Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 9, September, 2018

The Effect of Soil around the Basement Walls on the Base Level of Braced Framed Tube System

Mohammad Sadegh Barkhordari [a*], Mohsen Tehranizadeh [b]

[a] Master of Civil Engineering, Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran.

[b] Professor, Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran.

Received 12 June 2018; Accepted 06 September 2018

Abstract

According to the 2800 standard, the Iranian code of practice for seismic-resistant design of buildings, the base level refers to the level at which it is assumed that the horizontal movement of the ground is transmitted to the structure. In cases that there are reinforced concrete walls being run by an integrative structure in the underground perimeter, and the surrounding ground is dense and compressed, the base level is considered on the top of the basement wall. In tall structures, due to strong forces and moments at the foot of the structure, examining the location of base level and its movement becomes specially important. The aim of this study was to investigate the impact of changing the properties of the soil around the underground perimeter walls on the base level, taking into account the effects of soil-structure interaction systems. In this regard, the soil-structure system was investigated in two-dimensional models and the location of the base level was identified using shear and drift changes. The results indicated that taking into account the level of the upper stories is possible through performing appropriate walls integrated with the structure even without Compacting the soil around the structure.

Keywords: Base Level; Braced Framed Tube System; Soil-Structure Interaction; Near-Field Earthquake; Finite Elements.

1. Introduction

The progress and evolution of dynamics of structure on the one hand and information from recorded earthquakes, on the other hand, have shown that several factors are effective in determining the force of the earthquake. Some of these factors, such as period, mode shape and the structure capacity to embrace plastic deformation, are obtained from the dynamic properties of structures. Other factors such as soil type and the local seismicity can also affect the force of the earthquake. There are three systems that the interaction between them can affect the response of the structure. These systems are: the soil underlying and surrounding the foundation, the foundation, and structure. Numerous studies have attempted to explain and evaluate the collective response of these systems to a specific ground motion. Mirzaie et al. [1] employed a probabilistic approach to study the phenomenon of dynamic soil- structure interaction (SSI). The main aims of their research were as follow: First, considering the prevailing uncertainties in order to study the inelastic response of the structure and SSI, second, evaluating the practicing SSI provisions of the current seismic design codes on the structural performance. They found that SSI increases the ductility demand of structures (built on the flexible soil in reality) designed based on the conventional fixed- based assumption. Bathurst et al. [2] revisited model type, bias and input parameter variability on reliability analysis for simple limit states in SSI problems. They derived the formulation for the true probability of failure of a simple limit state function. Their general closed-form solution considers contributions due to model type, uncertainty in estimates of nominal values for correlated and uncorrelated load, and

---

* Corresponding author: m.s.barkhordari@aut.ac.ir

http://dx.doi.org/10.28991/cej-03091139

➢ This is an open access article under the CC-BY license (https://creativecommons.org/licenses/by/4.0/).

© Authors retain all copyrights.

uncertainty in method bias values. Hokmabadi et al. [3] carried out a number of investigation into the influence of foundation type on seismic performance of buildings considering SSI. They considered three types of foundation: shallow foundation, a pile-raft foundation in soft soil, and floating (frictional) pile foundation in soft soil. The results of their studies showed that the type of foundation is a major contributor to the seismic response of buildings with SSI. Xiong et al. [4] investigated the influence of SSI on the dynamic characteristics of buildings. They carried out a series of free-vibration experiments on a scale-steel-frame structure. They aimed at providing a survey of the influence of soil–structure interaction (structure-to-soil relative stiffness and mass ratio) on the fundamental period of buildings. They concluded that a newly proposed method by Luco using Dunkerley's formula exhibits excellent accuracy in predicting the fundamental period of the structure with SSI. Javdanian et al. [5] presented the investigations and results on the evaluation of the potential of liquefiable soil layers underlying and surrounding the foundation. They developed a model based on neuro-fuzzy group method of data handling. Their results clearly showed that the proposed model can be successfully utilized for strain energy-based estimation of liquefaction potential. Lu et al. [6] analyzed flexible-base multi-storey buildings considering soil-structure interaction. They used the cone model in order to simulate the dynamic behaviour of an elastic homogeneous soil half-space. Finally, they developed a novel performance-based design method for the site and interaction-dependent seismic design of flexible-base structures. Hassani et al. [7] evaluated inelastic displacement ratios for degraded structures considering soil-structure interaction. They considered a wide variety of effective parameters of hysteresis models and soil-structure systems. They found that SSI can significantly affect the inelastic displacement ratios and Equal displacement rule is not valid for soil-structure systems. Stefanaki et al. [8-9] presented a new strategy for dynamic substructuring which refers to physical testing with computational models in the loop. Karapetrou et al. [10] analyzed the seismic vulnerability of high-rise non-ductile RC buildings considering soil-structure interaction. Their studies showed the significants role of SSI and site effects under linear or nonlinear soil behavior in altering the expected structural performance. They also claimed that calculating fragility for fixed base structures may lead to unconservative results. Elias et al [11] studied a large number of building models with different number of floors and basement, floor masses and areas for floor plans, different lateral stiffness for the structures, and different soil types around the basement. Finally, Elias et al. [11] proposed a number of simple empirical equations for obtaining the base level position with good accuracy, which could be duly used by engineers and designers. In sum, despite base level being one of the pivotal parameters in determining the seismic force and preliminary design of structural sections, no study has investigated the effect of soil around the basement walls on the base level of the building.

The base level is one of the factors affecting the computational seismic mass of the building. If the location of the base level is not set correctly, the seismic mass of basement stories is considered during an earthquake, resulting in the unpredicted increase of stories shear and drift and creating damage in the structure.

Kelly, in his article, considers various factors influencing the location of base level as the reason of extensiveness of its meaning. A number of factors affecting base level include [12]:

- The position of the ground surface relative to the levels of stories
- Properties of the Soil adjacent to the building
- The existence of openings in the retaining walls
- Position and rigidity of vertical seismic resistant elements
- Position and location of seismic separators
- The height of the basement
- The behavior of basement walls
- The proximity of neighboring buildings
- The slope of the ground surface

Regarding buildings with basements, Kelly explains that it is better to consider the base level in the storey level which is close to the ground surface. In order to be able to consider the base level close to the ground surface, the soil around the basement should be dense and compact so that the formation and transmission of seismic force to the building occurs in the overall basement wall height. For high-rise and heavy buildings or where the soil of site is soft, the surrounding soil should become compacted enough so that the transmission of forces at the time of earthquake will be done appropriately [12].

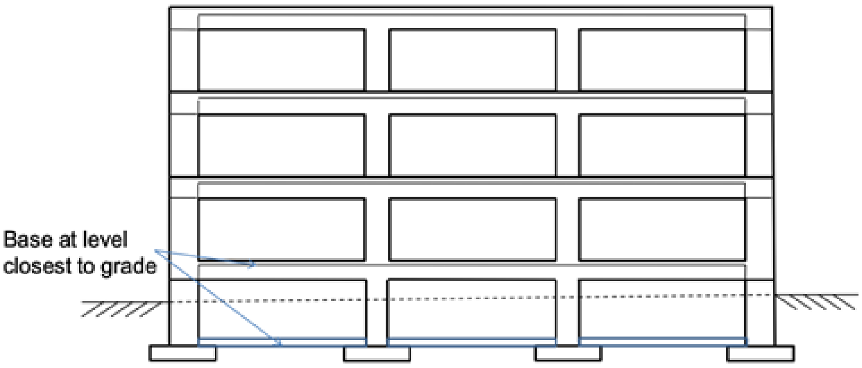

Figure 1. The base level of buildings with basements[4]

In the ASCE, it is mentioned that if the base level is considered near the ground surface, the soil around the building should not have liquefaction property in the maximum possible earthquake. In addition, it should not be from sensitive clay soils or poor cement soils prone to collapse in the maximum earthquakes. If the soil does not meet the above conditions, the base level is used on the foundation.

Tehranizadeh et al. reviewed investigations about the base level which were expressed and studied in the past years. They found that previous researchers focused on base-level in half-buried structures or lateral load resisting systems by consideration soil-structure interaction. Tehranizadeh et al. investigated the effects of peripheral basement wall openings and increasing the number of basement floors on the base level in high-rise buildings placed under near-field earthquakes. They claim that the results showed that a certain degree of opening in the peripheral basement wall of the buildings would not affect the position of the base level or the drift between the soil and the buried part of the structure. However, in case 50% and greater of the opening area is required, the base level must be considered one storey lower and the seismic mass corresponding to the first basement floor must be duly entered in the calculations. In addition, increasing the number of floors would result in the base level to further approach the ground surface (level) [13-14].

