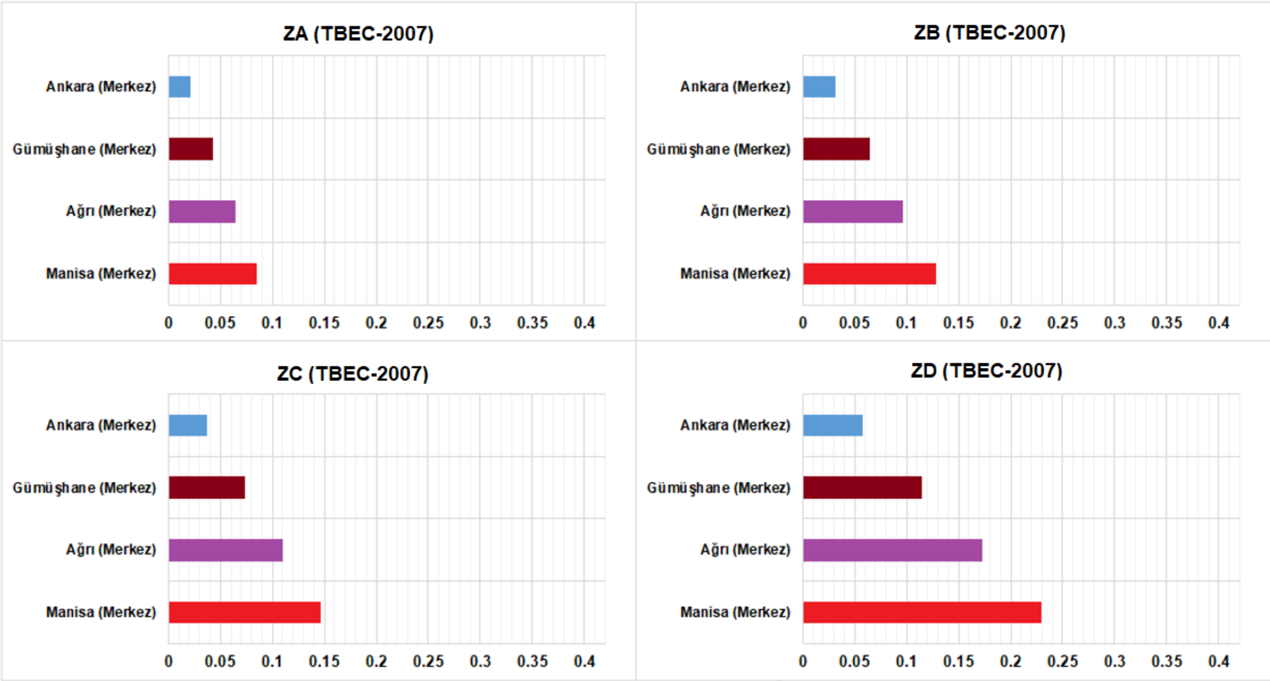

Figure 6. Comparison of displacements in different soil classes for the Limited Damage condition
Şekil 6. *Sınırlı Hasar durumu için yerdeğiştirmelerin farklı zemin sınıfları karşılaştırılması*

The comparison of the displacements obtained for different soil classes in case of significant damage (SD) of Manisa (Center), which is the settlement with the highest PGA value among the settlements considered in the study, is shown in Figure 7.

