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Numerical Investigation of the Foundation Burial Depth on Earthquake Damage and Seismic Behavior of Steel Structures Considering Soil-Structure Interaction

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Abstract: Typically, in the analysis of structures, it is assumed that the soil beneath the structure is rigid, and the interaction between the soil and the structure is ignored. However, the soil is not rigid in reality, and the presence of soil under the structure changes the dynamic properties of the structure and consequently its response. Buried and deep foundations are more important. Paying attention to the effect of soil on the performance of structures during earthquakes, particularly the depth of foundation burial, has been a subject of consideration for many researchers in recent decades. Studies on the effect of soil on the performance of structures have been mostly done in the field of site effect and soil interaction of the structure, and less attention has been paid to the phenomenon of buried depth of foundation. Therefore, this research aims to address the scientific gap: considering the interaction between soil and structure, as well as the depth of the foundation, how does the seismic behavior of the structure change? In other words, according to past research, the innovation in this research is that a complete structure has been analyzed by considering the interaction of soil and structure and the depth of the buried foundation under the earthquake. Therefore, the main purpose of this study in this study is to investigate the effect of different depths of foundation burial on seismic behavior and structural damages caused by earthquakes. To achieve this goal, using IACOS software, the three-dimensional model of 5, 10, and 15-storey steel structures under the El-Centro earthquake is analyzed. Deep is more similar to a buried foundation. Especially in cases where the slope length is smaller, due to less soil deformations within the slopes, the sloped foundation behavior tends to be more towards semi-deep foundations. In addition, according to the results of this study, in short buildings (5 floors), the effects of horizontal and cradle movement in the interaction of soil and structure are almost the same, but with increasing the height of the structure, the share of rocking motion prevails, so that in tall buildings (15 floors and above), more than 90% of the changes in the period of the structure are due to this movement.

Keywords: *Soil-Structure Interaction, Period, Seismic Behavior, Pier Cutting, Floor Drift, Earthquake Damage*

1. Introduction

The dynamic behavior of the soil as an unlimited environment is different from the dynamic behavior of the structure as a finite environment. Its dimensions depend on the dynamic behavior of the soil.(Alao, Lawal, Dewu, & Raimi, 2024; Rui et al., 2024). In the seismic analysis of structures, the movement of the free field of the earth, in which the presence of the structure is not considered in the motion of the earth, is applied to the existing supports. If the rigidity of the structure and foundation is considered, the movement of the soil in the vicinity of the structure will be different from the movement of the free field; this effect is called kinetic interaction. Also, the dynamic response of the structure to the base acceleration will cause soil deformation. This phenomenon of interaction is called inertia.(Eissa, 2021). The sum of the two kinetic and inertial interactions is called the soil-structure interaction and indicates the effect of soil movement on the structural response and the movement of the structure on the soil response. In the common dynamic analysis of a structure, the usual method is to determine the movement of the free field of the ground at the construction site, and the obtained motion is applied to the foot of the structure in a rigid form.(Li, Tian, & Cassidy, 2015; Xue, Zhou, Ge, Qiu, & Gong, 2020). It has been done. In the case of the structure being placed on soft soil, the situation is completely different, and a rotational component due to the flexibility of the support is added to the horizontal movements of the foundation.(Ouyang, Luo, Wang, & Zhang, 2023; Yin, Hao, Xiao, Shao, & Yuan, 2021). Part of the vibrational energy of the structure can be transferred to the soil under the foundation due to the radiation damping resulting from wave propagation and the dampening of the hysteresis of the soil materials. It is not taken. In this case, during the occurrence of an earthquake, the nonlinear behavior of the underlying soil and the occurrence of the phenomenon of soil-structure interaction in a structural response in a way that can be completely different from the response of a structure with a rigid foot under the effect of the movement of the free field of the ground(Xu, Miller, Hofmayer, & Graves, 2004). In all these methods, due to the uncertainty in the values and type of parameters available, especially in the soil part, the obtained results have a lot of uncertainty in Considering the parameters, forces, and dynamic stresses of the soil under the bed more accurately can lead to more accurate results. One of the best methods is to consider the soil using by finite element method and study and consider the dynamic condition of the substrate soil in the environment under seismic wave propagation with this method.(Bharti, Garg, & Chandrawanshi, 2025; Kirçil & Ethemoglu, 2025). The behavior of the environment away from the structure and considering a flexible volume in the distance between this semi-infinite boundary and the location of the structure greatly increases the accuracy of the calculations and the possibility of reliability in them. In this method, the elements can be considered as two-dimensional or three-dimensional with several different faces and vertices. The higher the stresses, forces, and changes in the positions of the soil element, the higher the accuracy of the results. It is quite clear that it is impossible to consider such models manually and requires very powerful processors and software, and the more powerful, advanced, and intelligent these hardware and software equipment are, the better results will be achieved in less time. Nowadays, with the possession of very advanced hardware and software facilities, it is easy to study and study many more and more detailed factors and parameters with much more precision, and to the extent of the possibilities, the results of the calculations can be brought closer to the real and expected results. One of the best of these software is Abaqus software. In this research, this powerful software is used to investigate the problem and extract the results.(Al Araji, Moradi, & Owaid, 2025; Ali, Akhaveissy, & Abbas, 2024; Katsimpini, 2024; Khalilzadehvahidi & Moradi, 2019; Mohammed Ali, Besharat Ferdosi, Kareem Obeas, Khalid Ghalib, & Porbashiri, 2024; Mohammed Ali Al-Araji, Jasim, & Al-Kasob, 2025; Moradi & Khalilzadeh Vahidi, 2018, 2021; Moradi & Khalilzadeh, 2021; Vahidi & Moradi, 2019).