This study aims at exploring the effect of changes in properties of the soil around the basement on the base level location of tall structures. To this end, five steel braced frames with different stories (20, 25, 30, 35 and 40), assuming that beams and columns of the basement are buried in the underground perimeter walls along with the soil around the structure, were modeled in a two-dimensional condition and investigated under the effect of near-field earthquakes.

2. Research Methodology

In this study, in order to evaluate the impact of the number of stories and height of the building, five groups of structures of 20, 25, 30, 35 and 40 stories have been considered as main models. The Plan of the building is a square with sides of 24-meter long. The height of stories above the ground surface has been considered similar and equal to 4 meters and the basement storey height has been 3 meters. Structures are of tube system with bracing (high ductility), and foundations are of raft foundations which are designed with the help of Etabs and Safe respectively. Designing and controlling are based on the most recent edition of Iran's National Building Regulations and bylaws (Section VI of National Building Regulations [Edition 2013]): Loads on the building, Iranian code of practice for seismic-resistant design of buildings (Edition 2014): Fourth edition of 2800 standard, the tenth issue of national building regulations (Edition 2013): Designing and construction of steel buildings, instructions of seismic retrofitting of existing buildings (Publication No. 360).

In this study, high volume of models and the longtime of analysis resulted in the exploration of structures merely with three basement stories. The intended building is assumed to be located in the north-west of Tehran. According to the existing geological and geotechnical studies, the depth of soil is about 35 meters in this region. The soil's shear wave velocity from the ground surface to a depth of 15 meters below ground has been considered 400 meters per second and for the remaining 20 meters has been considered 550 meters per second. Soil and structure modeling is two-dimensional and it is done using the OpenSees software.

2.1. Soil Modeling

In calculating seismic forces exerted on the structure, engineers consider structures which are generally assumed to be fixed at their bases in the process of analysis and design. In this case, the effects of soil-structure interaction are not considered. There are two methods to investigate the effects of soil-structure interaction: 1) direct method. 2) sub-structure methods. In this study, the direct method is used to model the surrounding soil. The direct method has been used to model the soil. The PressureIndependMultiYield material has been used to model the soil (Figure 2-a), which the volumetric stress-strain response is linear-elastic and is independent of the deviatoric response. This material is implemented to simulate the monotonic or cyclic response of materials whose shear behavior is insensitive to the confinement change. After defining the material, it is required to allocate it to an element. In this study, quad elements (Figure 2- b) are used [15-17].

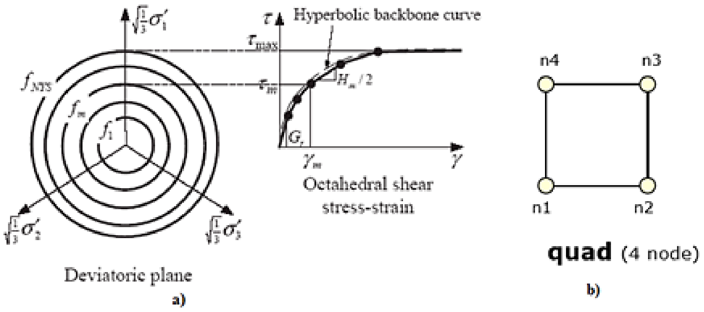

Figure 2. Pressure Independ Multi Yield material and quad element [13]

The dimensions of soil elements from the ground surface to a depth of 25 meters below the surface have been considered one meter and for the remaining depth have been considered two meters. To evaluate the validity of the soil, a soil column was modeled in the OpenSees program and a similar model was built in the Deepsoil software (Hashash, 2015). Period of the soil and an earthquake (Chi Chi earthquake record) at ground level were compared with the model built in the OpenSees. In Figure 3, the comparison of surface spectral acceleration obtained from the two software is shown.

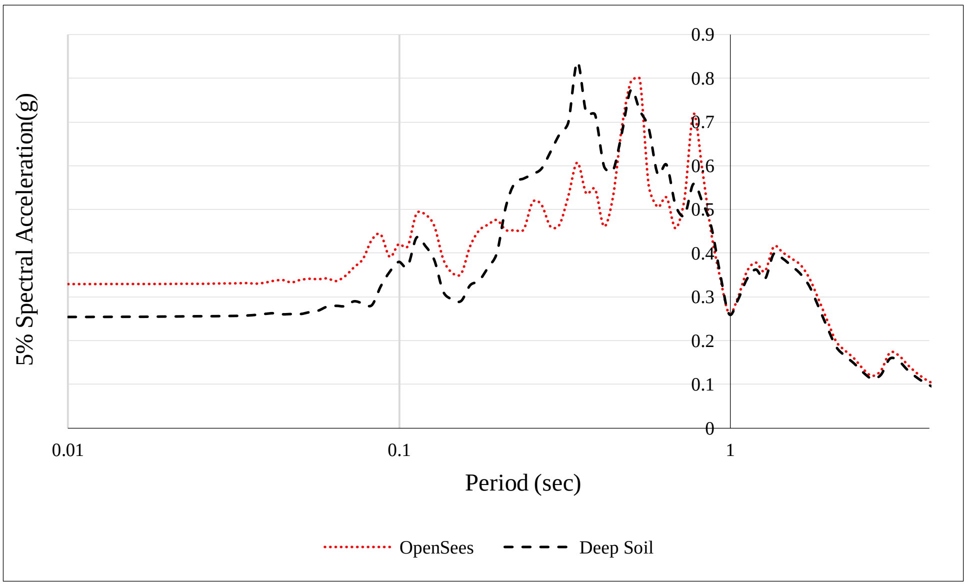

Figure 3. Comparison of surface spectral acceleration of Deepsoil and Opensees

Due to the fact that modeling of the large width of soil requires heavy calculations and increases analysis time, and also in order to absorb the outgoing waves and to avoid returning these waves to the computational domain, it is necessary to place artificial boundaries around the soil. Artificial boundaries should have the ability to absorb all the radiation output and no wave should be reflected back into the soil computational domain; thus, the viscose boundaries provided by Lysmer and Kuhlemeyer are used. Artificial boundaries, using two viscous damper (vertical and tangent to the mesh elements of the soil), are described as follows [18-20]:

$$C_n = a.\rho.V_P$$

$$V_P = \sqrt{\frac{2.G.(1-\nu)}{\rho.(1-2\nu)}} \tag{1}$$

$$C_s = b.\rho.V_S$$

$$V_S = \sqrt{\frac{G}{\rho}} \tag{2}$$

That C_n is a normal damper, C_S is a shear damper, ρ is soil density, ν is Poisson's ratio of soil, a, b are dimensionless coefficients, V_P is pressure wave velocity, and V_S is shear wave velocity. To model the dampers, viscous material and Zerolength elements are used.

2.2. Structural Modeling

The beam-column element is used to construct a column and beam element object, which is based on the displacement formulation and considers the spread of plasticity along the element. (Figure 4). This element is used for modeling beams and columns on the ground surface and the infrastructure below the ground surface [21]. The building plan is demonstrated in Figure 5. Given the beam-to-column connections are pinned connection, only the braced bays are modeled and a leaning column carrying gravity loads is linked to the frame to simulate P-Delta effects.

