Journal of Techniques, ISSN: 2708-8383, Vol. 6, No. 1, 2024, Pages 21-32
DOI: https://doi.org/10.51173/jt.v6i1.1654

JOURNAL OF TECHNIQUES

Journal homepage: *http://journal.mtu.edu.iq*

RESEARCH ARTICLE - ENGINEERING (MISCELLANEOUS)

Study of the Impact Irregular Concrete Facilities with the Shear Walls Based: The Effect of Soil-Structure Interaction with ABAQUS Software

Wisam Fawzi Aljuhaishi[1], Javad Esfandiari[1*]

[1]Department of Civil Engineering, Islamic Azad University, Kermanshah 083, Iran

[*] Corresponding author E-mail: j.esfandiari@iauksh.ac.ir

Article Info.

Article history:

Received
08 June 2023

Accepted
10 November 2023

Publishing
31 March 2024

Abstract

In the present study, the effect of the irregularity of concrete structures with special shear walls has been analyzed and modeled by considering the effect of soil-structure interaction using the dynamic analysis method with ABAQUS software. The results are presented in the form of diagrams with different soil interaction conditions, and the effect of the number of layers was investigated for different soils. The results showed that the bearing system of the flexural frame and the concrete shear wall under the lateral load of the earthquake has good strength and ductility, which is significant. This structural system should be used for cities with very high earthquake risk. As the number of floors increases, the effect of the shear walls on increasing the bearing capacity decreases. As the number of floors increases, the final displacement of the frame increases. The results showed that for soil type 1(hard soil which Vs=1000 m/s, v=0.15, q=50000 Kg/m^2, P=2000 Kg/m^3, r=0.5 m) structural system of concrete shear walls with better displacement, maximum structural stiffness, better behavior was observed in the structure. The three-story frame with a concrete shear wall has a significant increase in performance compared to similar frames with more floors, which shows the good performance of this system in structures with fewer floors.

Publisher: Middle Technical University

Keywords: Soil Structural Interaction; Dynamic Analysis; ABAQUS; Concrete Structures.

1. Introduction

In the design of structures, the assumption of a rigid connection of the structure to the ground is an important uncertainty. In fact, due to the properties of the soil and the effect of the site on the earthquake wave, the behavior of the structure will be different. An important and key issue in the behavior of the structure is the discussion of the interaction between structure and soil [1]. To increase the reliability and accuracy in the design of structures, the effects of the interaction between the soil and the structure should be considered [2]. To dynamically analyze a structure, an earthquake that is recorded in the free field of the soil (ie, when the structure is not constructed and the relevant excavations have not been done), enters the connection of the structure to the ground in a fixed state and dynamic analysis is performed. When the structure is built on hard soil, otherwise the response of the structure will be very different due to the phenomenon of soil interaction. The effect of soil-structure interactions SSI is important when large or hard structures such as nuclear reactors or dams are placed on relatively soft soil [3]. Due to the rigidity of the foundation relative to the soil and the inability of the soil to adapt to the movement of the free field, the foundation experiences an average of the free field movement of the soil, which is modified by this movement, called input stimulation. This effect is separate from the mass of the foundation and structure. In design regulations, the effect of interaction between structure and soil is usually ignored. Because in steel structures, the interaction effect is important and effective, there is a need to study the parametric performance of the structure in the inelastic domain by considering the interaction [4]. In the structures design, the effects of dynamic soil interaction of the structure are usually ignored. The nonlinear behavior of the soil changes the seismic response of the structure, and the presence of the structure affects the movement of the soil. Due to weight and inertia, the structure is forced by the soil and will alter its shape. The subject of studying the behavior of concrete shear walls is of great importance due to the widespread use of this load-bearing system. The use of concrete shear wall has been widely used in recent decades and experimental and numerical studies have shown that concrete shear wall is an effective and economical system to withstand lateral loads of wind and earthquake [5].

A thorough and accurate assessment of the systems necessitates taking the interaction between the soil and the structure into account (SSI). By analysing and contrasting the computerized representations of a 5-story frame construction built on the addition’s method (soil-inclusion-platform-structure) versus the piling framework, mid-rise constructions' responses are explored. Installation on solid ground, an anchorage, and drifting piling (soil-pile-structure) are examples of these heap toe circumstances. Flac 3D was used to create fully connected finite difference numerical models. Analysing buildings of various heights took the influence of the structure's dynamic features into consideration (3 storeys to 7 storeys) [6].

Nomenclature & Symbols			
SSI	Soil Structure Interaction	WR	Weathered Rock
SDOF	Single-Degree-Of-Freedom	IDA	Incremental-Dynamic-Analysis
AS	Alluvial Gravel	RC	Reinforcement Concrete
FE	Finite Element	MDOF	Multi Degrees of Freedom
WS	Weathered Gravel	SASSI	Evaluation of Soil-Structure Communication
DRM	Development Response Band	BNWF	Behavioral Winkler Basis framework
1D	Identification Card	V	Velocity
V̀	Factor	q	Uniform Load
P	Steel in m^3	r	Radius Of Area
E0	The Modulus of Elasticity	σ	Strain
G	The Drager-Prager Flow Potential Function	LPF	Load Per Structure Factor