During the last three decades, extensive research has been conducted on the problem of structural soil interaction and the simplified criteria of these studies have been included in building regulations such as FEMA 442 of the United States, NEHRP of Mexico, and Regulation 2800 of Iran. have an impact on the problem of soil-structure interaction, but the role and extent of the effect of each of these parameters on the problem of interaction is not yet known in detail and precisely. In any case, by considering the effects of site and the effect of soil-structure interaction, seismic vulnerability studies and preparation of nonlinear response spectra of structures can be brought closer to reality.

Extensive research conducted on structural soil interaction indicates that the structural response under dynamic interaction is dependent on the dynamic properties of the building, foundation properties, and stimulation characteristics.(Kurniawan, Aprilia, Grace, Saputra, & Yufrizal, 2025).

Gaztas and Milonakiz showed that considering the soil-foundation interaction of the structure leads to a more realistic behavior of the structure. The presence of soft soil in the substructure reduces the hardness and increases the natural period in the whole system, and the structure shows a smoother behavior.(Bapir, Abrahamczyk, & Afroz, 2024).

According to Jiang and Yan's research, two buildings with a distance of less than 2.5 times the width of the foundation will interact with each other, and when the distance is less than one times the width of the foundation, the response of the structures may increase or decrease significantly.(Anand & Kumar, 2018).

Based on the research of Hosseinzadeh et al., the effect of soil-structure interaction has been reported as an increase in the vibration time of the first mode and the damping ratio in the structure. In these studies, it was found that with increasing foundation burial, the effect of the soil-structure interaction phenomenon on the responses decreases. In addition, for buildings shorter than five floors, horizontal movements and foundation cradles, and taller buildings, only the movements of the foundation cradles are the main causes of the phenomenon. Soil and structure interactions were introduced. Based on the results of these studies, adjacent buildings did not have a significant effect on the frequency change and damping of each other, and it was stated that the effect of proximity in high frequencies is more important than in low frequencies.(Abdulaziz, Hamood, & Fattah, 2023).

The results of Aviles and Perez-Rocha's research indicate that by decreasing the burial depth of the foundation and the thickness of the soil layer under the structure, the effects of soil-structure interaction increase. In these studies, it was also found that in comparison with the rigid bed, the interaction phenomenon can lead to a significant reduction in yield strength and also yield displacement.

Volestas and Mick stated that considering the soil-foundation structure in comparison with the rigid-legged structure has two major effects on the structural responses: first, increasing the degrees of freedom and changes in the dynamic characteristics of the system. Second, the depreciation of a large part of the seismic energy of the soil-structure system by the propagation of backwaves or hysteresis damping of the soil materials. This means that the soil-structure system faces an increase in the period of the structure compared to the equivalent model and the rigid-leg model. Therefore, the assumption of a rigid connection of the structure to the ground is a simplistic hypothesis that is not always correct.(Dhadse, Ramtekkar, & Bhatt, 2021).

Based on the results of negative researches, Cárdenas et al., parameters such as seismic moment magnitude, central distances of earthquakes in distant and near basins, focal depth and characteristicsof alluvial layers of soil on bedrock, as site factors and parameters such as geometric dimensions of the structure plan, weight of the structure, buried depth, geometric shape of the foundation, As the interaction parameters of soil and structure, they have important effects on the results of dynamic analyses.(Dhadse et al., 2021).

According to the Journal 360 of the Management and Planning Organization of Iran, different numerical and analytical methods have been proposed to simulate the dynamic behavior of the soil-structure interaction system. Precise solutions can only be obtained through analytical formulas, but with a series of simplified assumptions, easier solutions can be obtained. Modeling soil and structures is usually done in two forms: continuous environment and discrete or simple model. are done. Also, the substructure method, in which a kind of continuous environment method is used, is used and is often the most appropriate method, even in the instructions for improving the method of considering the interaction. The substructure method is used.(Bapir, Abrahamczyk, Wichtmann, & Prada-Sarmiento, 2023).

In his study, Hoxia and his colleague defined and investigated the effect of kinematic interaction. Using records of different earthquakes that existed in different parts of the same place and using a random model, he investigated the filtering effect of the rectangular foundation buried under the earthquake wave and applied extractive equations for several cases whose laboratory results were available. The points were located on a horizontal line at different distances. The available laboratory samples with which the results were compared included a buried cylindrical tunnel, a foundation surrounded by cement and cemented soil materials, and a 4-story reinforced concrete building located on a strip foundation with piles. The results show that the numbers extracted from the random model have a close overlap with the laboratory results.(Dutta & Roy, 2002).

Saffak proposed a method for determining the effects of the interaction of the structure soil in our area, in cases where no movement of the field of freedom is available and the effects of the movement of the cradles are negligible. He proposed a relationship for calculating the natural frequencies of a system with flexible support. Using a simple two-degree degree of freedom model, he showed that the governing frequency of a structure with the interaction of the soil structure is always smaller than the dominant frequency of the base structure. It is stuck(Jasim & Al-Araji, 2025; Mylonakis & Gazetas, 2000; Romero-Ruiz, Linde, Keller, & Or, 2018).