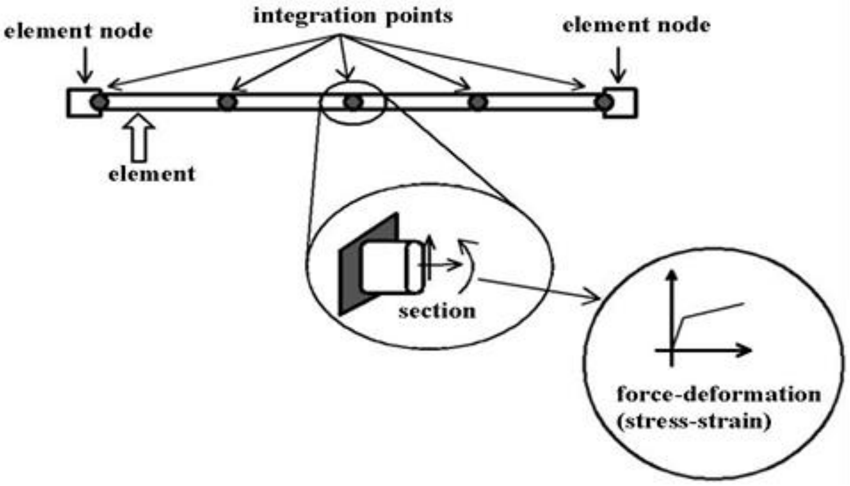

Figure 4. Beam-column element based on the displacement formulation[13]

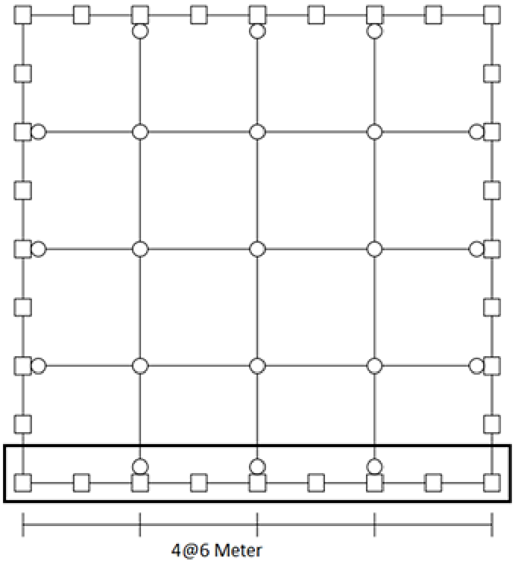

Figure 5. The Typical plan for the frame

The fiber model is potentially the easiest RC wall model to build and change in OpenSees. The peripheral basement wall was modeled using the Fiber and the Distributed Plasticity elements. The fiber type section model does not simulate deformation due to shear. Therefore, shear spring was introduced in series with the beam–column elements at the bottom of the wall. Wall thickness for the basement walls in all the models is 0.5 meter.

To define the steel and concrete, uniaxial materials Steel02 and Concrete01 (Figure 6 and 7) were used. The concrete material 01 is used to construct a uniaxial Kent-Scott-Park concrete material object with degraded linear unloading/reloading stiffness according to the work of Karsan-Jirsa and no tensile strength, and steel materials 02 is used to construct a uniaxial Giuffre-Menegotto-Pinto steel material object with isotropic strain hardening. Figure 10 shows the configuration of the direct method to model the soil-structure interaction [22-23].

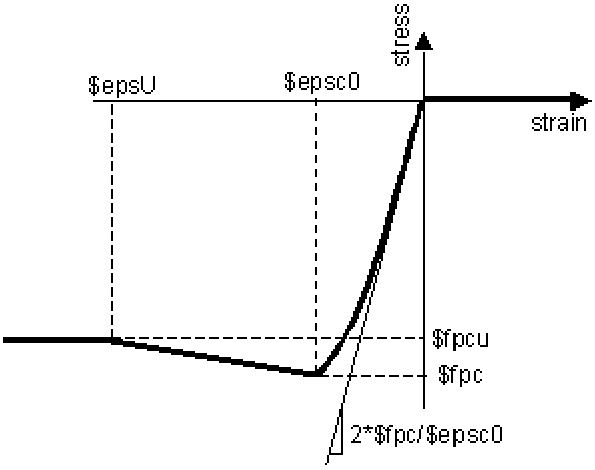

Figure 6. Uniaxial materials of Concrete01 [13]

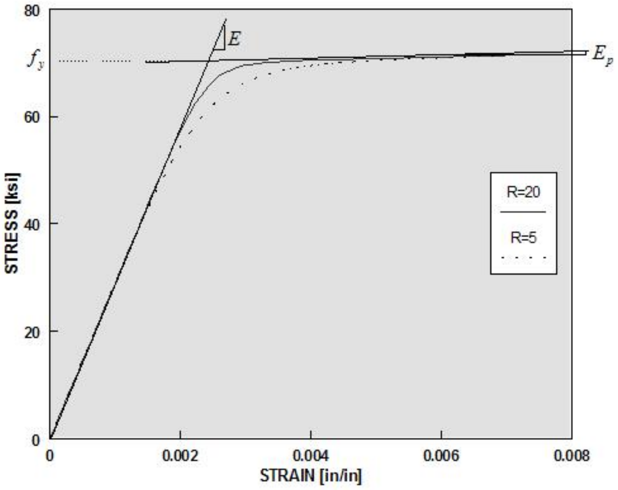

Figure 7. Steel materials 02 [13]

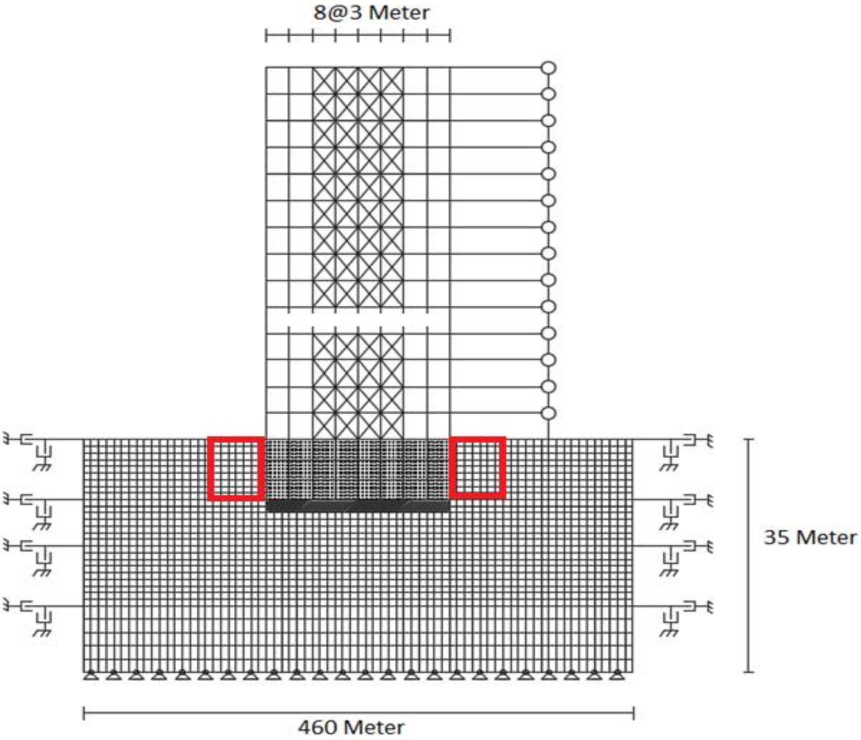

Figure 8. The configuration of the direct method for soil-structure interaction modeling

In order to investigate the effect of changes of soil properties around the building, the parameters of the soil on both sides of the building (with a width of 18 meters and a depth of 9 meters) on each side were changed according to Table 1. The distance of 18 meters has been estimated based on existing relationships to Rankine active pressure and Rankine passive earth pressure.

Table 1. Proposed values for the soil around the building

V_s (m/s)	100	200	300	400
soil mass density (ton/m^3)	1.3	1.5	1.65	1.8
shear modulus (kPa)	13000	60000	148500	288000
Cohesion (kPa)	18	37	50	75
Case	1	2	3	4

3. Model Verification

For modeling validation in this study, results from experiment and research conducted by Hosseinzadeh et al. were used. We used the response of the laboratory 20-storey structure with two-storey basement response. A view of soil-structure model with the buried base and the response obtained from the analysis and testing of soil-structure interaction are shown in Figures 9 and 10 [24].