The investigation of the structural interaction between soil and building (SSI) is performed on low-rise buildings and piloti-type constructions while accounting for Korean topographical features, and the impact is then determined theoretically. To achieve this, a five-story piloti-type development with four distinct soil properties—fill (FI), alluvial gravel (AS), weathered gravel (WS), and weathered rock—is constructed into multidimensional structural evaluation prototypes in addition to earthquake SSI evaluation employing the measurements from the Gyeongju Province seismic event and development response band (DRM) according to construction standards of weathered rock (WR). According to the analysis's findings, regardless of the type of earthquake, the seismic SSI has a significant impact on the weathered soil (WS), and its effects vary depending on the type of soil. Simple and logical estimations are suggested through parameter research to consider the impact of SSI on foundation shear in low-rise as opposed to piloti-style structures [7]. The base and surrounding soil are modelled analytically simply, and an improved finite element (FE) model of Shanghai Tower's superstructure is established. The subsequent collapse process and mechanism of the Shanghai Tower are forecasted while also accounting for the SSI. On failure sequences and collapse resistance capacity, the effects of the SSI are discussed. The findings show that the fundamental period of the Shanghai Tower has been greatly prolonged when SSI is considered, and the collapse margin ratio has improved with a commensurate drop in seismic demand. Additionally, the SSI has a small but significant influence on the failure modes of the Shanghai Tower after being subjected to strong earthquakes [8]. The effect of soil elasticity on the shaking behavior of open ground-story constructions. To examine popular open ground story construction concepts while considering soil's inherent adaptability, static nonlinear simulation (also known as pushover evaluation) was used in conjunction with SAP2000 technology. Variations in boundary circumstances are considered by simulating using three distinct soil types—hard, substrate, and soft—as stated in IS 1893 (Part 1) 2016. The present study shows that the lateral movement and additional pulling forces of the P-Delta influence increase due to the soil's elasticity [9]. The keys components of the risk assessment include the information of fragility details (which explain conditional on the intensity of input ground motion, the probability of exceeding a given collapse state or damage) for each building type that has been included in the exposure model and identified within the region. At least a structural drawing was utilized to evolve the Multi Degrees of Freedom MDOF numerical model of the structural system that involved also one real representative building and the predominant non-structural elements (like external facade walls and partition) from the regions were deemed for each building type (the so-called index building). However, running non-linear dynamic analysis of many such numerical models was found to be too large a computational effort when each was subjected to hundreds or tens of records, to permit fragility rules to be directly improved from this analysis. To mathematically establish the vulnerability criteria for every construction typology's mechanical framework, a studied dynamic relationship between soil and structure (SSI) was employed, which streamlines the single-degree-of-freedom (SDOF) comparable theory of systems [10]. Financial losses due to non-structural and structural deterioration; the finding shows that structure (with shallow foundation) on very soft soil is carried on experiencing decreased loss due to soil-structure interaction, while the existence of moderately soft soils fulfils increases the seismic losses because the considerable probability that soil- structure interaction and has detrimental effects. It confirms the well-known fact that, contingent upon soil properties and building components, SSI might have no effect or worsen how vulnerable buildings are to earthquakes. By employing a finite element model of the soil-block (i.e., the straightforward approach), incremental-dynamic-analysis (IDA) has been investigated for recovering vulnerability curves of strengthened concrete (RC) constructions and modelling soil-structure communication. It was discovered that considering of interaction between soil and structure performance when compared to the fixed-base case could significantly impact the projected effectiveness of constructions established on porous soils, generating a significant change in time [11]. According to [12], who additionally pointed out the important function of the connection between soil and structure due to unpredictable or linear soil behaviour in modifying and influencing the fragility curves of fixed-base concrete-reinforced structures, the fixed-base framework theories may produce unreliable results. However, the elimination of the structural distortion requirements comes at the expense of increased overall changes due to the interaction between soil and structure in aggregate. The study examined the effect of the (linear) soil-structure interaction's wavelength requirement on the brittleness of concrete-reinforced bridges. It was discovered that the actual weakness curves of a structure can be additionally exaggerated and overlooked by the frequency-independent theory, reduced, and that the former may result in a bridge behaviour that considerably diverges from the actual one. The comparison was made between the anticipated susceptibility of an example bridge and the grouped variables manufactured by the same researchers using both a typical, frequency-independent, Kelvin-Voigt approach [13]. Offered a fascinating investigation into the emphasizing of soil irregularities in the interaction between soil and structure with application to nuclear structure risk estimation. Findings of LS-DYNA's irregular temporal-domain soil-structure assessment of interaction for prolonged shaking have been contrasted with those from frequency-domain programs via equivalent-linear assessment, called Although it for Evaluation of Soil-Structure Communication (SASSI), and it was found that the unpredictable reactions and the equivalent-linear patterns are significantly various: It was determined that overestimating the danger of earthquakes and superstructure reaction may result from accounting for seeing while disregarding the unpredictability of elevation and slippage [14]. The importance of a behavioural method was emphasized by [15], who used the aggregated particular flexible springtime, and the beam based on the Behavioural Winkler Basis (BNWF) framework to derive vulnerability curves for a collection of concrete that has been strengthened event resistive structures. Another example of the effect of (nonlinear) Soil-Structure Collaboration on the seismic susceptibility of frame structures made of reinforced concrete was offered by [16] utilizing the beam approach on the Dynamic Winkler Basis framework. Although these models can be very comprehensive, they could exaggerate shear-induced deflections in the soil underneath foundations with shallow depths and they are limited to capturing the displacements as an outcome of the combined impact of compressive strains. However, the relationship between soils leads to liquefaction-induced dislocation processes. Recent research specifically showed that bending under shear is a result of sediment-structure interaction, which results in effects such as load-bearing mistakes, ratcheting, and soil deflections caused by incomplete discharge [17].

Furthermore, it was investigated that due to a skewed evaluation of soil volumetric flexibility, limited 1D site reaction evaluation is employed to represent free-field soil behavior and often overstates settling. Computer modelling in two dimensions (2D) is frequently useful since it simplifies the issue by using straightforward strain parameters. Nevertheless, these assumptions and the resulting construction foundations can underestimate the concept of excess pressure within pores. When soil reactions are analyzed using 2-D simulations, but distortions cannot be fully analyzed, for instance, the framework is carried out as a framework (by maintaining its vestibular features) [18]. The models with two dimensions are often capable of providing cautious estimates of the damaging impact of destabilization on the soil and building components. Consider a study that compared the accuracy of multiple hypotheses regarding the nature of the soil's responses (such as vertical acceleration and settlement time evolution) [19]. For instance, comprehensive two-dimensional simulations using computation point to the necessity for more study along with an evaluation of three-dimensional numerical modeling of shifting impacts, and it is assumed that the simulated construction foundations cause the soil to liquefy [20]. The objectives of this article are modeling and studying structures with concrete shear walls considering the effectiveness of Soil Structure Interaction (SSI) by dynamic analysis method, investigating the behavior of concrete structures by considering the interaction of soil and structures, investigating the effect of interaction on the response of structures with concrete shear walls under earthquake, and investigating the irregularity effect of structures with concrete shear walls by considering the effectiveness of SSI. The organization of this manuscript is as follows. Section 2 deals with the analysis of an Abaqus program. In section 3 we illustrate the analysis and results have been presented. Section 4 describes the conclusions.

2. ABAQUS Program

2.1. Soils analysed

One of the objectives of the present investigation is to investigate the impact of the soil's composition on the behavior of concrete structures with special shear walls. For this purpose, type 1, 2, 3, and 4 soils (where Vs=velocity, v=factor, q=uniform load, P=steel in m3, r=radius of area) have been used as shown in Table 1, which represent hard, medium, soft, and silty, respectively. The mentioned soils are 3 types of soils out of 4 types of soils in Regulation 2800 [21].

Table 1. Characteristics of analysed soils

Soil type	Vs (m/s)	ν	q (kg/m^2)	P(kg/m^3)	r(m)	Soil
1	1000	0.15	50000	2000	0.5	Hard
2	600	0.2	40000	1800	1.0	Medium
3	300	0.3	25000	1600	1.5	Soft
4	150	0.5	15000	1400	2.0	Silty

2.2. Specifications of accelerometers

In the present study, nonlinear time history analysis has been used for modeling. Modeling the nonlinear behavior of materials and the fact that in strongest earthquakes the structure enters the nonlinear phase, has led to the use of the term nonlinear time history analysis in this study. Accelerometers are used to determine the effect of ground motion. They should, as far as possible, reflect the actual motion of the ground in the construction area. In this research, 7 earthquake records extracted from the Pir information site have been downloaded.

2.3. Modelling method

In modern methods of modeling and structural analysis, the use of advanced computer programs has greatly developed due to their high accuracy and appropriate analysis time. Analysis of structures based on the number of loads on the structure in different dead and live loads, and especially earthquake loads provides important information to designers. Various methods for structural analysis have been introduced and proposed in the regulations, and one of the most accurate methods of structural analysis is dynamic analysis of time history. In this method, the analyses of the structural response to the earthquake are solved by applying the acceleration of the actual earthquake. In this chapter, the time history for the dynamic analysis on a concrete structure with a special double shear system has been performed by considering the soil interaction of the structure**.**

2.4. Pattern of nonlinear behaviour of concrete in modelling

These parameters describe the level of traction and pressure damage, respectively. Damage parameters can range from zero (undamaged materials) to one as shown in Fig. 1 (loss of total strength of materials). The modulus of elasticity E0 expresses the initial elastic stiffness (undamaged) of the material and the stress-strain relationship for uniaxial tensile and compressive loads as shown in Fig. 2, which are expressed in Equations (1) and (2).

$$\sigma_t = (1 - d_t)\, E_0(\varepsilon_t - \varepsilon_t{}^{pl}) \quad (1)$$

$$\sigma_t = (1 - d_c)\, E_0(\varepsilon_c - \varepsilon_c{}^{pl}) \quad (2)$$

The plastic damaged concrete model used in Abacus software is the Drager-Prager model, which is used to model the determination of concrete plastic behavior, including yield levels and plastic flow. The Drager-Prager flow potential function is by Equation (3).