After reviewing the previous research, it was found that in no study has the three-dimensional steel structure been investigated considering the interaction of soil and structure and the depth of buried foundation under the effect of earthquake load. Therefore, this research is an attempt to fill this scientific gap: if the interaction of soil and structure, as well as the depth of buried foundation, is considered, how does the seismic behavior of the structure change? In other words, according to the previous research, the innovation in this research is that a complete structure has been analyzed, considering the interaction of soil and structure and the depth of burial of the foundation under the earthquake. Therefore, the main purpose of this study is to numerically study the interaction behavior of the structure with the foundation under the effect of earthquake load with regard to the depth effect. In order to achieve the main purpose of the research, we first analyze the 3, 10, and 15-storey structures considering the buried depth of 3, 6, and 9 meters under the effect of the El-Centro earthquake, and the results are discussed and compared.

2. Research Method and Initial Modeling Assumptions

In this study, according to the purpose of the research, three steel structures with a flexural frame system have been designed, all of which have a regular plan, three openings of 5 meters in the X direction, and three openings of 4 meters in the direction of Y direction. The design of the structures has been based on valid international regulations. In the design of the structure, it is assumed that the compressive strength of concrete is about 40 MPa and is made of iron.ST37 has been used for beams and columns, and the rebar is of the S400 type. After the design of the structure, the foundation of the structure was designed using valid regulations. The dimensions of the soil part under the foundation are as follows: its length is 80 meters, its width is 80 meters, and its height is 40 meters. Also, in this part of the research, the Centro earthquake acceleration has been used. In this study, three different depths, 3, 6, and 9 meters, were used to investigate the effect of the buried depth of the foundation. Therefore, in this part of the research, 12 numerical models whose characteristics are shown in the table below are modeled and analyzed, and finally, their seismic behavior is evaluated.

Table 1: *Characteristics of Numerical Models in this Research*

Numerical Models	Details	
	Story	Foundation Depth
S5T1D0	5	**0**
S5T1D3	5	**3**
S5T1D6	5	**6**
S5T1D9	5	**9**
S10T1D0	10	**0**
S10T1D3	10	**3**
S10T1D6	10	**6**
S10T1D9	10	**9**
S15T1D0	15	**0**
S15T1D3	15	**3**
S15T1D6	15	**6**
S15T1D9	15	**9**

3. Discussion and review of the results

1.3. Investigation of Seismic Behavior of 5-Story Structure

The criteria and recommendations of the regulations of the seismic design of structures are based on the determination of the "design earthquake," and the effects of aftershocks on the design process have been ignored. However, in high-risk areas, aftershocks of different magnitudes and at different time intervals occur after the occurrence of the main shock. Therefore, it is very important to investigate the permanent displacements in the structural system in post-earthquake conditions. In the figure below, the contour of the permanent displacement for the 5-story structure after the Centro earthquake is shown.