Figure 9. A view of the structure installation process with the buried base [16]

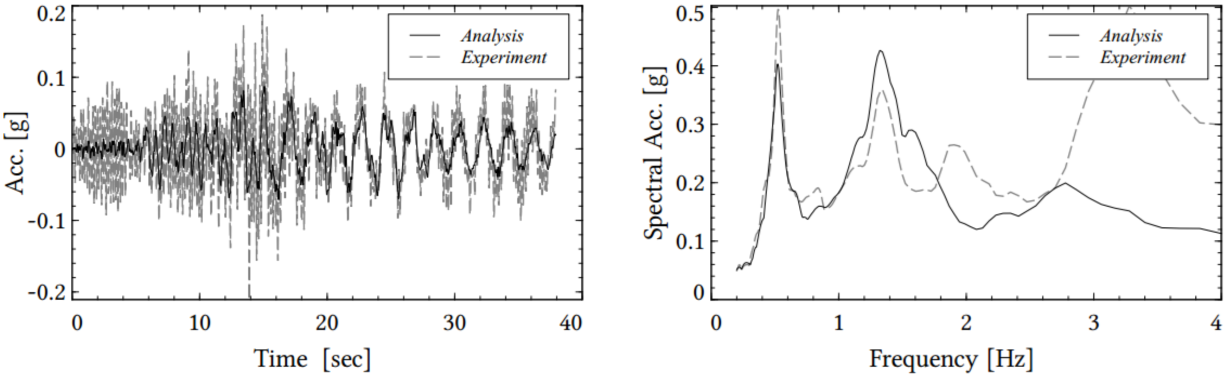

Figure 10. Comparison of accelerograph obtained from analysis and testing of soil-structure interaction and their acceleration response spectrum [16]

4. Earthquake Records

Near field earthquakes have caused a lot of damage in structures in the last few years. In addition, the Iranian 2800 standard has not considered the effects of earthquakes in the near field of fault for designing; therefore, it is essential to study such effects on structures. In this study, pulsed near-field earthquakes (Table 2) have been used to stimulate the soil-structure interaction system. The scaling of accelerographs was done by the method mentioned in the 2800 bylaw [25].

Table 2. Near field earthquake records

Event	Year	Station	Mag	Mechanism	Distance (km)	PGA (g)
Irpinia, Italy-01	1980	Sturno (STN)	6.9	Normal	6.8	0.13
Loma, Prieta	1989	Saratoga Aloha Ave	6.93	Reverse Oblique	8.5	0.35
Northride	1994	Pacoima	6.69	Reverse	7.26	0.22
Cape Mendocino	1992	Bunker Hill FAA	7.01	Reverse	8.49	0.2
Niigata, Japan	2004	NiG021	6.63	Reverse	10.21	0.35
Chuetsu-oki, Japan	2007	Joetsu Kakizaki	6.8	Reverse	9.43	0.23
Darfield, New Zealand	2010	HORC	7.0	Strike slip	7.29	0.45

5. Results

In this section, we review the results and charts that examined the property changes of the soil around the perimeter walls. Models were examined in both the presence and absence of seismic mass in the basement stories. To evaluate the relative displacement between soil and structure, nodes displacement of the interface between soil and structure were stored in nine different heights according to Figure 11.

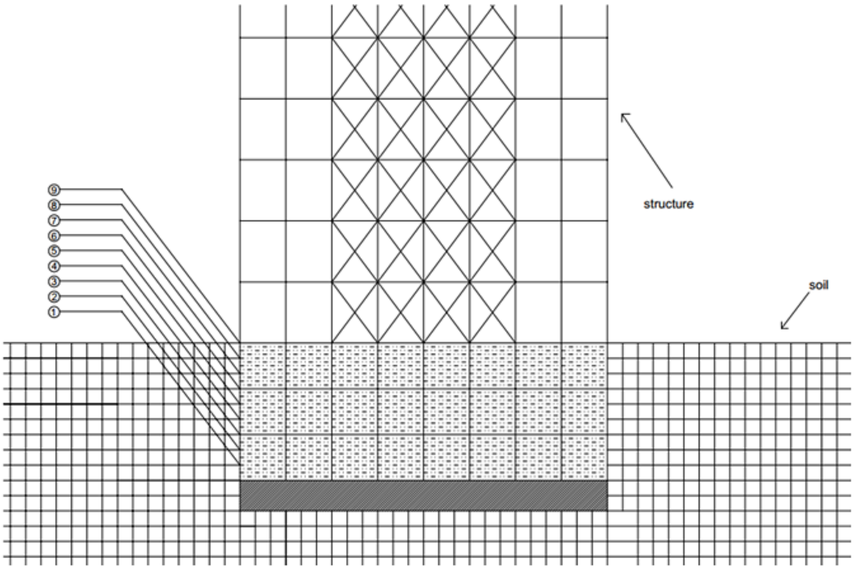

Figure 11. The number of nodes considered in the calculation of the relative displacement between soil and structure

The results show that changing soil properties and loosening the soil (Table 1) have no effect on the place of the base level. To understand why this happens, all the basement walls buried inside the frame were removed and the soil around the building was placed in Table 1 as the weakest soil. In this case, models were examined both in the presence and absence of seismic mass. The results show that the relative displacement, drift, and shear of stories increase in this case. The increase of relative displacement between soil and structure, in this case, has more changes than in the case of a retaining wall so that the maximum displacement to 20-storey construct is 7 times more than the case of basement walls existence.

One also should not overlook the fact that the rigidity of basement walls buried inside the frame has an influence on the relative displacement between soil and structure. Elias et al. [11a] listed a lot of reasons why base level moves towards the natural ground level. Elias et al. [11a] pointed out the soil and the basement structure behave as one rigid unit leading to an increase in the zero horizontal displacement level far from the foundation level. Therefore, it is reasonable that in the presence of basement walls, the relative displacement, drift, and shear of stories decrease.

In order to investigate the effect of properties of the soil around the structure, soil parameters of both sides of buildings were changed up to 18 meters from each side in accordance with Table 1. Figures 12 to 26 show that the properties of soil and loosening the soil around the basement walls have no effect on the base level location. The results of the analysis of models without basement wall show the relative displacement, drift and shear increase in this case. The relative displacement between soil and structure, in this case, has more changes than in the case of retaining wall existence. The increase of relative displacement, drift, and shear is due to the softening of the buried section of the structure and accordingly the increase of relative displacement between soil and structure and including the seismic mass of basement stories in calculations.

Another possible explanation for the increase of relative displacement is that the frame consists of a pipe system frame on the perimeter and bracings across four spans, which means that the large stiffness of the superstructure floors. Removing the basement retaining walls can lead to the occurrence of the "soft storey" phenomenon. When a softer part in the lower floors supports the upper heavier stories, a great part of the energy released during the earthquake is absorbed by this soft storey and only a fraction of this energy is distributed among the higher floors. This would produce great drifts between the upper and lower parts of the soft storey, which could eventually lead to the increased drift between the soil and the structure.

Therefore, it can be concluded that the effect of the existence of a retaining wall, compared to the soil property change and loosening the soil, is so high that in the first case the wall controls and determines the behavior of the structure and surrounding soil. It was also observed that by weakening the soil around the building and removing the retaining walls, the force generated in the buried section in the elements and, in fact, the force existing between soil and structure will be decreased. This occurs for two reasons: 1) by removing the retaining wall, rigidity in the buried section is reduced. 2) softening of the soil makes the soil apply less forces to the structure.

From the Figures 12, 15, 18, 21, and 24 it is apparent that for structures with retaining wall the variation of relative displacements between the structure and soil will increase while the number of stories increases from 20 to 30 storey structures, but this trend will not occur for 30 to 40 storey structures. To explain this discrepancy, the results of previous studies can help. Turan et al. in [26] evaluated the SSI effects for buildings with a basement. From their studies, it can be detected that the ratio of the structure height to basement embedment depth affect the structural response. Turan et al. concluded that as the height of the structure above ground decreases to a specific number, the amplification factors will increase. But if the decrease of structure height above ground is more than that specific number, then it will decrease the amplification factor. Hence, the case in which the amplification factor will increase as the number of stories decrease results in higher strain levels within the soil leading to degradation in its stiffness and nonlinearity for this case and consequently, the relative displacement from 40 to 30 storey structures increases while decreases for a 25 storey structure.