$$G = \sqrt{(\mathrm{f}_c - \mathrm{m.f}_t.\tan\beta)^2 + \mathrm{q}^{-2}} - \mathrm{p}^{-}.\tan\beta \quad (3)$$

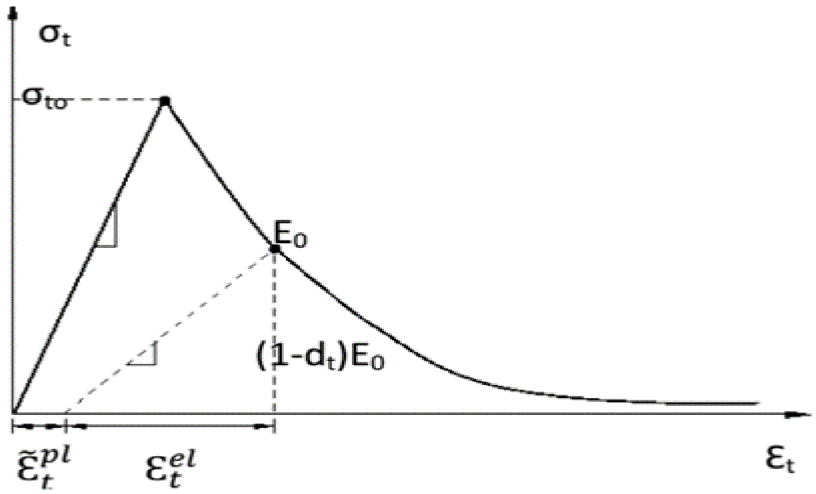

Fig. 1. Behavior of concrete in uniaxial loading in tension

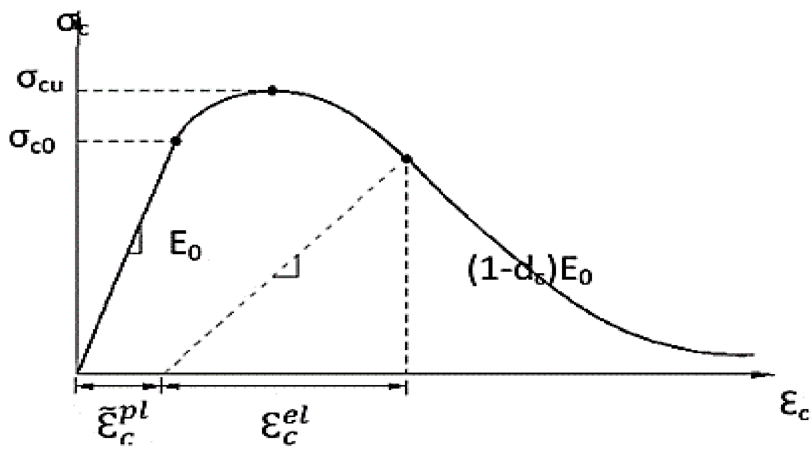

Fig. 2. Behavior of concrete in uniaxial loading under pressure

2.5. Modelling in Abacus

Rod elements are used for rebar and volumetric elements are used for modeling concrete and soil. The interaction between rebar and concrete or the definition of embedded region is done. The interaction between soil and concrete is the contact behavior. In the interaction behavior between soil and concrete, tangential behavior with a coefficient of friction of 0.4 between soil and concrete is used. The interaction is of surface-to-surface contact type. The meshing is done in such a way that it is small meshes under the structure and coarse meshes in the far parts of the structure as shown in Fig. 3. The nonlinear behavior of the rebar was modeled by modeling the behavior of steel with a mass of 7850 kg/m³, a Poisson's ratio of 0.3, a Young's modulus of 210 GPa, and a nonlinear yield strain of 0.09 for a stress of 370 MPa. Concrete behavior was performed with the concrete damage plasticity model. Soil behavior was modeled by Mohr-Coulomb plasticity. The dimensions of the soil environment are 30 × 200 × 200 meters. The type of loading is entered as a lateral load of the model as shown in Fig. 4.

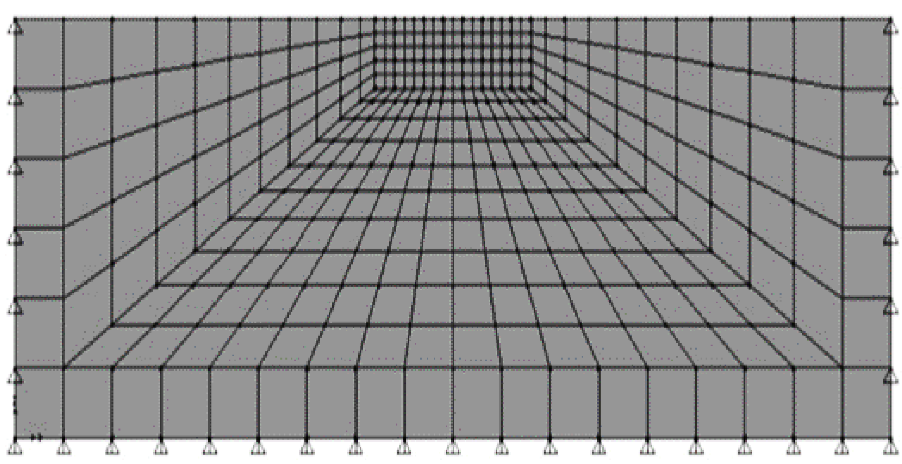

Fig. 3. Soil meshing model

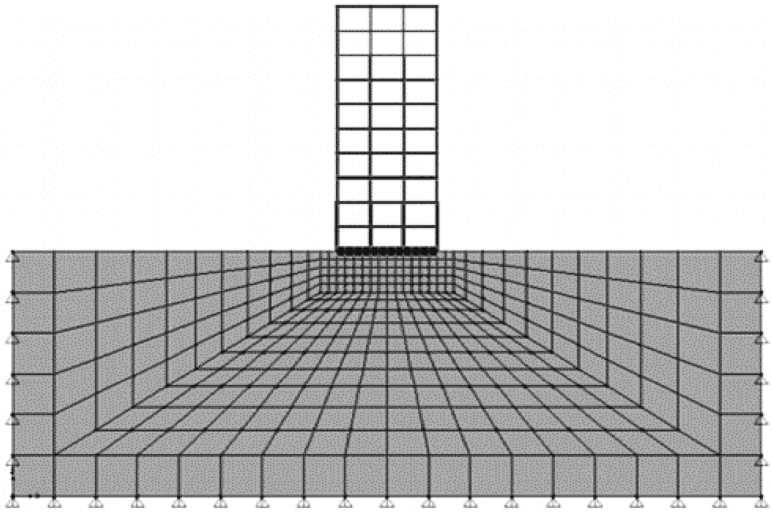

Fig. 4. Structural soil interaction model

3. Analysis and Results

The results of the numerical analysis of the irregular effect of concrete structures with special shear walls are evaluated by considering the effect of soil-structure interaction through dynamic analysis. Different soils of the structure with different numbers of different layers have been used. In the third chapter, the methodology for performing the analysis was thoroughly described. Analysis was performed on different modes of analysis. The outputs are examined and analyzed in the form of diagrams.

3.1. The effect of different soil materials on 3-story concrete structures

The displacement load diagrams of a 3-story concrete structure for 4 different soil types are presented (see Fig. 5). In the displacement load diagram, the vertical axis represents the ratio of the load borne by the frame to the code-specified load, allowing for a proper comparison of the bearing capacity of the frame for different soils. In the horizontal axis, the relocation of the roof is also given**.** As can be seen from Fig. 5, by changing the type of soil for 3-story structures, the rate of increase of the load-bearing ratio to the load of the regulation is reduced. Concrete structures with 3-story structures, for type 1, type 2, type 3, and type 4 soils, have load bearing ratios of 4.78, 2.24, 1.66, and 1.12, respectively, which show varying bearing capacities.