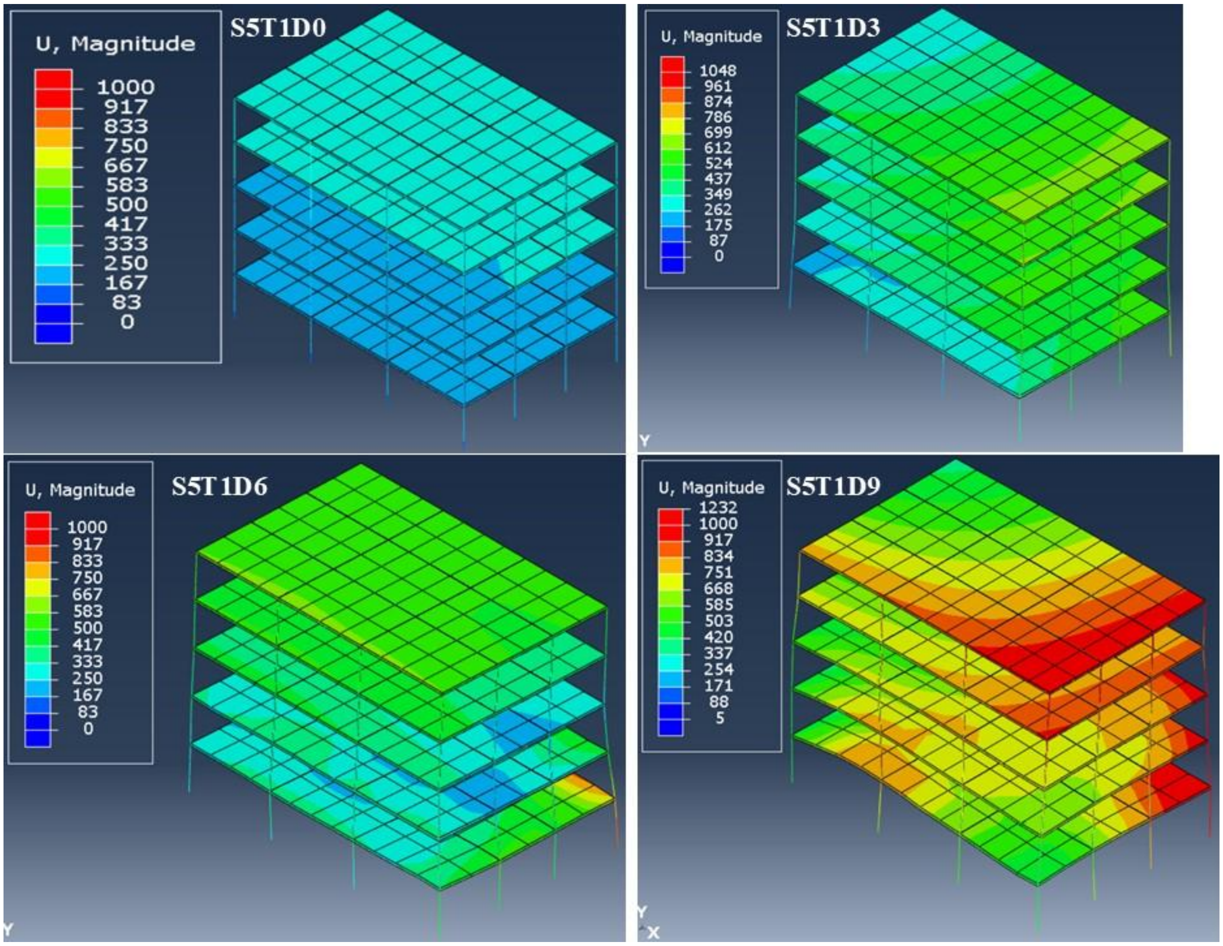

Figure 1: *The effect of foundation depth on the contour of waste displacement of a 5-story structure after an earthquake*

As can be seen, the permanent displacements have increased with increasing depth of the foundation. In better words, in the S5T1D0, S5T1D3, S5T1D6, and S5T1D9 structures, the maximum lasting displacement of the structure has been about 250, 700, 800, and 1250, respectively. The study concludes that the greater the depth of the buried foundation of a structure, regardless of the type of structure, the damping of the system and consequently its effect on the response of the system to the stimulation will be reduced, and the maximum displacement of the structure will increase. The greater the depth of the burial, the more the frequency of resonance of the system and consequently its period increases, and the structure reaches a state of stagnation later. With the increase in the depth of the burial, the damping of the system decreases rapidly, and the structure reaches a state of stagnation later. It seems that the reason for this phenomenon is the increase in the rocking movement with the increase in the buried depth of the foundation. In other words, based on the results of this research, it can be said that the rocking movement has a significant effect on the seismic behavior of the structure, so that it leads to the transfer of the concentration of deformations from the upper floors to the first floor. The maximum base cut is mainly increased.

In the figure below, the effect of foundation depth on stress contour in the columns of a 5-story structure is shown.

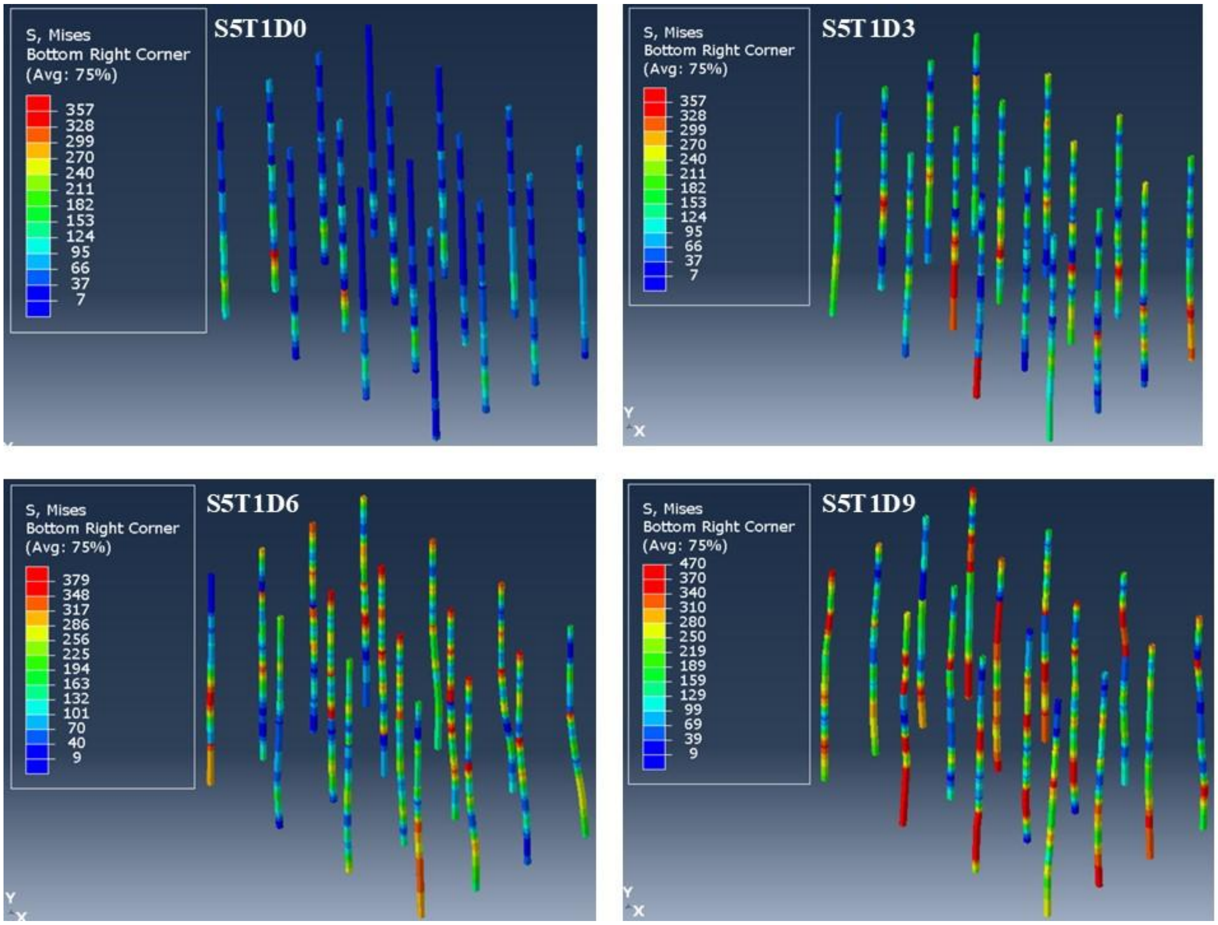

Figure 2: *Effect of Foundation Depth on Stress Contour in Columns of 5-Story Structure*

