SCIENNOVATION
A Journal of Structural Science and Innovation

RESEARCH ARTICLE

Date Received: 17. February 2020
Date Accepted: 12. March 2020

EVALUATION OF 10-STOREY REINFORCED CONCRETE BUILDING BY NONLINEAR DYNAMIC ANALYSES CONSIDERING SOIL-STRUCTURE INTERACTION

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Keywords:
Earthquake Resistant Structures Design, Time History Analysis, Soil-structure Interaction, TBEC-2018

Abstract

In our country, which is located on an active fault line, population growth and the construction brought by this population growth are increasing rapidly. This is why it is required to consider soil-structure interaction to obtain more realistic result in structural earthquake analyses. However, considering the soil-structure interaction in the calculations sometimes gives positive results and sometimes negative results. Whether the soil is rigid or not also affects this situation. In addition, soil structure interaction starts from the moment the construction starts. Stresses and deformations occurring in a newly constructed building affect the soil on which the building sits, while simultaneously the response of the soil affects the building. Especially for loose soils, also known as soft soils, the extent of this interaction becomes even more important. This study intends to reveal the effect of soil-structure interaction in seismic analyses. Within the scope of the study finite element model were created for a 10-storey reinforced concrete. Nonlinear time history analyses were applied to the model. The results of the study show that the natural vibration period and shear forces of the building increase in the model where the soil-structure interaction is taken into account, and significant differences occur in the collapse mechanisms of the structure.

10 Katlı Betonarme Binanın Yapı-Zemin Etkileşimi Dikkate Alınarak Doğrusal Olmayan Dinamik Analizi

Anahtar Kelimeler;
Depreme Dayanıklı Yapı Tasarımı, Zaman Tanım Alanında Analiz, Yapı-Zemin Etkileşimi, TBDY-2018

Özet

Aktif bir fay hattı üzerinde bulunan ülkemizde nüfus artışı ve bu nüfus artışının getirdiği yapılaşma hızla artmaktadır. Bu nedenle yapısal deprem analizlerinde daha gerçekçi sonuçlar elde etmek için zemin-yapı etkileşiminin dikkate alınması gerekmektedir. Ancak zemin-yapı etkileşiminin hesaplamalarda dikkate alınması bazen olumlu bazen de olumsuz sonuçlar vermektedir. Zeminin rijit olup olmaması da bu durumu etkilemektedir. Ayrıca zemin yapı etkileşimi inşaatın başladığı andan itibaren başlamaktadır. Yeni inşa edilen bir binada meydana gelen gerilme ve deformasyonlar binanın oturduğu zemini etkilerken eş zamanlı olarak zeminin tepkisi de binayı etkiler. Özellikle yumuşak zeminler olarak da bilinen gevşek zeminler için bu etkileşimin boyutu daha da önemli hale gelmektedir. Bu çalışma, yapı-zemin etkileşiminin sismik analizlerdeki etkisini ortaya koymayı amaçlamaktadır. Çalışma kapsamında 10 katlı betonarme bir yapı için sonlu eleman modeli oluşturulmuştur. Modele doğrusal olmayan zaman tanım alanında dinamik analiz uygulanmıştır. Çalışma sonuçları, yapı-zemin etkileşiminin dikkate alındığı modelde yapının doğal titreşim periyodunun ve kesme kuvvetlerinin arttığını ve yapının göçme mekanizmalarında önemli farklılıklar oluştuğunu göstermektedir.

1 INTRODUCTION

Earthquake is a reality in Turkey. Nonlinear analysis methods are used to obtain more realistic results when dealing with the earthquake resistance of structures (Hosseini et al., 2017; Argyroudis et al., 2019). Nonlinear time history dynamic analyses is a method giving more realistic results among these analyses (Ayoub et al., 2022). Dynamic analyses allows applying real ground motions to the structures (Nguyen et al., 2021; Tagle et al., 2021). Although nonlinear calculation methods have been known for a long time, simpler methods were preferred due to the long analysis time (Zareie et al., 2021; Wan et al., 2023). Today, with the development of computer technology, the use of nonlinear analyses has become widespread (Lv & Chen, 2022).

In seismic analyses, it is usually assumed that the building is connected from the foundation level to the ground with fixed support (Ateş et al., 2018; Forcellini, 2021; Avcı & Yazgan, 2022). Soil effects are not taken into account in this assumption. Especially in soft soils, analyses that take into account soil effects give more realistic results (Akhoondi & Behnamfar, 2021; Anand & Satish Kumar, 2021).