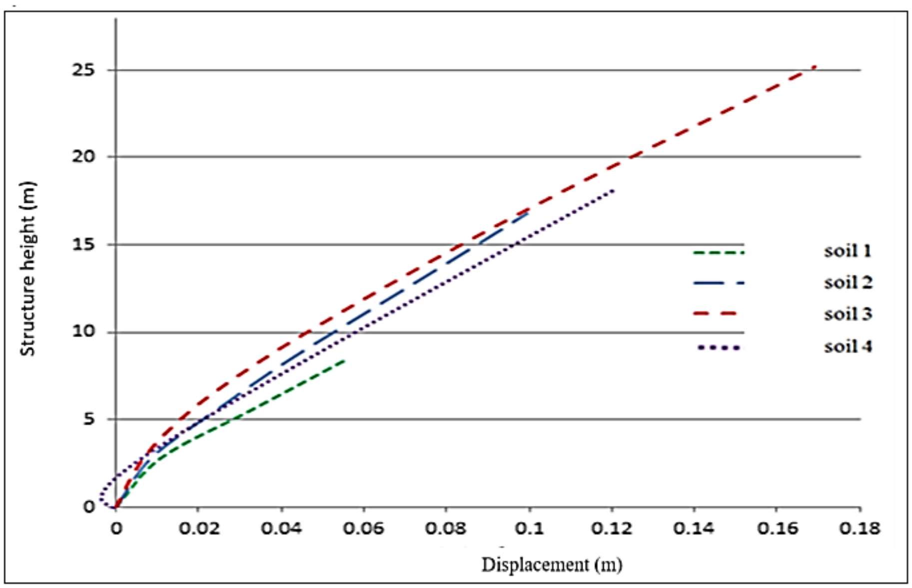

Fig. 5. Diagram of the effect of soil type on the displacement of a 3-story structure by comparison with other floors

The standard provides a final capacity of 2800. To determine the absorbed energy and ductility of the frame, the last load capacity value was limited to 0.8 of the final loads, and the diagrams were redrawn. Using the surface below the displacement load diagram, the absorbed energy of the system was determined. Table 2 shows the amount of energy absorbed, the final displacement, and the ratio of bearing capacity to the standard base shear. It should be noted that the final displacement corresponds to the point in the diagram where the structure has lost 20% of its bearing capacity.

Table 2. The values of absorbed energy, final displacement and frame strength for different soils

Final displacement (mm)	LPF	Absorbed energy frame (N-m)	Model
0.085	4.87	13963	Soil type 1
0.23	2.24	30096	Soil type 2
0.35	1.66	34530	Soil type 3
0.39	1.12	36212	Soil type 4

Figs. 6, 7, and 8 of Load Per Structure Factor (LPF) diagrams show the final displacement and energy absorbed against the number of layers for type 1 soil.

Figs. 7-17 show the ratio of bearing capacity to displacement of the roof of a 3-story structure, 6-story structure, and 9-story structure, respectively. It can be seen from the figure that the 9-story structure with a concrete shear wall and soil type 1 has a significant increase compared to structures with 3-story and 6-story structures.

By changing the type of soil, the effect of concrete shear walls in increasing the bearing capacity decreases. Additionally, by increasing the number of floors, the final displacement of the frame increases. This increase is linear. Furthermore, in frames with a high number of floors, the energy wasted in the structural system increases. Figure 9 shows the displacement changes in the height of the structure at maximum load.

3.2. The effect of different soil materials on 6-story concrete structures

Fig. 10 shows the graph of the ratio of load capacity to roof displacement. The increase in LPF (Load Per Structure Factor) for type 1 and 3 soils is 112% and 149%, respectively.

Table 3 shows the amount of energy absorbed and the final displacement of the concrete structure.

The hardness of the 6-story concrete structure for type 1 soil is clearly shown in Figs. 11 and 12.

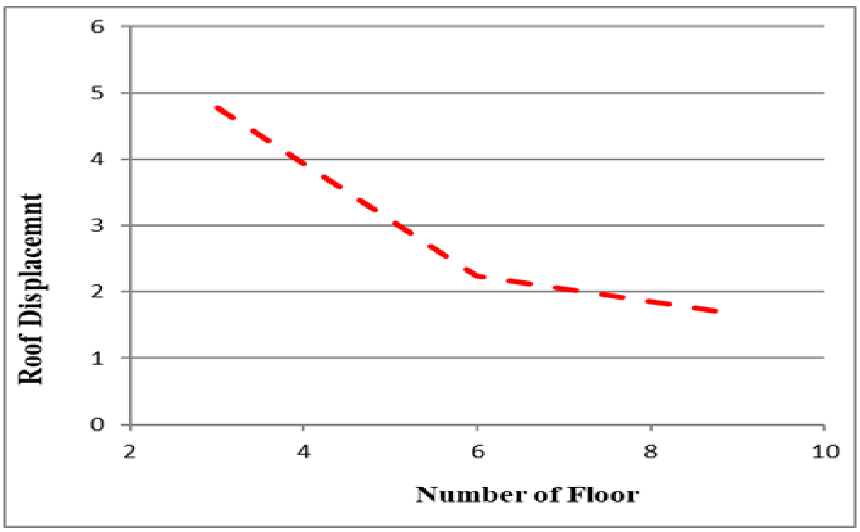

Fig. 6. Diagram of ground type's impact upon the displacement of the roof of a 3-story structure by comparison with other floors

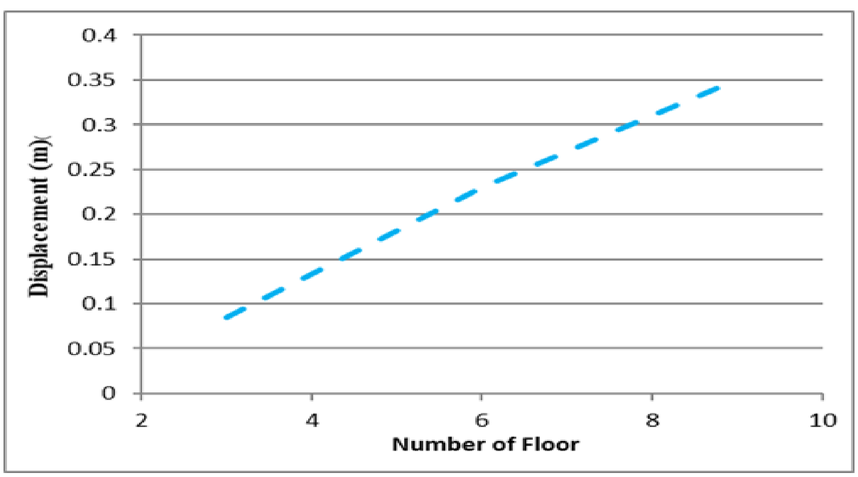

Fig. 7. Diagram of the effect of soil type on the final displacement of a 3-story structure by comparison with other floors

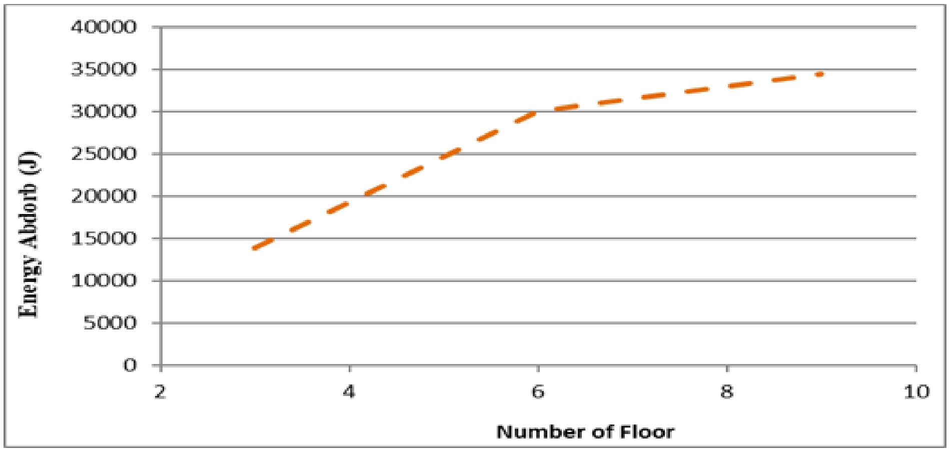

Fig. 8. Diagram of the ground type's impact on the absorbed energy of a 3-story structure compared to other classes