As can be seen, in all structures, the maximum stress is higher at the bottom of the columns of the first floor, and as the height of the structure increases, the amount of stress in the columns decreases. Also, in the S5T1D0 structure, the stress at the bottom of the column in one of the columns has reached 370 MPa. In other words، in this structure, due to the El-Central earthquake, only one column has reached the level of the plastic joint. In the S5T1D3 structure, the stress at the bottom of the column of the first floor and the column of the second floor has reached the limit of 370 MPa, and in most of the columns of the second floor, a plastic joint is formed. In the S5T1D6 structure, at the bottom of the columns of the first, second, and third floors, the stress has reached the limit of 370 MPa, and the plastic joints have formed in the lower part of the columns of the third floor. Also, in the structure of S5T1D9, in the columns of the first, second, third, and fourth floors, the stress has been observed at about 370 MPa, and most of the columns of the fourth floor have reached the limit of the plastic joint.

In other words, the results of this study show that the deformation of the columns, which is caused by the forces exerted by the structure placed on it, causes the displacement of the structure, the cutting and the anchor of the foundation, as well as the stress in the beams and columns, to change. It seems that, in other words, the rocking motion has a significant effect on the seismic behavior of the structure, so that it leads to the transfer of the focus of deformations from the upper floors to the first floor. Subsequently, the structure enters into a nonlinear behavior at a lower base shear, and the corresponding displacement of the maximum shear is mainly increased. Due to the phenomenon of soil-structure interaction and due to the increase in the buried depth of the foundation, it can be safely stated that if this phenomenon is not applied in the analyses, the response of the system may be significantly different from reality, and the analysis may have been erroneous.

In the figure below, the maximum floor drift for a 5-story structure is shown.

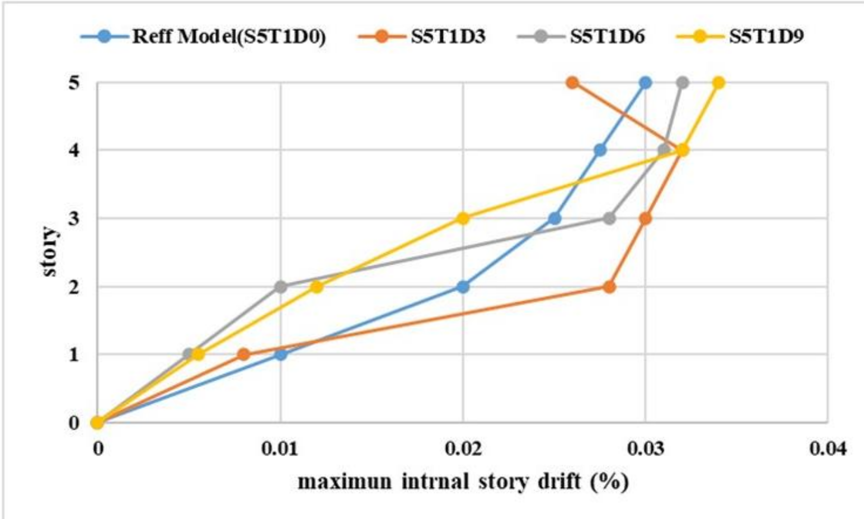

Figure 3: *The Effect of Foundation Depth on the Maximum Floor Drift for a 5-Story Structure*

As can be seen, in the part of the structure that has been buried, the drift of the floors is less than the drift of the unburied structure. Also, based on the figure above, it can be said that the effect of increasing the buried depth of the foundation is more than the elastic area by considering the interaction of the soil of the structure in the non-elastic area, which means that by increasing the buried depth of the foundation, we see a greater increase in the elastic force created in the structureAnd for this reason, in the upper floors of the ground, the drift of floors has increased. In general, increasing the buried depth of the foundation decreases the behavior coefficient of the structure. Reducing the behavior coefficient means that in order not to exceed a certain ductility, we are allowed to reduce the elastic force created in the structure for design. Increasing the depth of foundation burial increases the behavior coefficient, because increasing the depth of foundation burial causes a greater increase in the elastic force created in the structure.

2.3. Investigation of Seismic Behavior of 10-Story Structure

In the figure below, the effect of foundation depth on the contour of the waste displacement of a 10-story structure after the earthquake is shown.