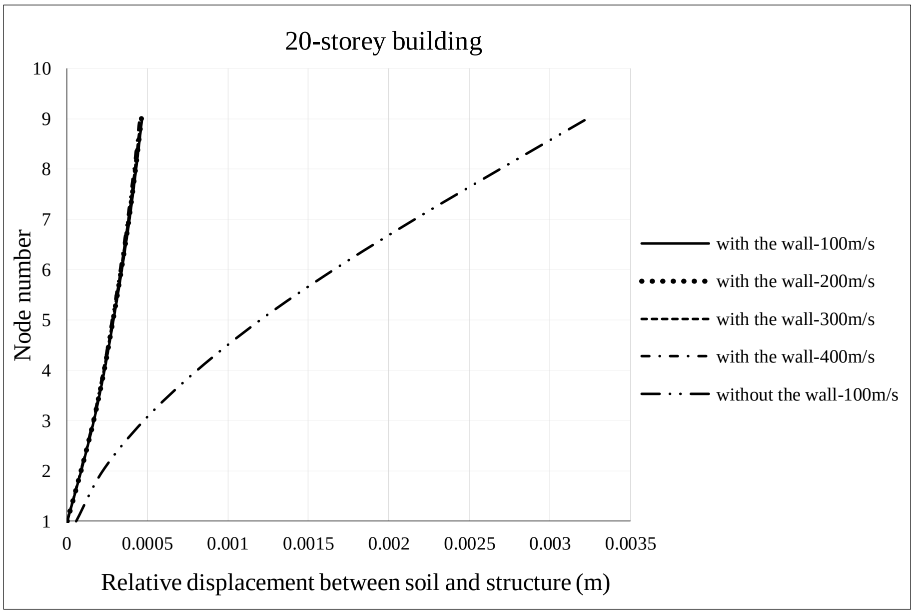

Figure 12. Diagram of the relative displacement between soil and buried section of the 20-storey structure

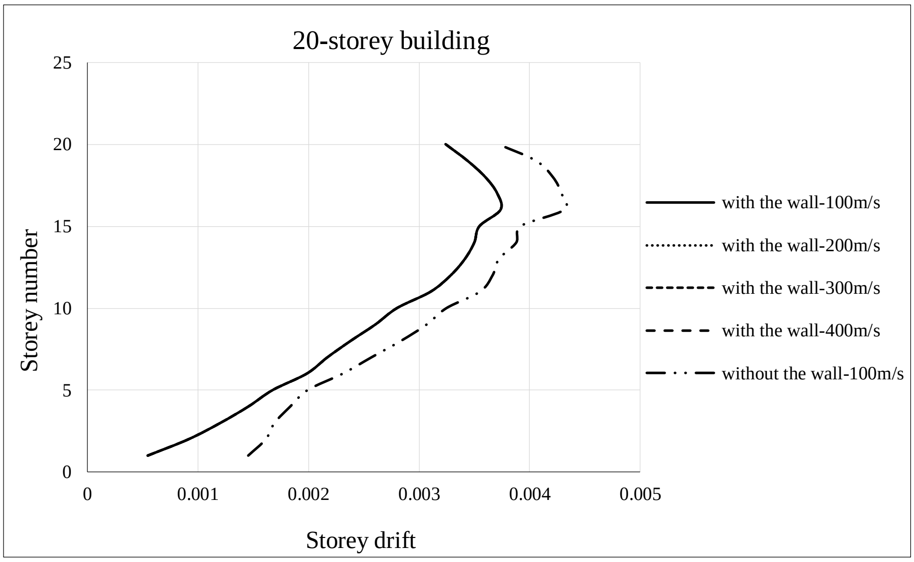

Figure 13. Diagram of the relative displacement of stories of the 20-storey structure

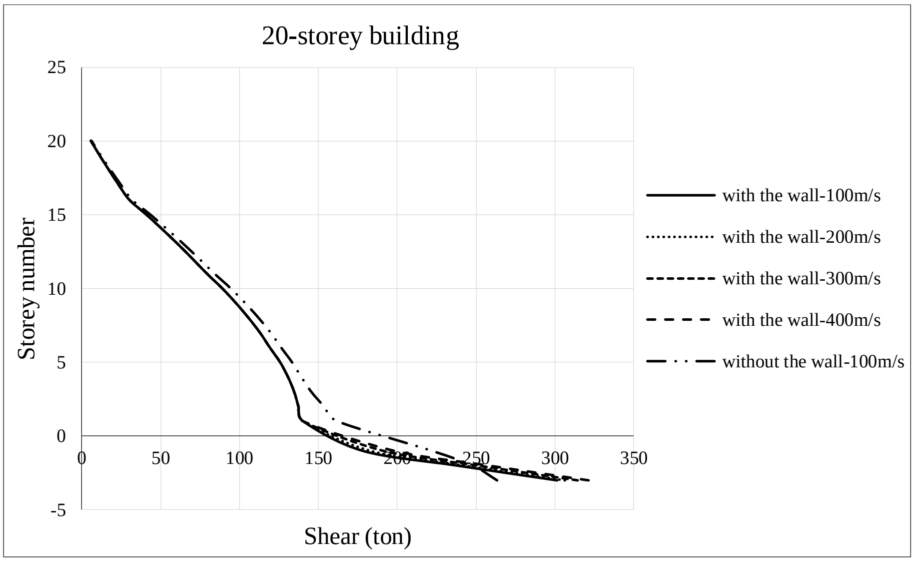

Figure 14. Diagram of shear changes of stories of the 20-storey structure

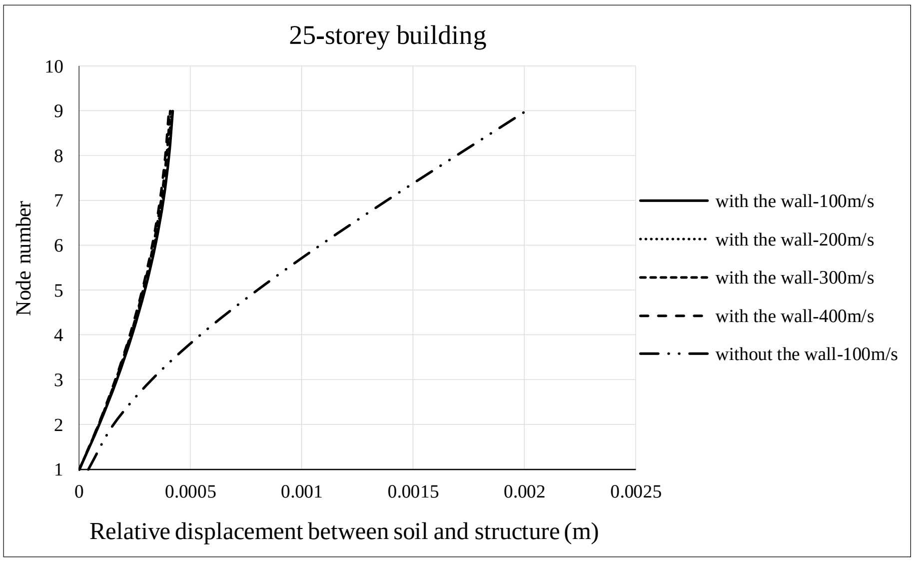

Figure 15. Diagram of the relative displacement between soil and buried section of the 25-storey structure

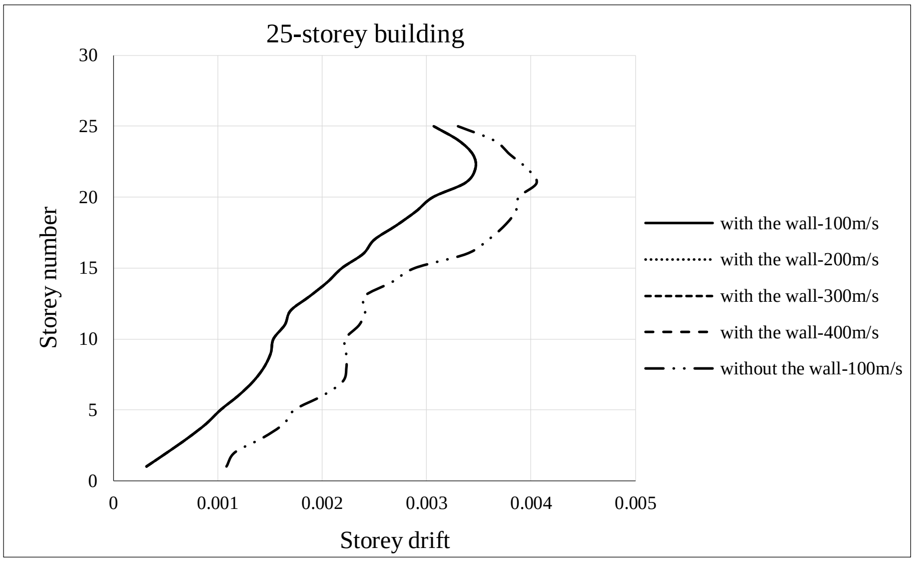

Figure 16. Diagram of the relative displacement of stories of the 25-storey structure