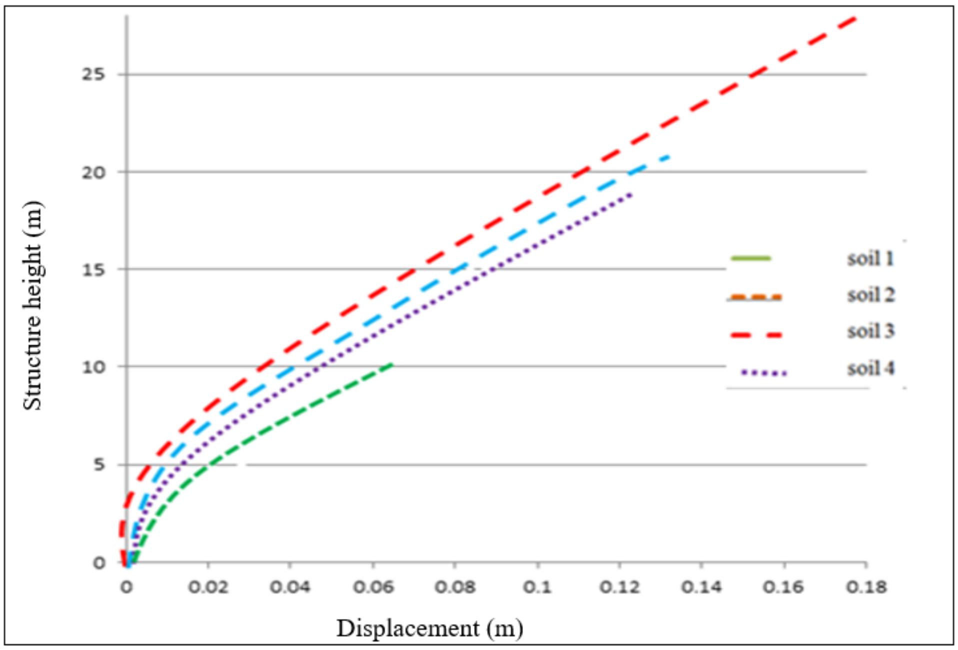

Fig. 9. Graph of displacement changes in the height of the structure for different soils

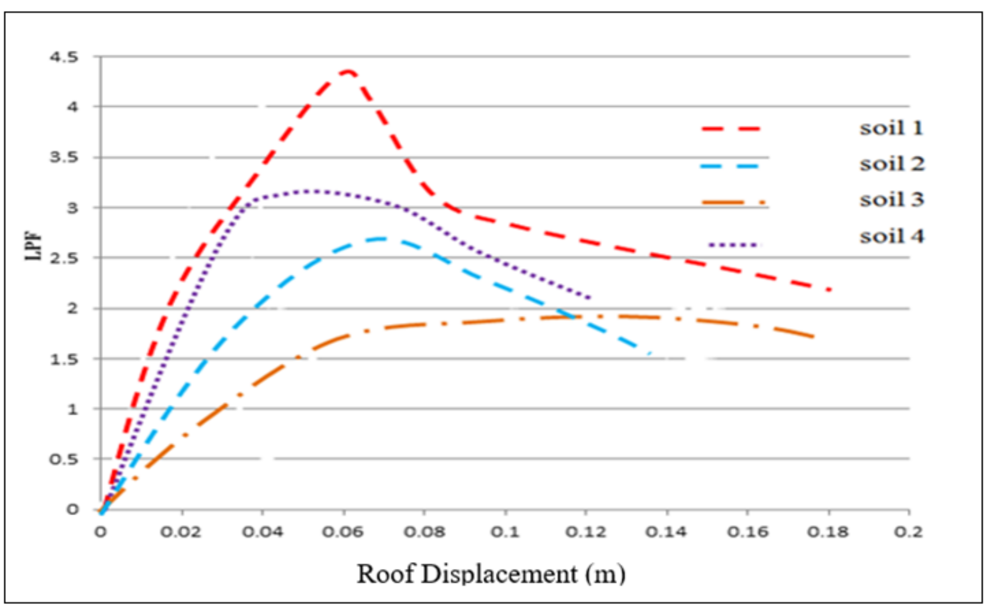

Fig. 10. LPF diagram against the displacement of the roof of a 12-story structure compared to other floors

Table 3. Values of absorbed energy, final displacement and frame LPF

model	Absorbed energy frame (N-m)	final displacement (mm)	LPF
9573	0.071	3.24	Soil type 1
18987	0.19	1.49	Soil type 2
33775	0.35	1.31	Soil type 3
36250	0.42	1.14	Soil type 4

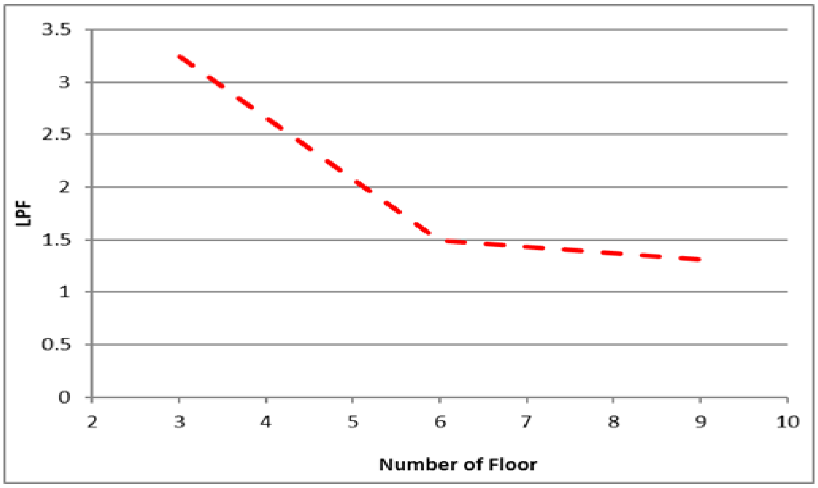

Fig. 11. Diagram of the impact of the number of floors on the LPF of a 6-story structure for 4 different soil types

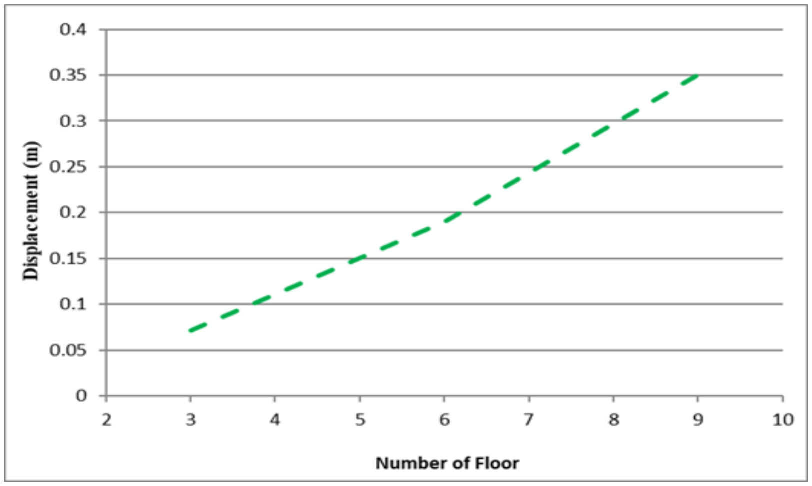

Fig. 12. Diagram of ground type's impact upon the final displacement of a 6-story structure by comparison with other floors

According to Figs. 13 and 14, it can be said that with increasing the number of floors, similar results were observed with the concrete structure for type 1 soil.