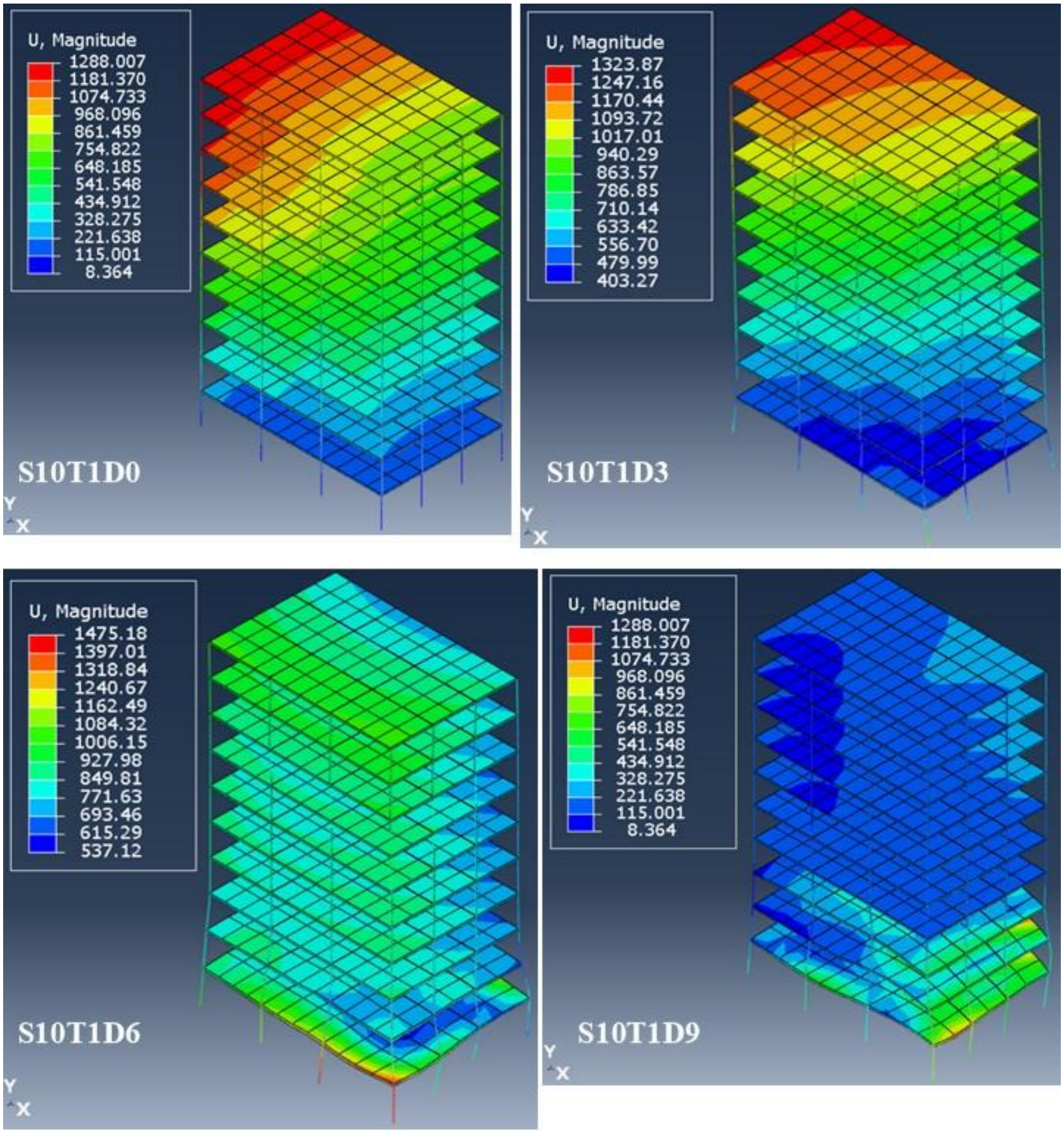

Figure 4: *The Effect of Foundation Depth on the Contour of Waste Displacement of a 10-Story Structure after the Earthquake*

According to the figure above, with increasing the depth of foundation burial, the amount of residual location change after the earthquake has decreased. It seems that the cause of this phenomenon is the rocking movement of the foundation. In other words, in the structure of S10T1D0, S10T1D3, S10T1D6, and S10T1D9, the maximum permanent displacement of the structure is about 1200, 1350, 1400, and 1250, respectively.

According to the above figure and from the study of this research, it can be concluded that the greater the depth of the buried foundation of a structure, regardless of the type of structure, the damping of the system and consequently its effect on the response of the system to the stimulation will be reduced and the maximum displacement of the structure will increase. The greater the depth of the burial, the more the frequency of resonance of the system and consequently its period increases, and the structure reaches a state of stagnation later. With the increase in the depth of the burial, the damping of the system decreases rapidly, and the structure reaches a state of stagnation later. It seems that the cause of this phenomenon is the increase in the rocking motion with the increase in the buried depth of the foundation.

In other words, based on the results of this study, it can be said that the rocking motion has a significant effect on the seismic behavior of the structure, so that it leads to the transfer of the concentration of deformations from the upper floors to the first floor. Subsequently, the structure enters into a nonlinear behavior with less base shear, and the corresponding displacement of maximum displacement of the base shear is mainly increased.

In the figure below, the effect of foundation depth on stress contour in the columns of a 10-story structure is shown.