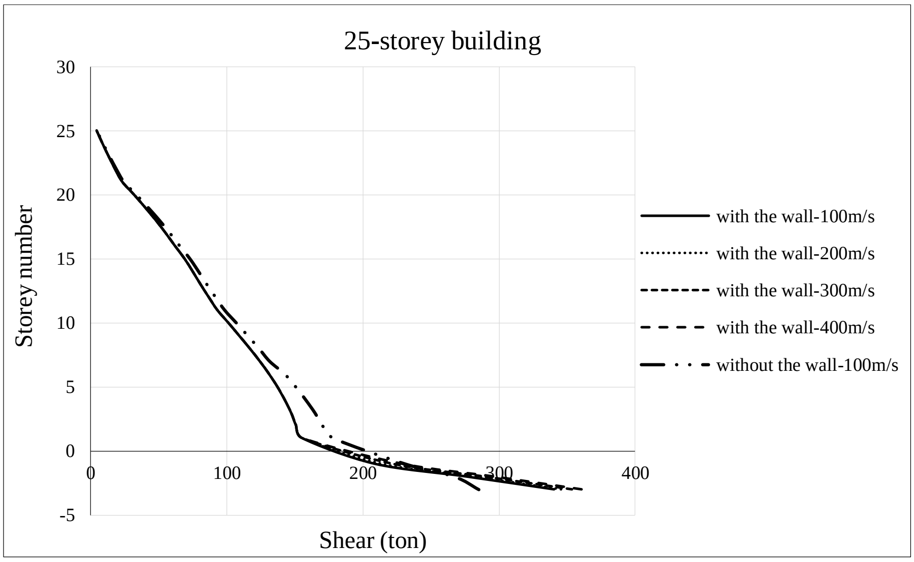

Figure 17. Diagram of shear changes of stories of the 25-storey structure

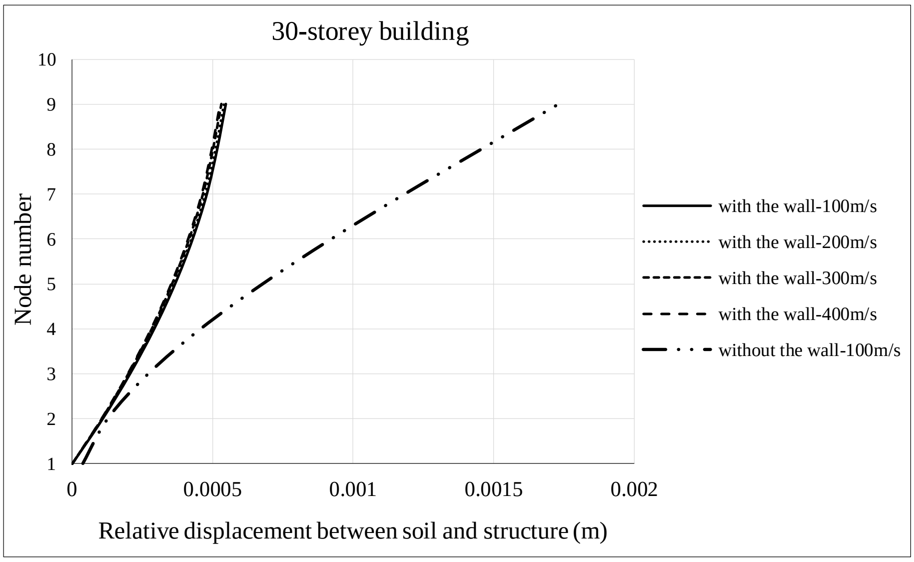

Figure 18. Diagram of the relative displacement between soil and buried section of the 30-storey structure

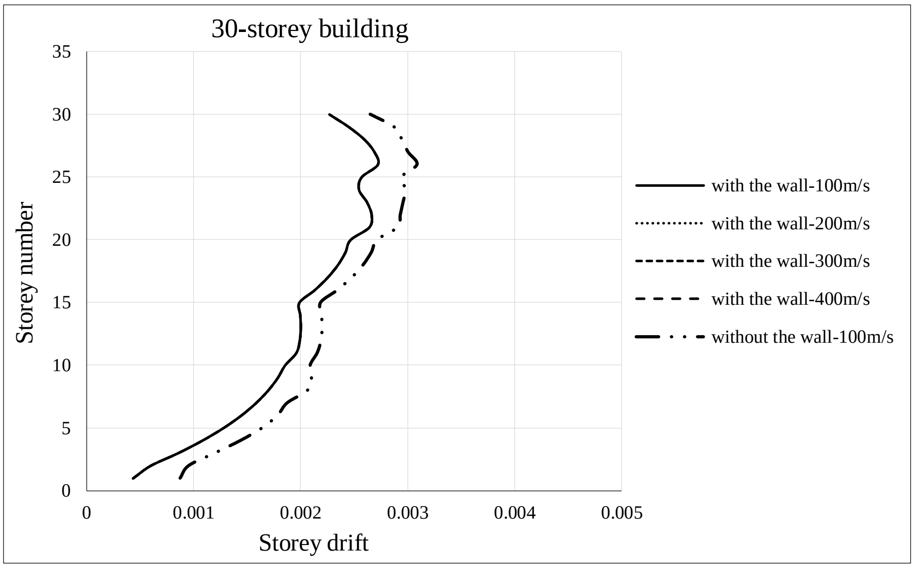

Figure 19. Diagram of the relative displacement of stories of the 30-storey structure

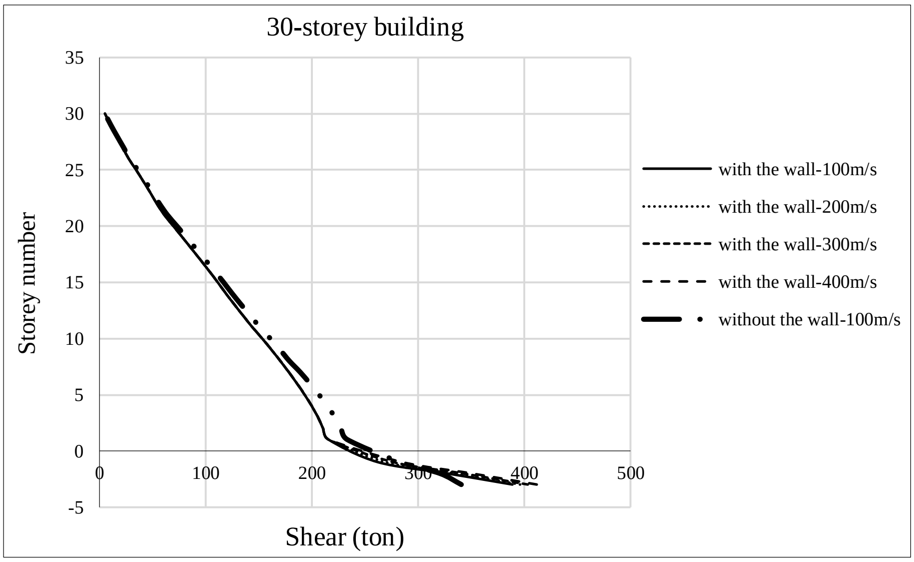

Figure 20. Diagram of shear changes of stories of the 30-storey structure

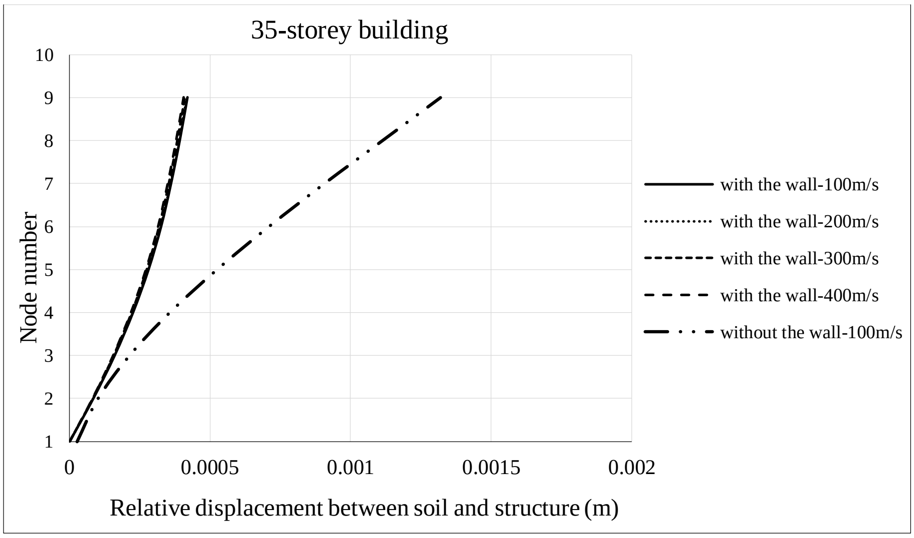

Figure 21. Diagram of the relative displacement between soil and buried section of the 35-storey structure