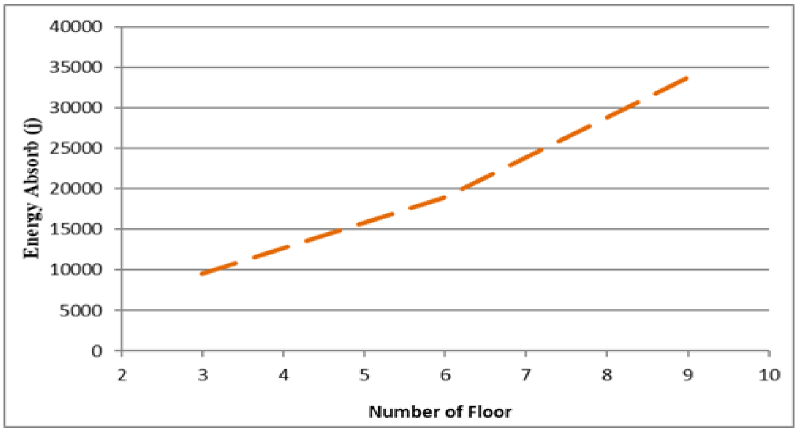

Fig. 13. Diagram of ground type's impact upon the absorbed energy of a 6-story structure by comparison with other classes

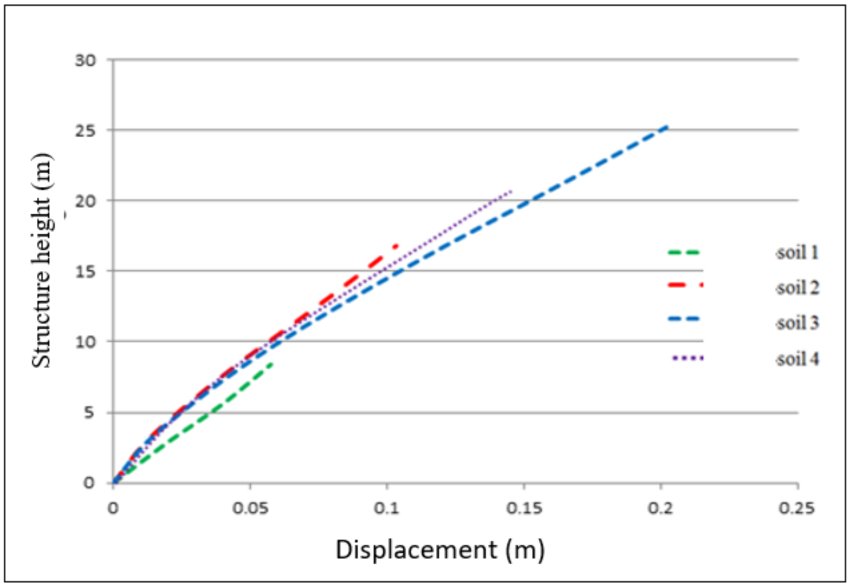

Fig. 14. Diagram of the effect of soil type on the displacement of a 6-story structure by comparison with other floors

3.3. The effect of different soil materials on 9-story concrete structures

Fig. 15 In this section, the effect of different soil types on 9-story concrete structures is investigated.

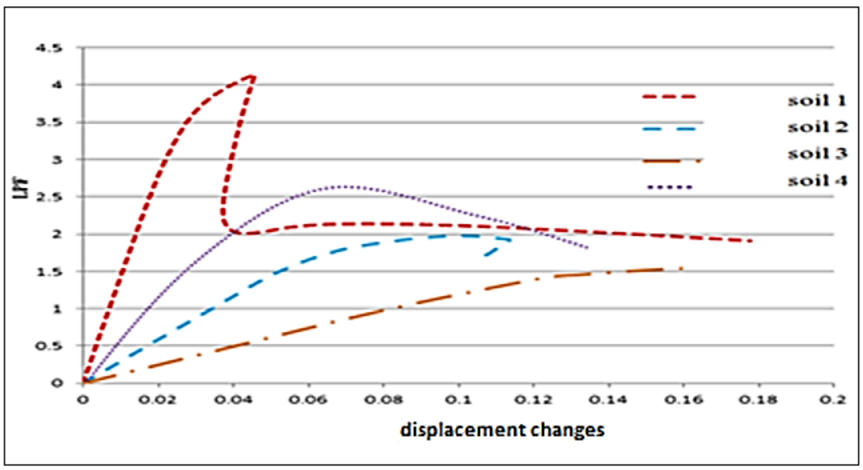

Fig. 15. LPF diagram against roof displacement for a 9-story structure

Fig. 16 shows the ratio of bearing capacity to displacement of the roof of a 9-story structure. It can be seen from the Figure that the 9-story structure with concrete shear wall and soil type 1 has a significant increase compared to structures with different soils. Similar to the number of other soils, this increase is 101% and 170% for type 2 and 3 soils, respectively.

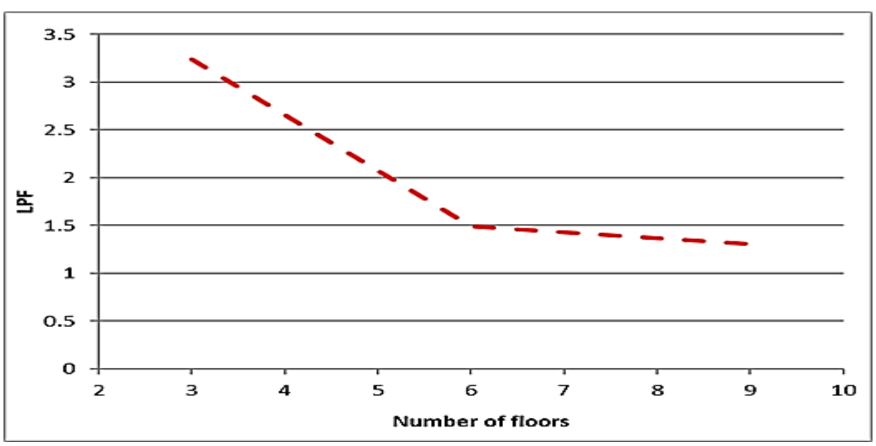

Fig. 16. Diagram of ground type's impact upon the final displacement of a 9-story structure by comparison with other floors

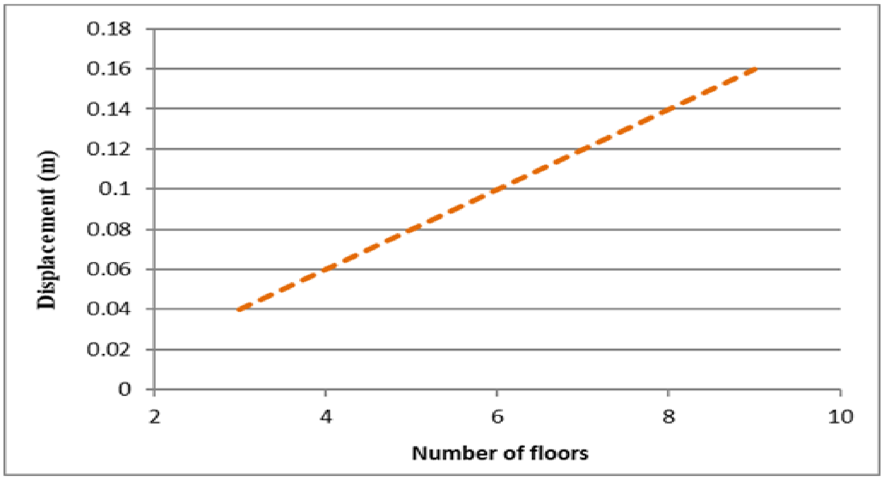

Fig. 17. Diagram of ground type's impact upon the final displacement of a 9-story structure by comparison with other floors

According to Fig. 18, it can be said that by changing the type of soil, the bearing capacity ratio decreases and the final displacement of the concrete structure is increased. The absorbed energy is also increased but this increase is less than other structures.