Structures are damaged in earthquakes. However, structures may change from linear to nonlinear behaviour after a while under earthquake effect (Bayraktar & Hökelekli, 2020; Kamgar et al., 2022). In this case, analysing according to the *Design According to Strength* in TBEC 2018, where linear calculation is taken into account, will not give correct results. For this purpose, *Deformation And Design-Based*, where nonlinear calculation is taken into account, are performed. Earthquake calculation methods to be used *Deformation And Design-Based* in Nonlinear Time History Methods (TBDY, 2018).

2 MATERIAL AND METHOD

The dynamic behaviour of the structure under seismic forces is investigated according to the direct integration of the time-dependent differential equations at each time step. Due to the nonlinear behaviour of the structure, the stiffness varies at each time step (TBDY, 2018). In 2018 Turkish Building Earthquake Code, it is compulsory to use for high-rise buildings. It can be used for all kinds of buildings. Real or artificial earthquake acceleration records are required for analyses.

Although it is complex, it is the most realistic analysis among nonlinear analyses. In addition, since the structure resists the earthquake by plastic deformation, it is important to include the inelastic behaviour in the analysis (Alemdar, 2004; Eren, 2010).

The thickness and amplitude of the raft foundation is 100 cm. Concrete class is C30/37, reinforcement class is B420C. S_S short period map spectral acceleration coefficient, S_1 map spectral acceleration coefficient for 1 second period were taken from https://tdth.afad.gov.tr/ as 0,515 and 0,124 respectively. Weight per unit volume for sand soil 18 kN/m^3 (Kézdi & Réthási, 1974), angle of internal friction 35 (Peck et al., 1991), shear modulus 70 MPa (Bowles, 1996), Poisson's ratio was chosen as 0,3 (Cernica, 1995). Weight per unit volume for clay soil 19 kN/m^3 (Kézdi & Rétháti, 1974), cohesive 70 kN/m^2 (HOEK & BRAY, 1991), angle of internal friction 30 (HOEK & BRAY, 1991), young's modulus 100 MPa (Hallam et al., 1977), poisson's ratio was chosen as 0,1 (Poulos 1975). Weight per unit volume for gravel soil 21 kN/m3 (Kézdi and Rétháti 1974), angle of internal friction 45 (HOEK and BRAY 1991), young's modulus 150 MPa (Cernica 1995), poisson's ratio was chosen as 0,2 (Cernica 1995). Total depth of soil is 35 metres. Acceleration records of the 1971 San Fernando earthquake at Fort Tejon station were used for dynamic analysis in time history. SAP2000 v22.0.0 software was used for the analyses. IDECAD v10.94 software was used for obtaining reinforced conrete data. Typical plan (ground floor plan) of the building is shown in Figure 1 and 3D views of the finite element models is shown in Figure 2.