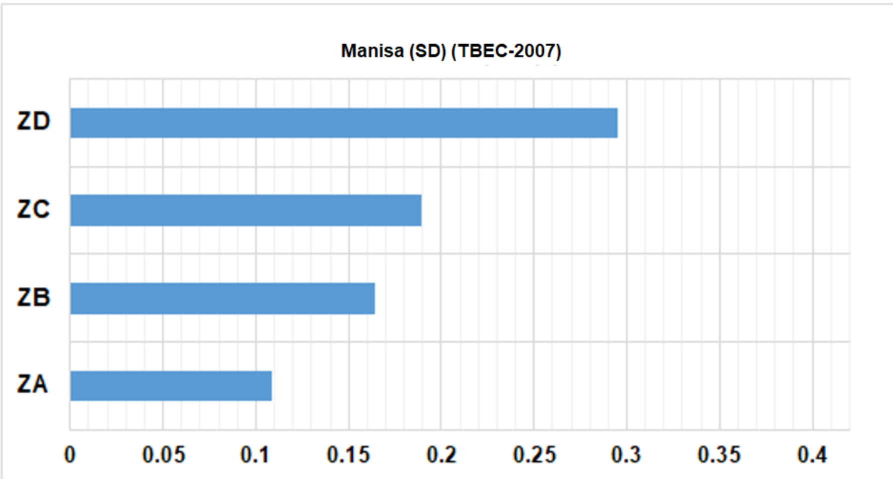

Figure 7. Comparison of displacements for the SD condition of Manisa
Şekil 7. *Manisa için SD için yerdeğiştirme değerlerinin karşılaştırılması*

As the local soil properties weakened and its strength decreased, the target displacements expected from the structure for the performance levels increased significantly.

The target displacements obtained from the structural analysis results for the PGA values of the seismic risk change predicted in the Current Turkey Earthquake Hazard Map are shown in Table 6.

Table 6. Comparison of target displacements (TBEC-2018)
Tablo 6. *Hedef yer değiştirmelerin karşılaştırılması (TBEC-2018)*

Local Soil Class	Limit State	Manisa (Center) (m)	Ağrı (Center) (m)	Gümüşhane (Center) (m)	Ankara (Center) (m)
ZA	DL	0.100	0.050	0.039	0.032
	SD	0.128	0.064	0.051	0.041
	NC	0.223	0.111	0.088	0.071
ZB	DL	0.150	0.075	0.059	0.048
	SD	0.193	0.096	0.076	0.061
	NC	0.334	0.167	0.131	0.107
ZC	DL	0.172	0.086	0.068	0.055
	SD	0.222	0.111	0.087	0.071
	NC	0.384	0.192	0.151	0.123
ZD	DL	0.270	0.135	0.106	0.086
	SD	0.347	0.173	0.137	0.111
	NC	0.601	0.301	0.237	0.192

The comparison of the target displacements obtained for the NC condition of Manisa (Center) and Ağrı (Center) with different seismic risks is given in Figure 8.

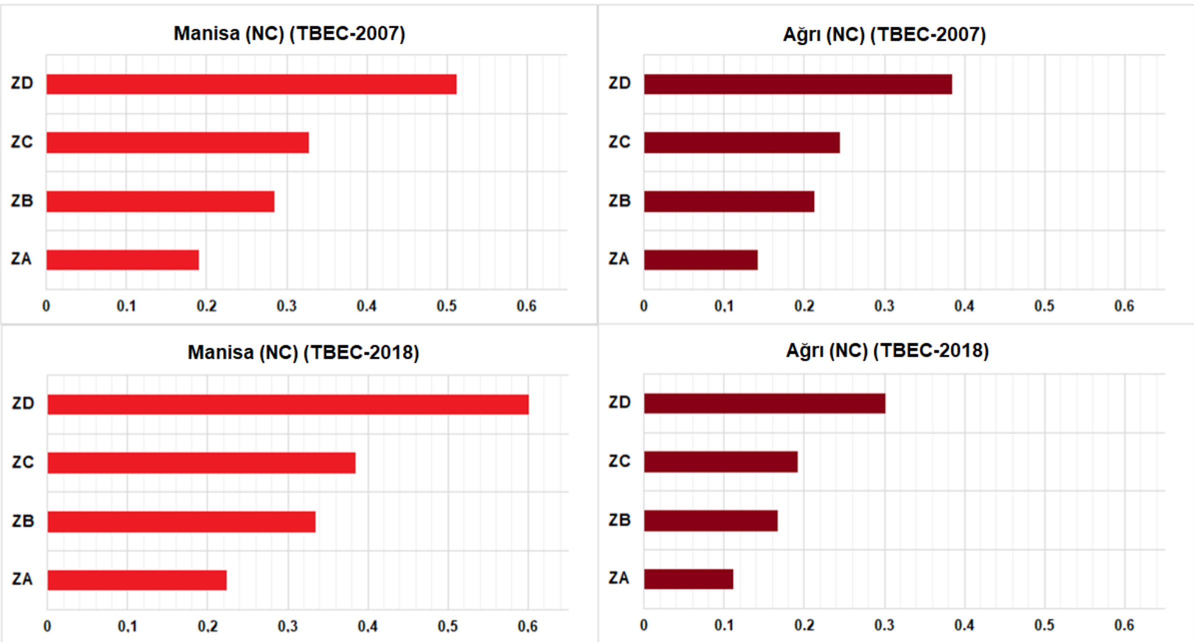

Figure 8. Comparison of displacement for different soil classes of Manisa and Ağrı
Şekil 8. *Manisa ve Ağrı için farklı zemin sınıfları için sınır durumların karşılaştırılması*