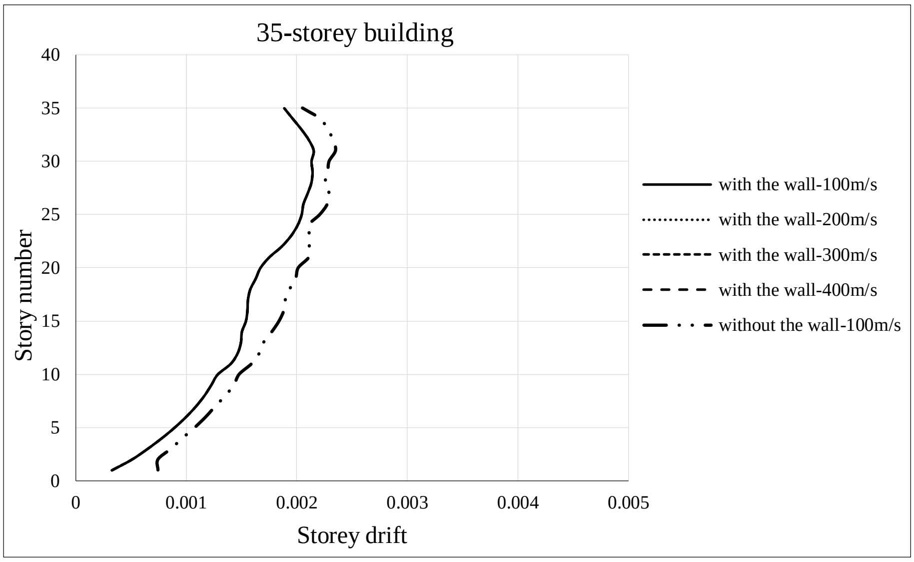

Figure 22. Diagram of the relative displacement of stories of the 35-storey structure

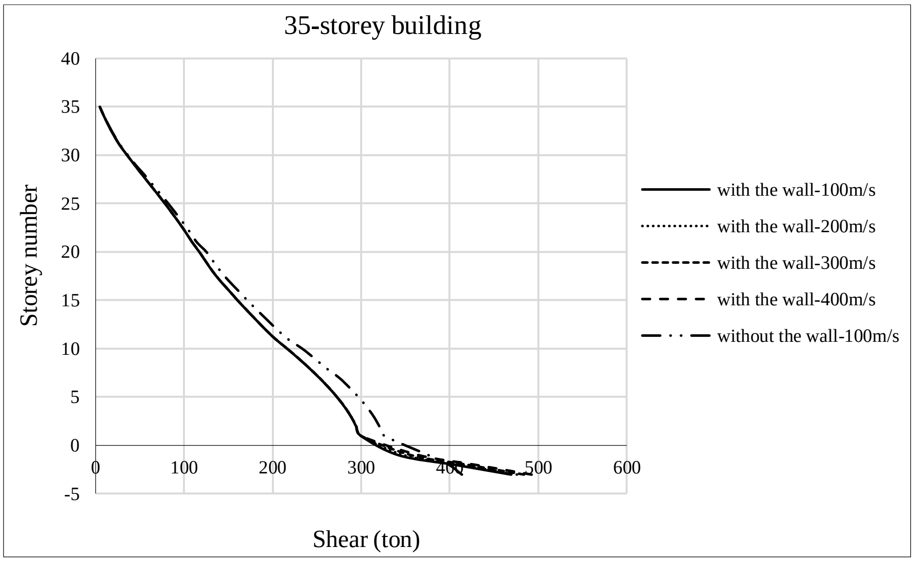

Figure 23. Diagram of shear changes of stories of the 35-storey structure

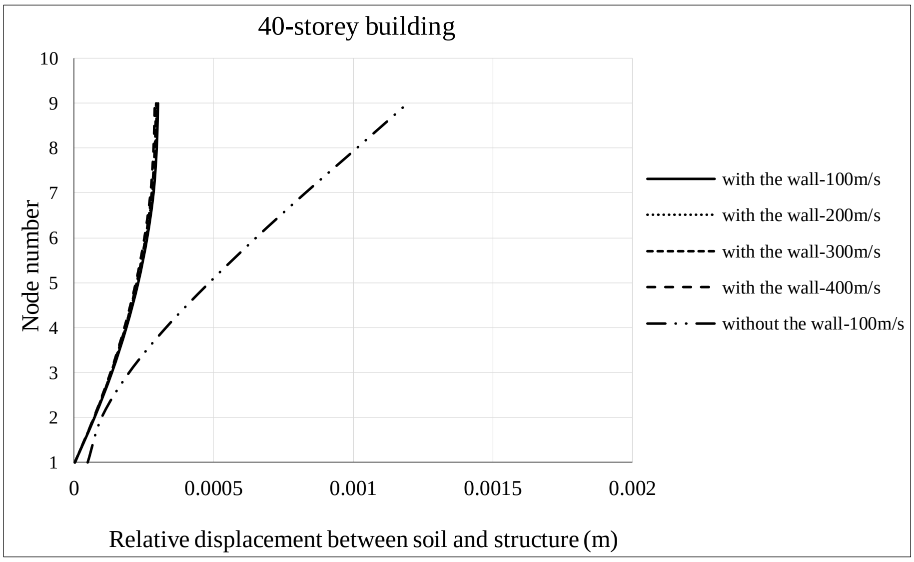

Figure 24. Diagram of the relative displacement between soil and buried section of the 40-storey structure

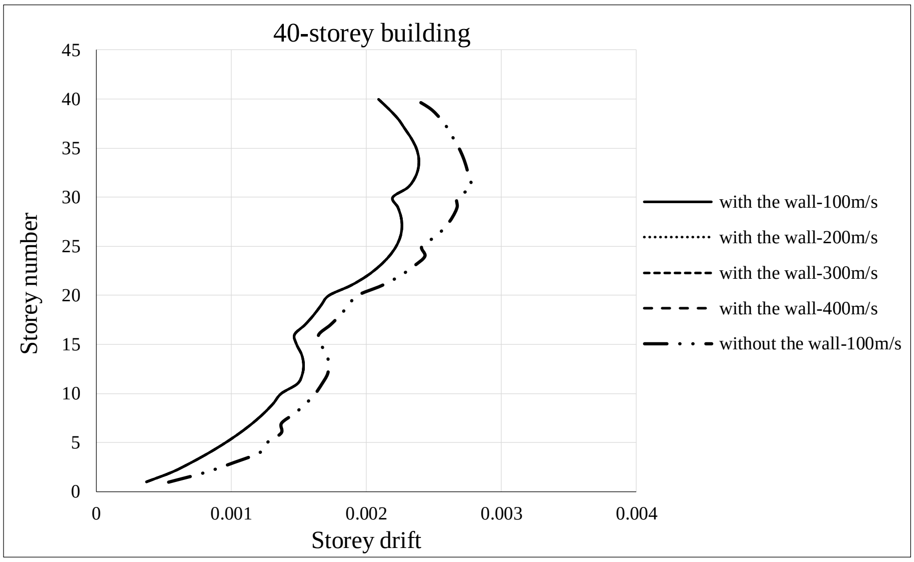

Figure 25. Diagram of the relative displacement of stories of the 40-storey structure

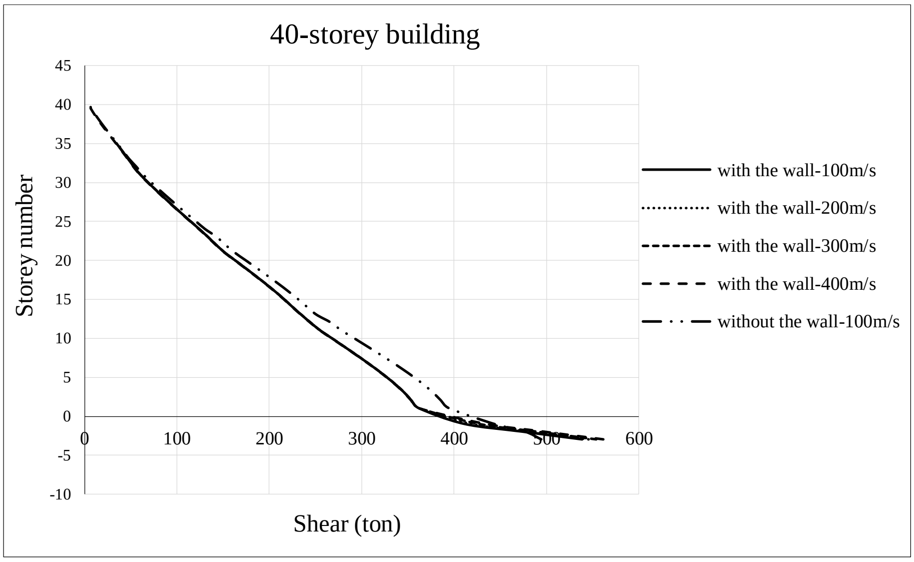

Figure 26. Diagram of shear changes of stories of the 40-storey structure

6. Conclusion

The effect of soil around the basement walls on the base level of braced framed tube system under near-field earthquakes was studied by duly considering the soil–structure interaction. The direct method was used to model the soil. Nonlinear elements and materials were used for modeling the soil and the elements of the structure.