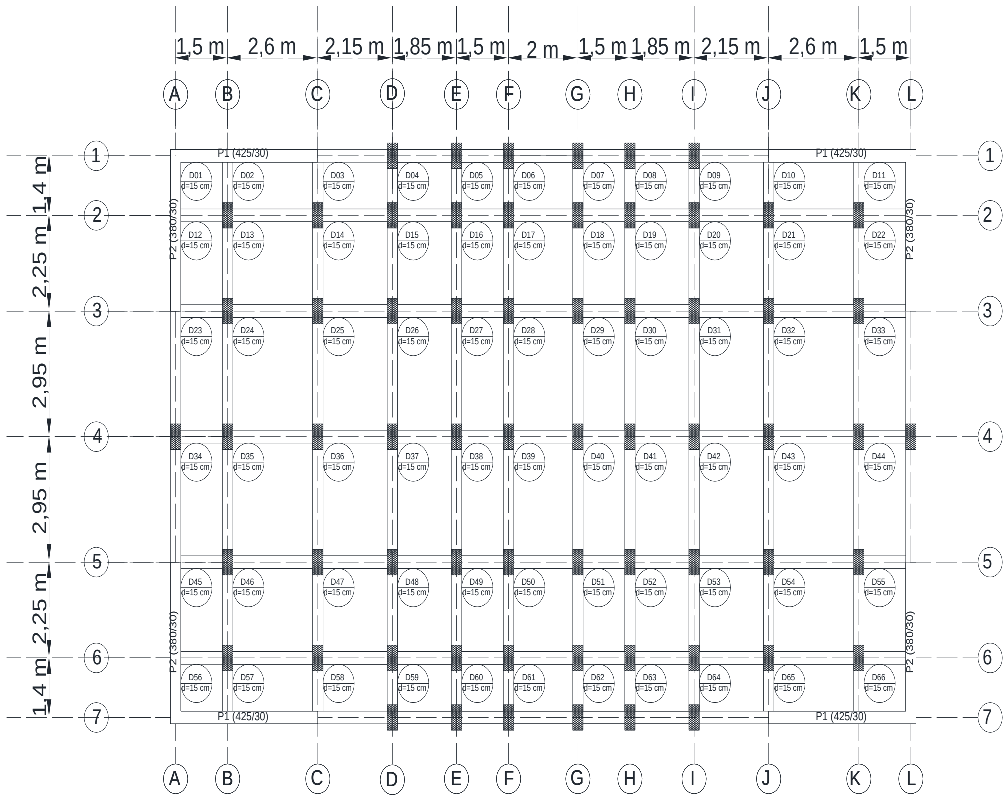
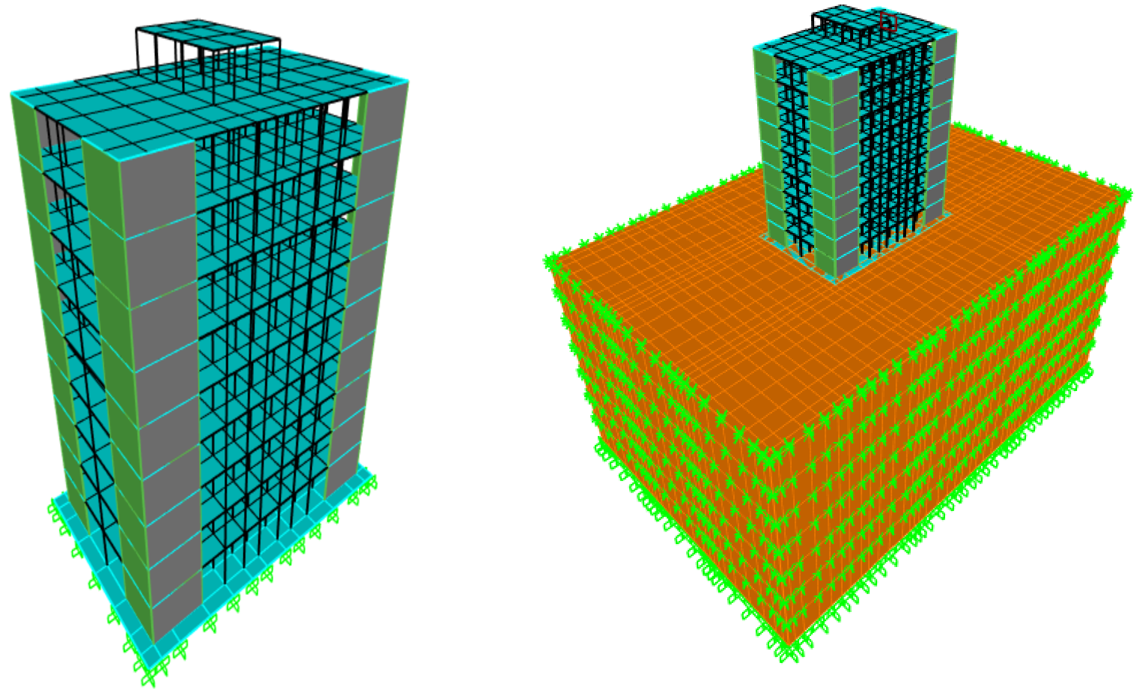


Figure1. Ground floor and typical floor plan



(a) *(b)*

Figure 2. 3D model of ten-storey building with **a-** fixed support **b-**with soil.

1971 San Fernando earthquake records (Fort Tejon station) is used in time history