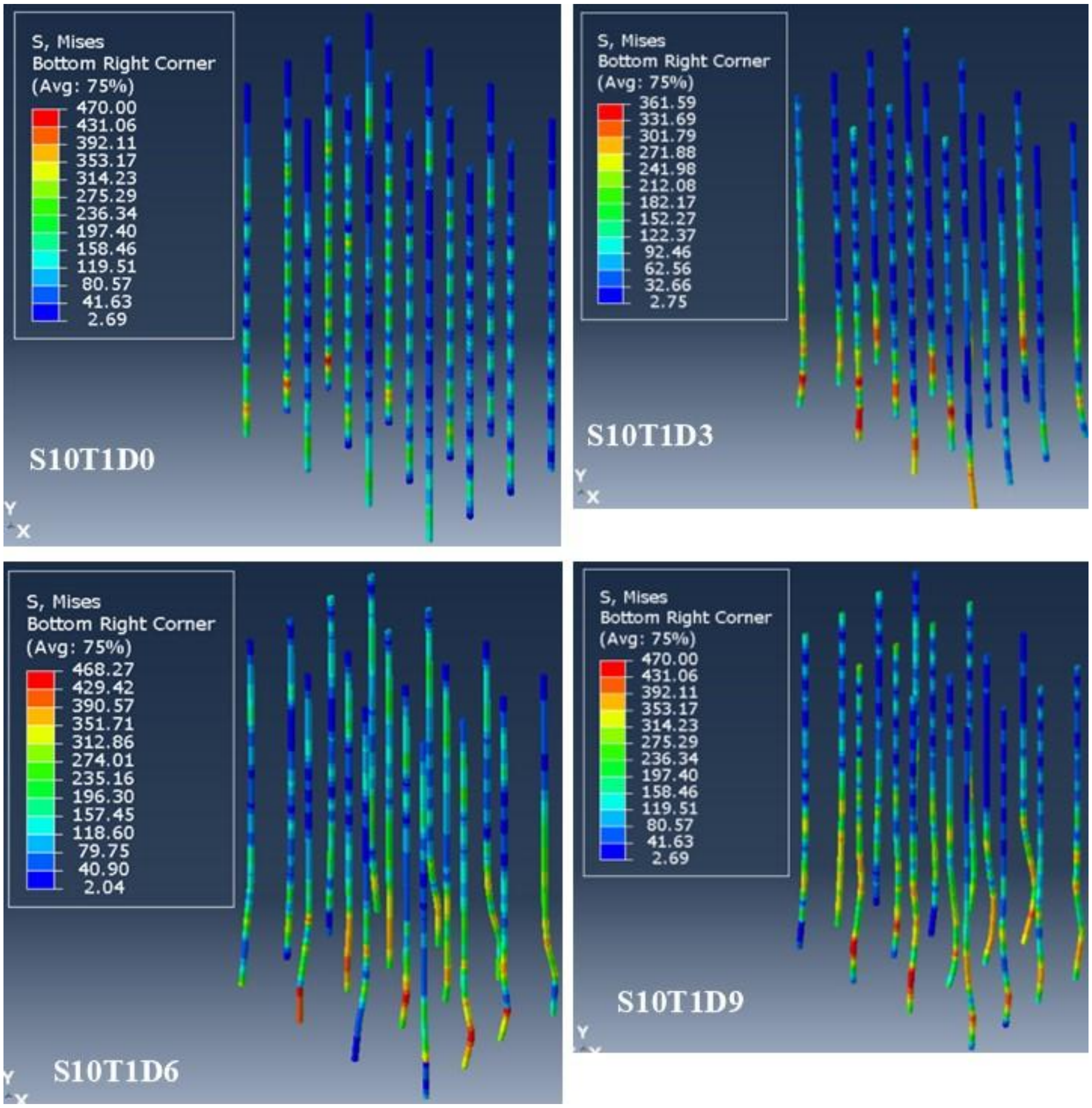

Figure 5: *Effect of foundation depth on stress contour in columns of a 10-story structure*

As can be seen, with the increase in the depth of the structure, the part of the column that is buried in the retaining wall, the amount of stress in it has increased. It seems that the cause of this phenomenon is the rocking movement of the foundation and its large deformation, and as a result, the deformations of the soil caused by the forces exerted by the structure on it, cause the displacement of the structure, the cutting and the anchor of the foundation, etc Also, the tension in the beams and columns should be changed.

In the figure below, the diagram of the maximum drift of floors in a 10-story structure is shown, considering the effect of the buried depth of the foundation.

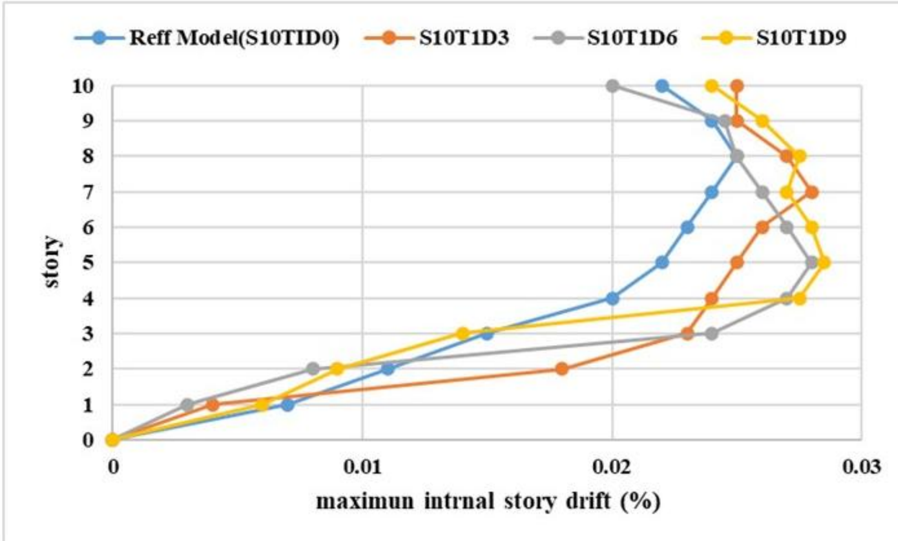

Figure 6: *Diagram of the maximum drift of floors in a 10-story structure considering the effect of the buried depth of the foundation*

Based on the figure above, in the higher floors, the maximum drift of the floors has increased with increasing the depth of the foundation buried, while in the lower floors, the maximum drift of the floors has decreased with increasing the depth of the burial.