The diagram of displacement changes corresponding to the maximum force against the floor height is shown in Fig. 19.

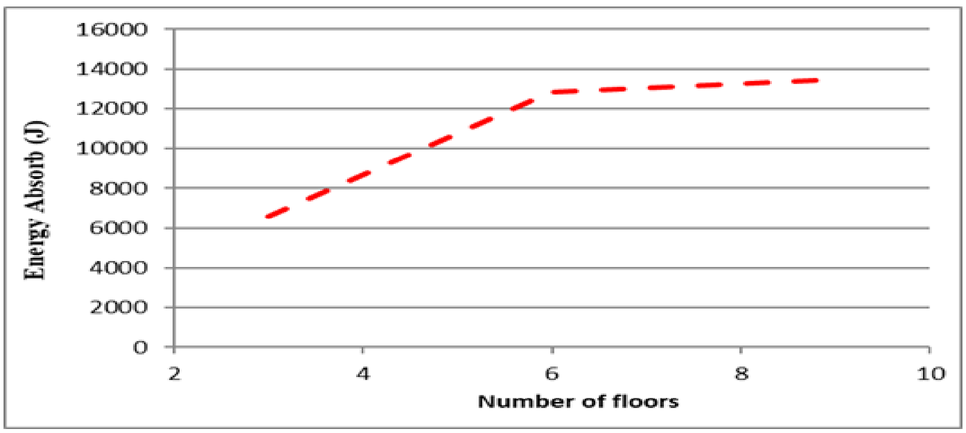

Fig. 18. Diagram of ground type's impact upon the absorbed energy of a 9-story structure by comparison with other classes

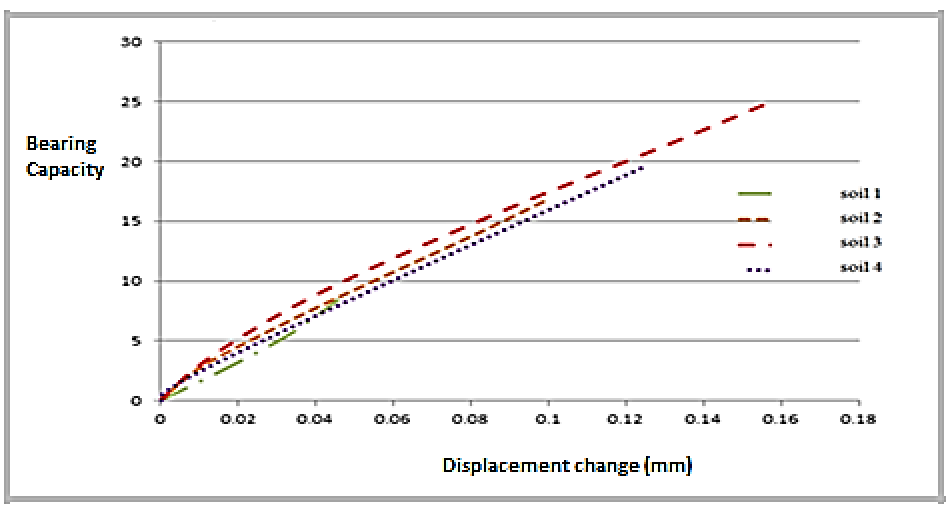

Fig. 19. Graph of displacement changes in the height of a 9-story structure for different soils

3.4. The effect of different soil materials on 12-story concrete structures

In this section, the effect of different soil materials on the structure of a 12-story shear wall is investigated (Fig. 20). Fig. 21 shows the ground type's impact upon the final displacement of a 12-story structure by comparison with other floors.

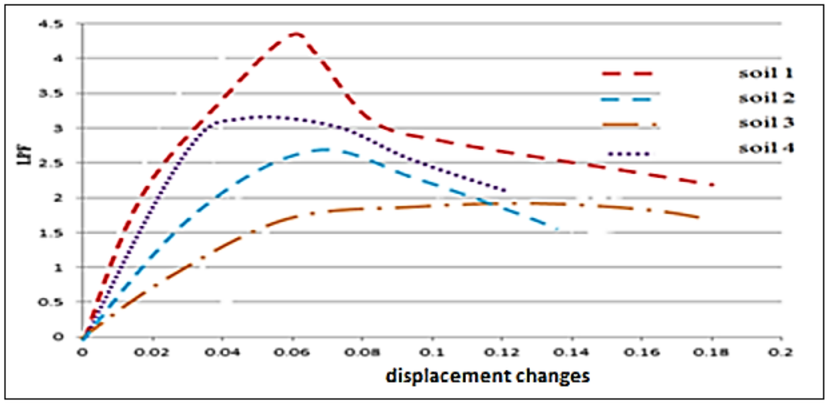

Fig. 20. LPF diagram against the displacement of the roof of a 12-story structure compared to other floors

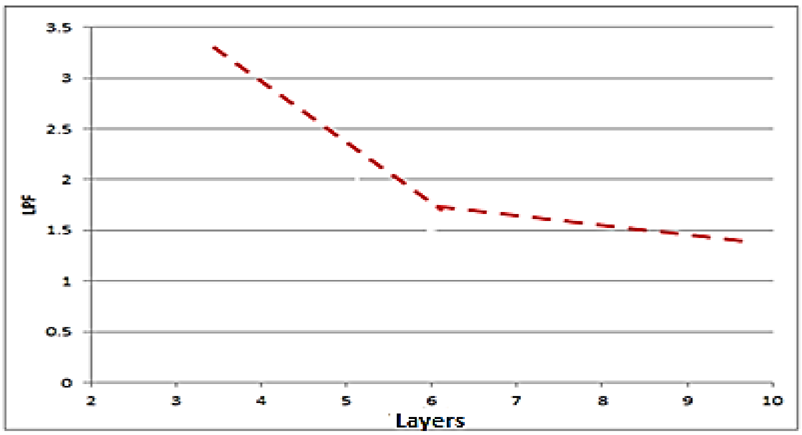

Fig. 21. Diagram of ground type's impact upon the final displacement of a 12-story structure by comparison with other floors

Fig. 22 describe the change in the soil type, it directly affects the bearing capacity ratio, final displacement, and the energy absorbed by the concrete structure.