analysis in this study for azimuth 0° and azimuth 90°. Figure 3 shows the relationship of acceleration and time for San fernando earthquake.

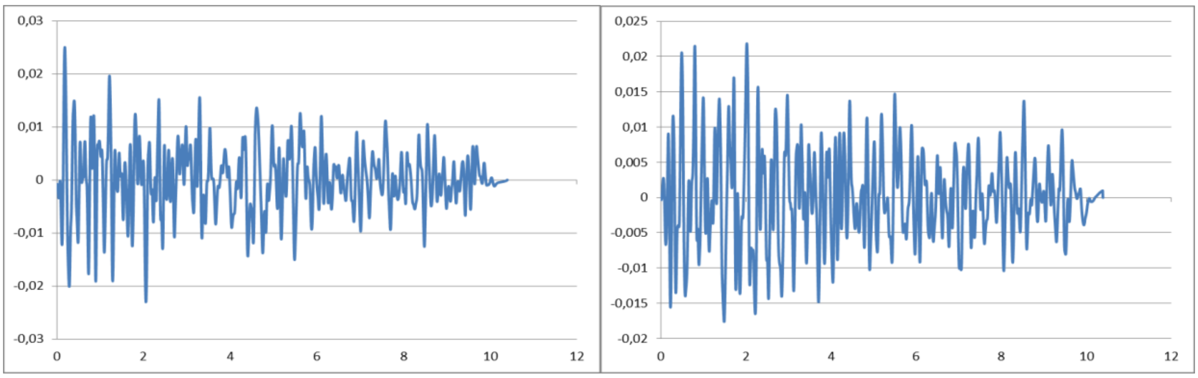


Figure 2. San Fernando earthquake Fort Tejon station accelogram **(a)** azimuth 0° and **(b)** azimuth 90° (AFAD, 2023).