The highest target displacements were obtained for soil class ZD, while the lowest displacements were obtained for ZA. The highest target displacements were obtained for Manisa (Center), while the lowest values were obtained for Ankara (Center) for which the lowest PGA value was predicted.

4. Conclusion
4. Sonuçlar

One of the factors affecting the level of structural damage caused by earthquakes is local soil conditions. Local soil conditions directly affect both the earthquake characteristics and the effect of the earthquake on the structures. This study, unlike other studies, it was investigated to what extent different local soil classes in settlements with different seismic risks affect the boundary conditions used for the performance levels of the structures. Considering the 1996 earthquake zone map, four cities in different earthquake zones were selected. The predicted PGA values for these cities were compared. Structural analyzes were performed for the RC structure model for four different local soil classes using the obtained values. No changes were made to the structural properties of the RC building model. Seismic risk and local soil conditions are taken into account as variables. Since the structural properties did not change, there was no change in the natural vibration period, seismic capacity, elastic, and effective stiffness values.

Turkey's earthquake hazard on a regional basis has been replaced by a geographical location-specific earthquake hazard with the updated map. Depending on this change, the earthquake risks of the settlements started to show variability. While an increase occurred for the provinces of Ağrı (Center) and Gümüşhane (Center) considered in this study, there was a decrease for the other provinces. The highest increase was in Manisa (Center) and the highest decrease was in Ağrı (Center).

The largest target displacements were obtained for ZD, while the lowest target displacements were obtained for ZA. The largest displacements were obtained for Manisa (Center), which has the highest seismic risk, and Ankara (Center), which has the lowest seismic risk. With the current seismic hazard map for Manisa (Center) and Ankara (Center), the seismic risk has increased compared to the previous map, and the target displacements have increased. As the seismic risk has decreased with current seismic hazard map for Ağrı (Center) and Gümüşhane (Center), target displacements have also decreased.

Since the weakening of the local soil properties will increase the earthquake effects on the structure, the target displacements have also increased. As the local soil strength increased, the expected displacements for the performance levels decreased as well. These results showed a complete agreement for the predicted values in the last two maps. The seismic hazard and risk change also significantly affected the expected target displacements. With the reduction of seismic risk, target displacements have decreased significantly.
In this study, structural analyzes were carried out using the values predicted in the last two earthquake zone and hazard maps used in our country. One of the important differences between the two maps is that the previous map is based on a regional basis, while the current map is based on location-specific earthquake hazards. While the target displacement values obtained for Manisa (Center) and Ankara (Center) increased compared to the values predicted for the current map, they decreased for Ağrı (Center) and Gümüşhane (Center).

It is seen that both the seismic hazard and the local soil conditions where the structures will be constructed significantly affect the expected target displacements for the performance levels of the structures. In this context, seismic hazard analysis will be important in order to more accurately reveal the seismic risk of any region. Determining the local soil properties and classes according to the results of experiments and measurements to be made in the field will add meaning to the results to be obtained. With these data, the earthquake-soil-structure triple interaction will be placed in a healthier and more realistic database. Accurately obtaining the damage levels that any earthquake can cause in any local soil class, in any structure, depends on the target displacements to be obtained for the expected performance levels from the structure.

Author contribution
Yazar katkısı

Concept/Design: FA; Data Collection, Processing, and Literature Search: EI; Drafting manuscript, Critical revision of manuscript: AB

Declaration of ethical code
Etik beyanı

The authors declare that all of the rules stated to be followed within the scope of the “Higher Education Institutions Scientific Research and Publication Ethics Directive” were followed, and none of the actions specified under the title of “Actions Contrary to Scientific Research and Publication Ethics” have been carried out.

Conflicts of interest
Çıkar çatışması beyanı

The authors declare that they have no conflict of interest.

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