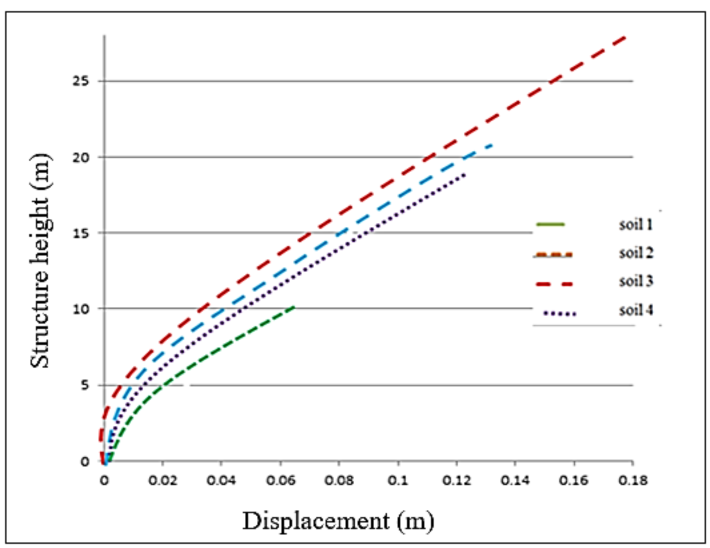

Fig. 22. Graph of changes in displacement with height for the structure across different soil types

4. Conclusion

In the present article, the effect of irregularity of concrete structures with shear walls was evaluated according to the effect of soil-structure interaction for four types of soil according to the regulations. Analysis and modeling were performed with Abacus software. Analysis was performed for different structures at height. Graphs of bearing capacity ratio, displacement and absorbed energy for 3, 6, and 9 storey structures for concrete structures were investigated. The results were obtained are bending frame concrete shear and bearing system wall under earthquake lateral load have good ductility and strength, which makes this structural system to be used for cities with high earthquake risk. The interaction of structural soil with changing soil type affects the behavior of the structure. By increasing the number of floors, the impact of the shear walls on increasing the bearing capacity decreases. As the number of floors increases, the final displacement of the frame increases. In frames with a high number of floors, the energy lost in the structural system increases. Three-story frame with concrete shear wall has a significant increase compared to similar frames with more floors, which shows the good performance of this system in structures with fewer floors. For soil type 1 (hard soil) structural system of concrete shear wall with displacement, better maximum structural stiffness, better behavior was observed in the structure.

Acknowledgement

This work is partially supported by Department of Civil Engineering, Islamic Azad University, Kermanshah 083, Iran. Thanks to the Ministry of Higher Education & Scientific Research, IRAQ and to the Middle Technical University, IRAQ.

References

[1] Sameti, A.R.; Ghannad, M.A. Equivalent Linear Model for Existing Soil-Structure Systems. Int. J. Struct. Stab. Dyn., 16, 1450099, 2014, https://doi.org/10.1142/S0219455414500990.
[2] V. Anand and S. R. K. Satish, “Seismic soil-structure interaction: a state-of-the-art review,” Structure, vol. 16, pp. 317–326, 2018. https://doi.org/10.1016/j.istruc.2018.10.009.
[3] H. Tahghighi and A. Mohammadi, “Numerical evaluation of soil-structure interaction effects on the seismic performance and vulnerability of reinforced concrete buildings,” International Journal of Geomechanics, vol. 20, no. 6, Article ID 04020072, 2020. https://ascelibrary.org/doi/epdf/10.1061/%28ASCE%29GM.1943-5622.0001651.
[4] Bolisetti, Chandrakanth, and Andrew S. Whittaker. "Numerical investigations of structure-soil-structure interaction in buildings." Engineering Structures, 215, 110709, 2020, https://doi.org/10.1016/j.engstruct.2020.110709.
[5] Oz, I.; Senel, S.M.; Palanci, M.; Kalkan, A. Effecto of soil-structure Interaction on the seismic response of existing low and mid-rise RC buildings. Appl. Sci., 10, 8357, 2020, https://doi.org/10.3390/app10238357.
[6] Hokmabadi, A.S.; Fatahi, B. Influence of foundation type on seismic performance of buildings considering soil-structure interaction. Int. J. Struct. Stab. Dyn, 16, 1550043, 2016, https://doi.org/10.1142/S0219455415500431.
[7] Argyroudis, Sotirios A., et al. "Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience." Reliability Engineering & System Safety, 191, 106567, 2019, https://doi.org/10.1016/j.ress.2019.106567.
[8] A. K. Jha, K. Utkarsh, and R. Kumar, “Effects of soil-structure interaction on multi storey buildings on mat foundation,” Advances in Structural Engineering, pp. 703–715, 2015. https://doi.org/10.1007/978-81-322-2190-6_56.
[9] Jiménez, Guillermo A. López, and Daniel Dias. "Dynamic Soil–Structure Interaction Effects in Buildings Founded on Vertical Reinforcement Elements." Civil Eng, 3(3), 573-593, 2022, https://doi.org/10.3390/civileng3030034.
[10] Oz, I.; Senel, S.M.; Palanci, M.; Kalkan, A. Effecto of soil-structure Interaction on the seismic response of existing low and mid-rise RC buildings. Appl. Sci., 10, 8357, 2020, https://doi.org/10.3390/app10238357.
[11] Kim, Seung Dae, et al. "Evaluation of Seismic Performance and Soil-Structure Interaction (SSI) for Piloti-Type Buildings considering Korean Geotechnical Conditions." Advances in Civil Engineering 2021, https://doi.org/10.1155/2021/7876389.
[12] Ahmed H. Hussein, Farouk M. Muhauwiss, Riyadh A. Abdul-Jabbar, "Collapsibility of Gypseous Soil Treated with Pectin-Biopolymer through Leaching", Journal of Engineering, vol. 2023, Article ID 6379835, 11 pages, 2023. https://doi.org/10.1155/2023/6379835.
[13] Li, Mengke, et al. "Influence of soil–structure interaction on seismic collapse resistance of super-tall buildings." Journal of Rock Mechanics and Geotechnical Engineering, 6(5), 477-485, 2014, https://doi.org/10.1016/j.jrmge.2014.04.006.
[14] Malekizadeh, Mohammad, Nader Fanaie, and Ali Akbar Pirasteh. "Vertical component effects of earthquake and soil-structure interaction on steel gabled frames." Journal of Constructional Steel Research, 196, 107409, 2022, https://doi.org/10.1016/j.jcsr.2022.107409.
[15] Rama Rao, G. V., J. C. Sunil, and R. Vijaya. "Soil-structure interaction effects on seismic response of open ground storey buildings." Sādhanā, 46(2), 1-17, 2021, https://doi.org/10.1007/s12046-021-01633-0.
[16] Jothi Saravanan T, Rama Rao G V, Prakashvel J, Gopalakrishnan N, Lakshmanan N and Murty C V R, Dynamic testing of open ground storey structure and in-situ evaluation of displacement demand magnifier. J. Perform. Constr. Facil. 31: Paper ID. 04017055, 2017, https://ascelibrary.org/doi/abs/10.1061/(ASCE)CF.1943-5509.0001052.
[17] Crowley H, Polidoro B, Pinho R, van Elk J. Framework for developing fragility and consequence models for local personal risk. Earthq Spectra, 33(4), 1325–45, 2017, https://doi.org/10.1193/083116eqs140m.
[18] Kruiver, Pauline P., et al. "Incorporating dwelling mounds into induced seismic risk analysis for the Groningen gas field in the Netherlands." Bulletin of Earthquake Engineering, 20(1), 255-285, 2022, https://doi.org/10.1007/s10518-021-01225-7.
[19] Pitilakis KD, Karapetrou ST, Fotopoulou SD. Consideration of aging and SSI effects on seismic vulnerability assessment of RC buildings. Bull Earthq Eng, 12(4), 1755–76, 2014, https://doi.org/10.1007/s10518-013-9575-8.
[20] Karapetrou ST, Fotopoulou SD, Pitilakis KD. Seismic vulnerability assessment of high-rise non-ductile RC buildings considering soil–structure interaction effects. Soil Dyn Earthq Eng, 73, 42–57, 2015, https://doi.org/10.1016/j.soildyn.2015.02.016.
[21] Esfandiari, Javad. "Numerical and Experimental study of the interaction between strip contact surfaces with new geometry and sandy soils and investigation by GEP method." Journal of Civil and Environmental Engineering 52(108), 161-174, 2022, 10.22034/JCEE.2021.39835.1944.