In this study, a 10-storey building is modelled in three different ways, considering fixed support, stratified soil and sole stratified soil, and a comparison is made. The building is symmetrical on both sides. The floor heights are 2,35 metres only on the roof floor. The typical floors are 3 metres. Beam width is 30 cm, height is 60 cm. All column dimensions are same and 30*60cm2. The thickness of the shear walls is 30 cm. The slabs are 15 cm thick. Figure 4 shows the cross sectons of the structural elemants.

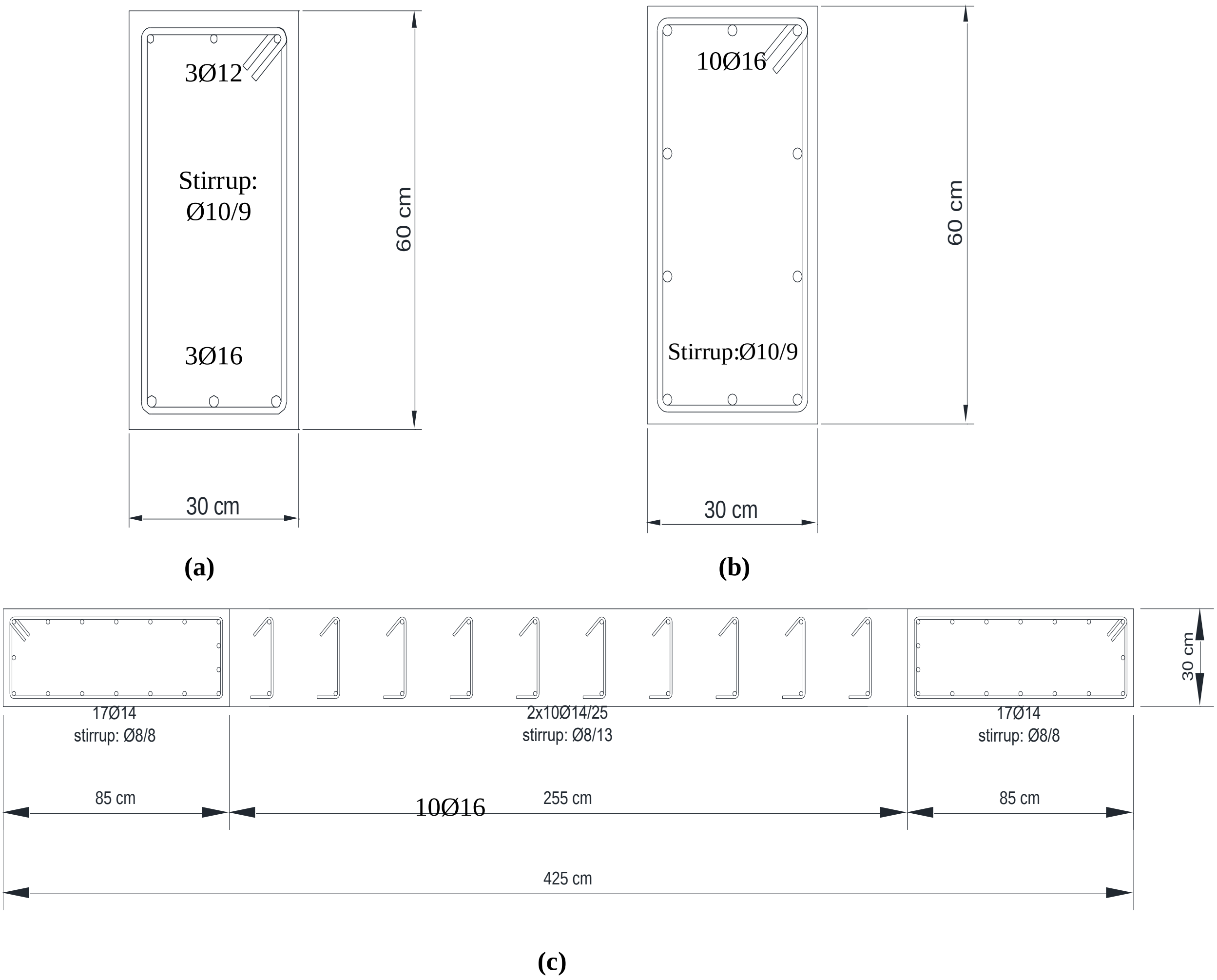


Figure 4. Cross section of **(a)** beams and **(b)** columns **(c) shear walls**

3 RESULTS

At the results of the analysing the building model were investigated as “Interstory drifts according to story levels”, “base shear forces”, “Gradient of interstory drifts for both of X and Y directions” and “Maksimum roof displacements”. Share forces resulting from time history analyses are shown in figure 5.

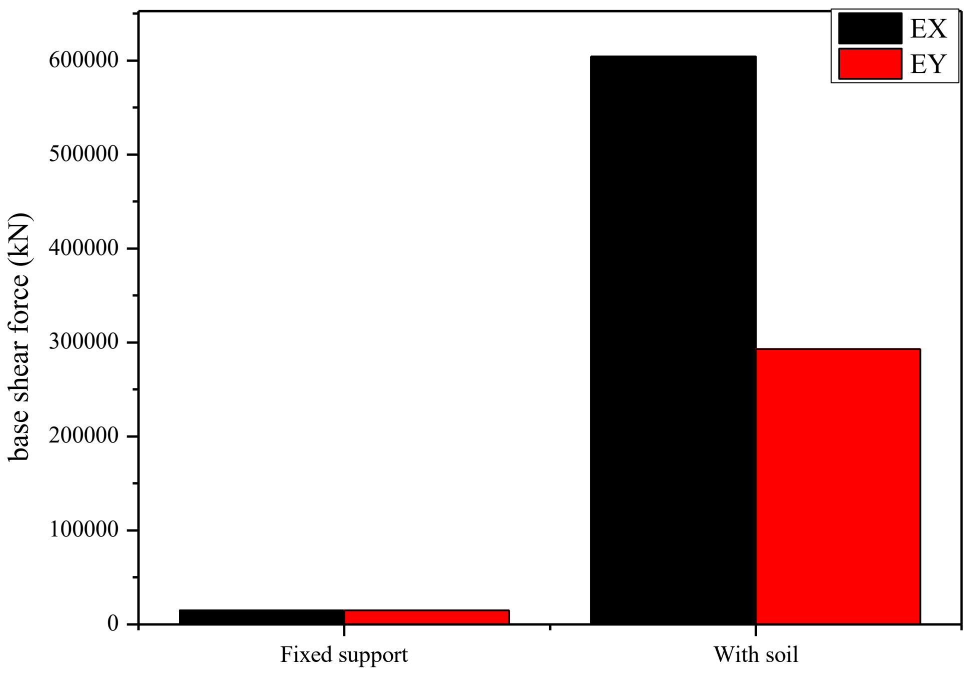


Figure 5. Shear forces of the model

Figure 5 shows that shear forces in the models considering soil-structure interaction reduces base shear forces. In the Y direction, base shear force is over due to Y direction is more rigid than X direction. Also in this graphic, it's seen that stratified soil model gave different acceleration values than sole stratified soil model.