The results showed that retaining walls can have the greatest impact on the location of the base level. It occurs when the retaining wall runs seamlessly with structures (beams and columns of the basement stories bury in retaining wall) and the retaining wall meets enough rigidity. In this case, the retaining wall also controls the weakening effects of soil and the base level is not displaced by weakening the soil. In fact, the analysis indicated that considering the level of upper stories, even without slamming the soil around the structure, is possible by the implementation of appropriate walls integrated with structure. If the retaining wall is not appropriate (firm and solid), the seismic mass corresponding to the underground surface level will enter the calculations. Added mass can cause an increase in storey shear and drift.

7. References

[1] Mirzaie, Fariborz, Mojtaba Mahsuli, and Mohammad Ali Ghannad. "Probabilistic analysis of soil ‐ structure interaction effects on the seismic performance of structures." Earthquake Engineering & Structural Dynamics 46, no. 4 (2017): 641-660. doi: 10.1002/eqe.2807.

[2] Bathurst, Richard J., and Sina Javankhoshdel. "Influence of model type, bias and input parameter variability on reliability analysis for simple limit states in soil–structure interaction problems." Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards 11, no. 1 (2017): 42-54. doi:10.1080/17499518.2016.1154160.

[3] Hokmabadi, Aslan S., and Behzad Fatahi. "Influence of foundation type on seismic performance of buildings considering soil–structure interaction." International Journal of Structural Stability and Dynamics 16, no. 08 (2016): 1550043. doi: 10.1061/9780784413425.034.

[4] Xiong, Wei, Li-Zhong Jiang, and Yao-Zhuang Li. "Influence of soil–structure interaction (structure-to-soil relative stiffness and mass ratio) on the fundamental period of buildings: experimental observation and analytical verification." Bulletin of Earthquake Engineering 14, no. 1 (2016): 139-160. doi:10.1007/s10518-015-9814-2.

[5] Javdanian, Hamed, Ali Heidari, and Reza Kamgar. "Energy-based estimation of soil liquefaction potential using GMDH algorithm." Iranian Journal of Science and Technology, Transactions of Civil Engineering 41, no. 3 (2017): 283-295. doi: 10.1007/s40996-017-0061-4.

[6] Lu, Yang, Iman Hajirasouliha, and Alec M. Marshall. "Performance-based seismic design of flexible-base multi-storey buildings considering soil–structure interaction." Engineering Structures 108 (2016): 90-103. doi: 10.1016/j.engstruct.2015.11.031.

[7] Hassani, Nemat, Majid Bararnia, and Gholamreza Ghodrati Amiri. "Effect of soil-structure interaction on inelastic displacement ratios of degrading structures." Soil Dynamics and Earthquake Engineering 104 (2018): 75-87. doi: 10.1016/j.soildyn.2017.10.004.

[8] Stefanaki, Aikaterini, and M. V. Sivaselvan. "A simple strategy for dynamic substructuring: I. Concept and development." Earthquake Engineering & Structural Dynamics (2018). doi: 10.1002/eqe.3039.

[9] Stefanaki, Aikaterini, M. V. Sivaselvan, Scot Weinreber, and Mark Pitman. "A simple strategy for dynamic substructuring: II. Experimental evaluation." Earthquake Engineering & Structural Dynamics 47, no. 9 (2018): 1823-1843. doi: 10.1002/eqe.3039.

[10] Karapetrou, S. T., S. D. Fotopoulou, and K. D. Pitilakis. "Seismic vulnerability assessment of high-rise non-ductile RC buildings considering soil–structure interaction effects." Soil Dynamics and Earthquake Engineering 73 (2015): 42-57. doi: 10.1016/j.soildyn.2015.02.016.

[11] Elias, Wassim Joseph, and Michel Farid Khouri. "Identifying the Fixed Base Location of Building Structures under Seismic Excitation." Int J Sci Res (IJSR) 3, no. 12 (2012): 2612-2618.

[12] Kelly, D. J. "Location of base for seismic design." Structure Magazine, December (2009).

[13] Tehranizadeh, Mohsen, and Mohammad Sadegh Barkhordari. "Effect of Peripheral Wall Openings in Basement and Number of Basement Floors on the Base level of Braced Framed Tube System." International Journal of Civil Engineering (2017): 1-17. doi: 10.1007/s40999-017-0270-z.

[14] Tehranizadeh, Mohsen, Mohammad Sadegh Barkhordari and Sepehr Moosavi,. "Base level Investigation in various buildings and corresponding effective factors". Journal of Structural and Construction Engineering (2017): 4(Special Issue 1), 5-16. doi: 10.22065/jsce.2017.87639.1213.

[15] Yang, Zhaohui, and Ahmed Elgamal. "Influence of permeability on liquefaction-induced shear deformation." Journal of Engineering Mechanics 128, no. 7 (2002): 720-729. doi:10.1061/(asce)0733-9399(2002)128:7(720).

[16] Yang, Zhaohui, Ahmed Elgamal, and Ender Parra. "Computational model for cyclic mobility and associated shear deformation." Journal of Geotechnical and Geoenvironmental Engineering 129, no. 12 (2003): 1119-1127. doi:10.1061/(asce)1090-0241(2003)129:12(1119).

[17] Yang, Zhaohui, Jinchi Lu, and Ahmed Elgamal. "OpenSees soil models and solid-fluid fully coupled elements." User's Manual. Ver 1 (2008). doi:

[18] Lysmer, John, and Roger L. Kuhlemeyer. "Finite dynamic model for infinite media." Journal of the Engineering Mechanics Division 95, no. 4 (1969): 859-878.

[19] Kausel, Eduardo. "Local transmitting boundaries." Journal of engineering mechanics 114, no. 6 (1988): 1011-1027. doi: 10.1061/(asce)0733-9399(1988)114:6(1011).

[20] Kausel, Eduardo, and John L. Tassoulas. "Transmitting boundaries: a closed-form comparison." Bulletin of the seismological society of America 71, no. 1 (1981): 143-159.

[21] Mazzoni, Silvia, Frank McKenna, Michael H. Scott, and Gregory L. Fenves. "OpenSees command language manual." Pacific Earthquake Engineering Research (PEER) Center 264 (2006).

[22] Taucer, Fabio, Enrico Spacone, and Filip C. Filippou. A fiber beam-column element for seismic response analysis of reinforced concrete structures. Vol. 91, no. 17. Berkekey, California: Earthquake Engineering Research Center, College of Engineering, University of California, 1991.

[23] Uriz, Patxi, Filip C. Filippou, and Stephen A. Mahin. "Model for cyclic inelastic buckling of steel braces." Journal of structural engineering 134, no. 4 (2008): 619-628. doi:10.1061/(asce)0733-9445(2008)134:4(619).

[24] Hosseinzadeh, N., M. Davoodi, and E. Rayat Roknabadi. "Comparison of soil-structure interaction effects between building code requirements and shake table study." Journal of Seismology and Earthquake Engineering 11, no. 1 (2009): 31-39.

[25] Davoodi, M., M. Sadjadi, P. Goljahani, and M. Kamalian. "Effects of near-field and far-field earthquakes on seismic response of sdof system considering soil structure interaction." In 15th World Conference on Earthquake Engineering. Lisbon, Portugal. 2012.

[26] Turan, Alper, Sean D. Hinchberger, and M. Hesham El Naggar. "Seismic soil–structure interaction in buildings on stiff clay with embedded basement stories." Canadian Geotechnical Journal 50, no. 8 (2013): 858-873. doi:10.1139/cgj-2011-0083.