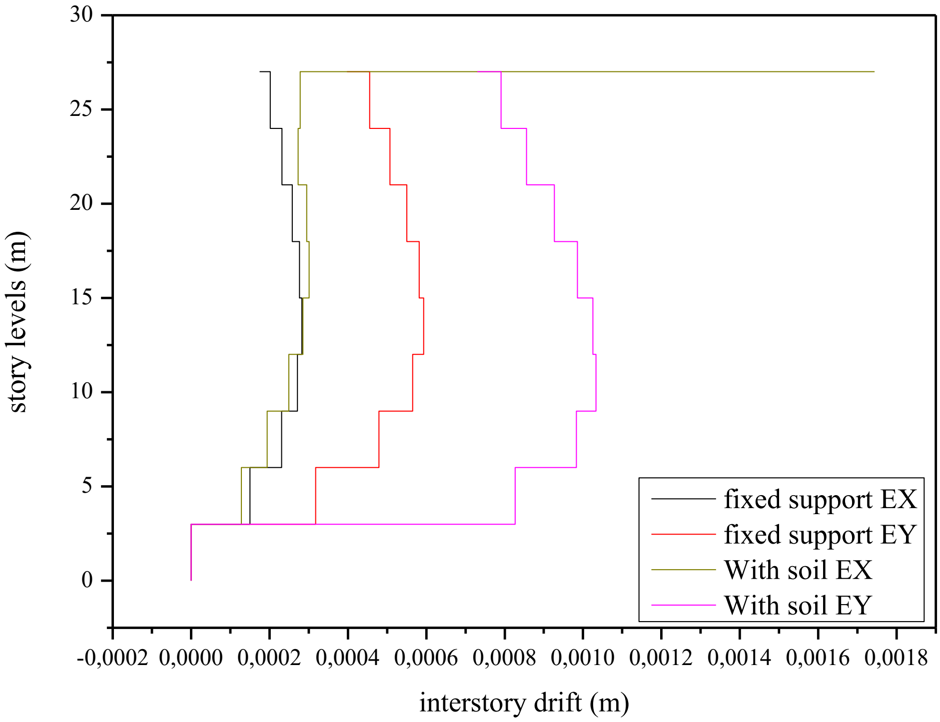


Figure 6. Interstory drifts according to story levels

As it is understood from Figure 6, the structure through time history analysis made farther drift. Especially in the Y direction, there was more drift. That's why, Y direction is strong direction.

As it s understood from the analysis, natural dominant vibration period increased due to soil reduced rigidity of structure. In the model with soil, the period of the structure increased by 35.22%.

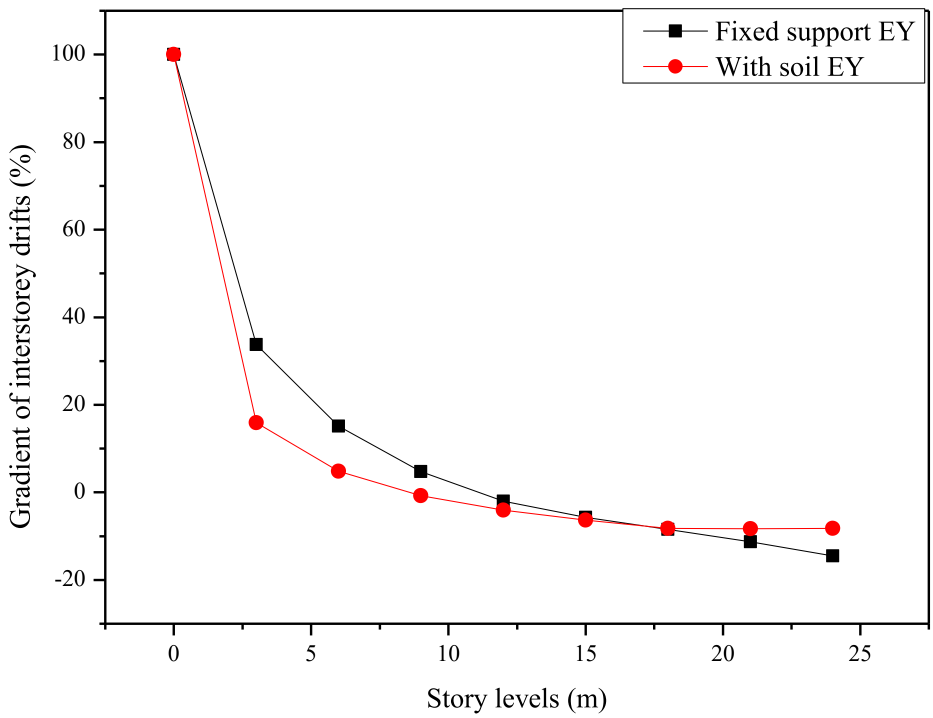


Figure 7. Gradient of interstory drifts at Y direction

Figure 7 shows that gradient of interstory drifts of the structure is above zero only at the 12 m story level. It is dropped to below zero in the others. While increasing the floor level, gradient of interstory drifts gradually come close to each other.

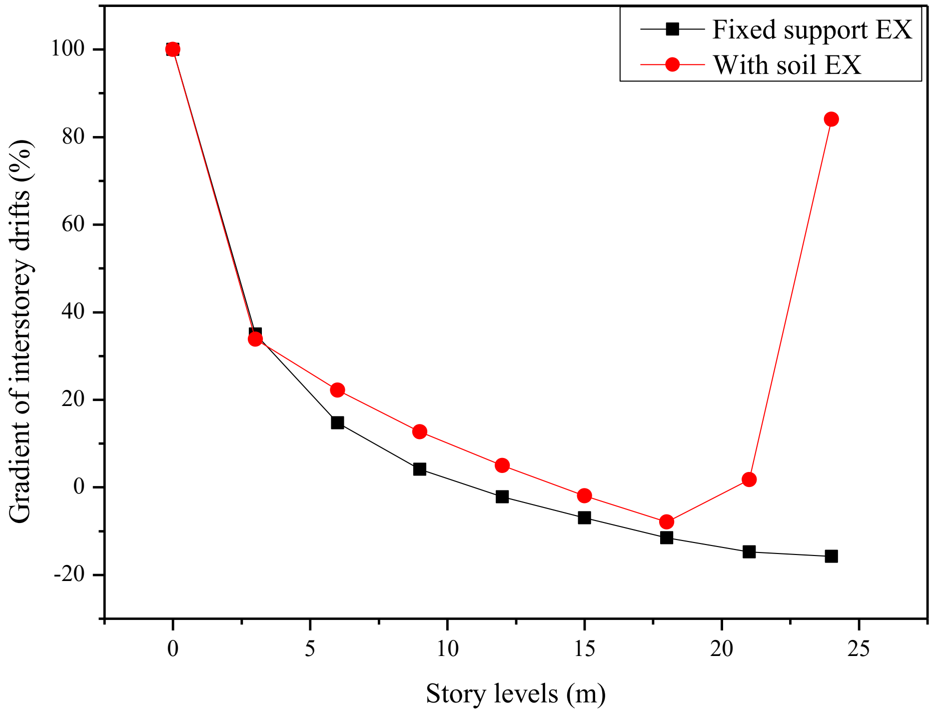


Figure 8. Gradient of interstory drifts at X direction

As it is understood from Figure 8, whole gradients of interstory drifts of models except fixed support EX is dropped below to zero at the 15 m story level. In the X direction, at nonlinear time history analysis of model with sole strafied soil showed an increase at 24 m story level.

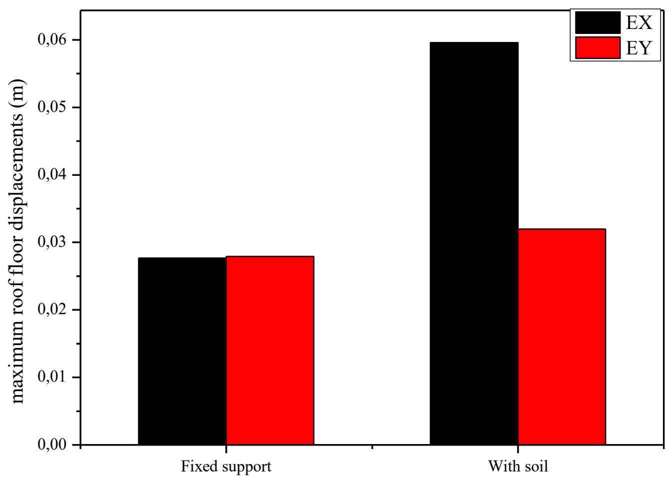


Figure 9. Maksimum roof displacements

In this study; fixed support, sole stratified soil and stratified soil are compared. For these comparings, nonlinear time history analyses are performed. Hence, soil data of previously committed studies is used. Subsequently, these data are entered SAP2000 v22.0.0 software.

4 CONCLUSIONS

Nonlinear time history analyses of 10-storey reinforced concrete building were carried out according to fixed support and soil structure interuption. As it is understood these analyses, every three analyses reveal that soil effect change behavior of building in earthquakes. In particular, this alteration is further obvious in soft soils. Also stratified soil in comparion with sole stratified soil makes a sum of changes in the behaviour of building.

As a results of dynamic analysis, In Y direction, the structure made a more drift than X direction. Which indicates this is the strong direction. In both analyses, in Y direction more shear force occurred than X direction. Soil effects also changed the max acceleration values and natural vibration periods. Gradient of interstory drifts converged each other the toppest floor in time history analysis.

For the maximum roof floor drifts, the results were close to each other for the model with fixed support and the model with soil.

5 REFERENCES

Akhoondi, M. R., & Behnamfar, F. (2021). Seismic fragility curves of steel structures including soil-structure interaction and variation of soil parameters. *Soil Dynamics and Earthquake Engineering*, *143*, 106609. https://doi.org/https://doi.org/10.1016/j.soildyn.2021.106609

Alemdar, Z. (2004). Yapılarda Deprem Analizi Yapmak için Kullanılan Değişik Hesap Metodları.

Anand, V., & Satish Kumar, S. (2021). Evaluation of seismic response of inelastic structures considering soil-structure interaction. *Innovative Infrastructure Solutions*, *6*, 1-19.

Argyroudis, S. A., Mitoulis, S. A., Winter, M. G., Kaynia, A. M., & Safety, S. (2019). Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience. *Reliability Engineering*, *191*, 106567.

Ateş, Ş., Tonyali, Z., Soyluk, K., & Samberou, A. M. S. (2018). Effectiveness of soil–structure interaction and dynamic characteristics on cable-stayed bridges subjected to multiple support excitation. *International Journal of Steel Structures*, *18*, 554-568.

Avcı, Y., & Yazgan, U. (2022). Probabilistic estimation of inelastic displacement demands in soil–structure interaction systems on cohesive soils. *Earthquake engineering and structural dynamics*, *51*(1), 22-43.

Ayoub, N., Deü, J.-F., Larbi, W., Pais, J., & Rouleau, L. (2022). Application of the POD method to nonlinear dynamic analysis of reinforced concrete frame structures subjected to earthquakes. *Engineering Structures*, *270*, 114854. https://doi.org/https://doi.org/10.1016/j.engstruct.2022.114854

Bayraktar, A., & Hökelekli, E. (2020). Influences of earthquake input models on nonlinear seismic performances of minaret-foundation-soil interaction systems. *Soil Dynamics and Earthquake Engineering*, *139*, 106368. https://doi.org/https://doi.org/10.1016/j.soildyn.2020.106368

Bowles, J. E. (1996). Foundation Analysis and Design, The McGrawHill Companies. *Inc., Singapore*.

Cernica, J. N. (1995). *Geotechnical engineering: soil mechanics*. Wiley New York.

Eren, F. E. (2010). *Betonarme Perdelerde Kesme Kuvveti Dinamik Büyütme Katsayısının Doğrusal Olmayan Zaman Tanım Alanında Hesap Yöntemi İle İrdelenmesi* Fen Bilimleri Enstitüsü].

Forcellini, D. (2021). Analytical fragility curves of shallow-founded structures subjected to Soil-Structure Interaction (SSI) effects. *Soil Dynamics and Earthquake Engineering*, *141*, 106487. https://doi.org/https://doi.org/10.1016/j.soildyn.2020.106487

Hallam, M., Heaf, N., & Wootton, L. R. (1977). *Dynamics of marine structures: methods of calculating the dynamic response of fixed structures subject to wave and current action*.

HOEK, E., & BRAY, J. (1991). Rock Slope Stability (in Turkish), Chamber of Mining Engineering of Turkey. 141.

Hosseini, M., Hashemi, B., & Safi, Z. (2017). Seismic Design Evaluation of Reinforced Concrete Buildings for Near-Source Earthquakes by Using Nonlinear Time History Analyses. *Procedia Engineering*, *199*, 176-181. https://doi.org/https://doi.org/10.1016/j.proeng.2017.09.225

Kamgar, R., Dadkhah, M., & Naderpour, H. (2022). Earthquake-induced nonlinear dynamic response assessment of structures in terms of discrete wavelet transform. *Structures*, *39*, 821-847. https://doi.org/https://doi.org/10.1016/j.istruc.2022.03.060

Kézdi, Á., & Rétháti, L. (1974). *Handbook of soil mechanics* (Vol. 1). Elsevier Amsterdam.

Lv, H., & Chen, S. (2022). Analysis of nonlinear soil-structure interaction using partitioned method. *Soil Dynamics and Earthquake Engineering*, *162*, 107470. https://doi.org/https://doi.org/10.1016/j.soildyn.2022.107470

Nguyen, P.-C., Tran, T.-T., & Nghia-Nguyen, T. (2021). Nonlinear time-history earthquake analysis for steel frames. *Heliyon*, *7*(8). https://doi.org/10.1016/j.heliyon.2021.e06832

Peck, R. B., Hanson, W. E., & Thornburn, T. H. (1991). *Foundation engineering*. John Wiley & Sons.

Tagle, S. J., Jünemann, R., Vásquez, J., de la Llera, J. C., & Baiguera, M. (2021). Performance of a reinforced concrete wall building subjected to sequential earthquake and tsunami loading. *Engineering Structures*, *238*, 111995. https://doi.org/https://doi.org/10.1016/j.engstruct.2021.111995

Türkiye Bina Deprem Yönetmeliği, TBDY (2018).

Wan, Z., Chen, J., Tao, W., Wei, P., Beer, M., & Jiang, Z. (2023). A feature mapping strategy of metamodelling for nonlinear stochastic dynamical systems with low to high-dimensional input uncertainties. *Mechanical Systems and Signal Processing*, *184*, 109656. https://doi.org/https://doi.org/10.1016/j.ymssp.2022.109656

Zareie, S., Ahmad, R., Zabihollah, A., & Issa, A. S. (2021). Dynamic response of frame structures with shape memory alloy -magnetorheological fluid-based bracing system by nonlinear time-history analysis. *Journal of Building Engineering*, *43*, 102914. https://doi.org/https://doi.org/10.1016/j.jobe.2021.102914