3.3. Investigation of Seismic Behavior of 15-Story Structure

In the figure below, the effect of foundation depth on the contour of the waste displacement of a 15-story structure after the earthquake is shown.

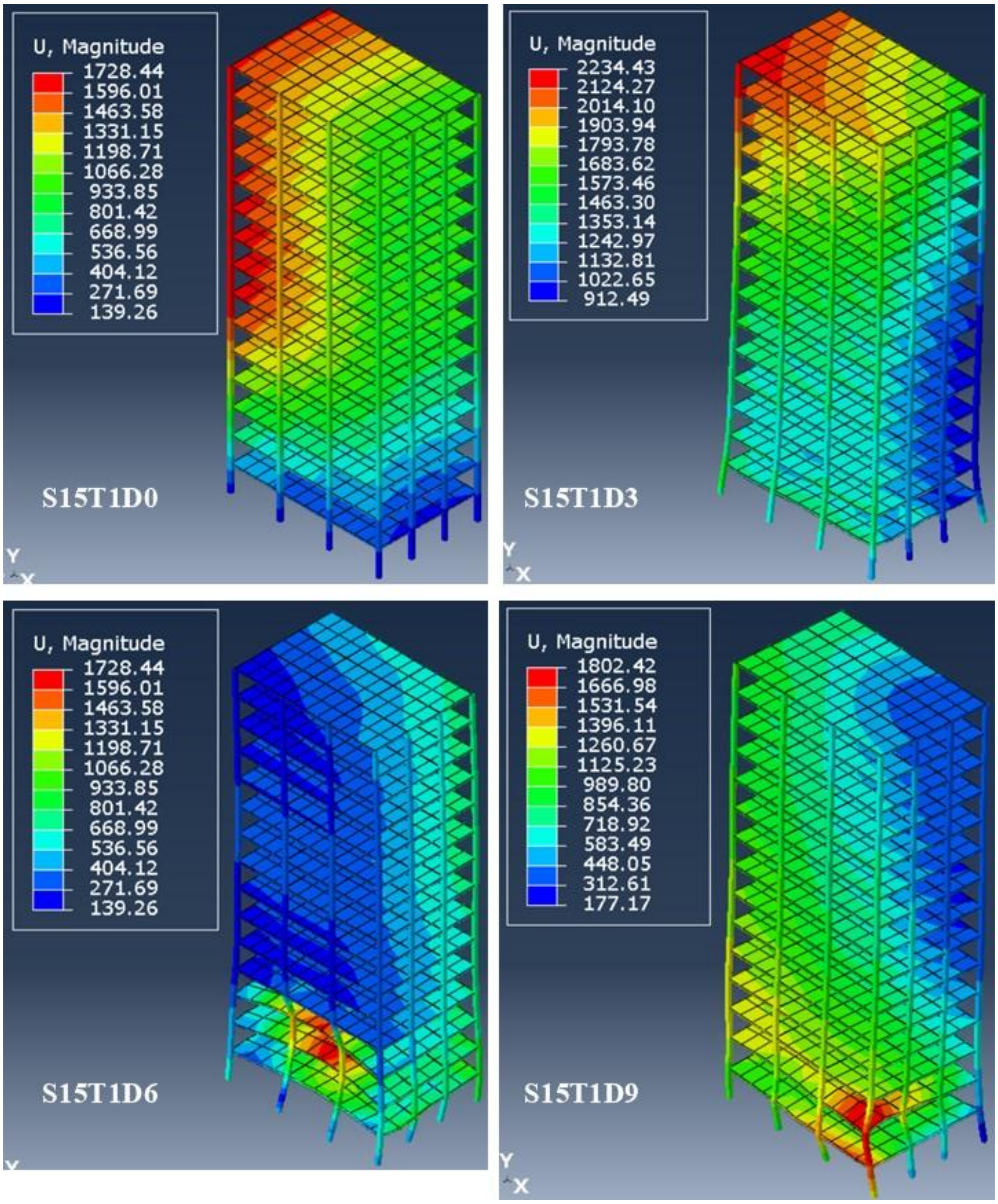

Figure 7: *The effect of foundation depth on the contour of the displacement of a 15-story structure after the earthquake*

As can be seen, with increasing depth of the foundation, the permanent displacements have increased. In other words, in the S15T1D0, S15T1D3, S15T1D6, and S15T1D9 structures, the maximum lasting displacement of the structure is about 1700, 2000, 1800, and 1850, respectively. (Rocking) and torsion, which is very likely to lead to the flexibility of the environment under the foundation.

The study concludes that the greater the depth of the buried foundation of a structure, regardless of the type of structure, the damping of the system and consequently its effect on the response of the system to the stimulation will be reduced, and the maximum displacement of the structure will increase. The greater the depth of the burial, the more the frequency of resonance of the system and consequently its period increases, and the structure reaches a state of stagnation later. With the increase in the depth of the burial, the damping of the system decreases rapidly, and the structure reaches a state of stagnation later. It seems that the cause of this phenomenon is the increase in the rocking motion with the increase in the buried depth of the foundation.

In other words, based on the results of this study, it can be said that the rocking motion has a significant effect on the seismic behavior of the structure, so that it leads to the transfer of the concentration of deformations from the upper floors to the first floor.

Subsequently, the structure enters into a nonlinear behavior with less base shear, and the corresponding displacement of maximum displacement of the base shear is mainly increased.

In the figure below, the effect of foundation depth on stress contour in the columns of the 15-story structure is shown.

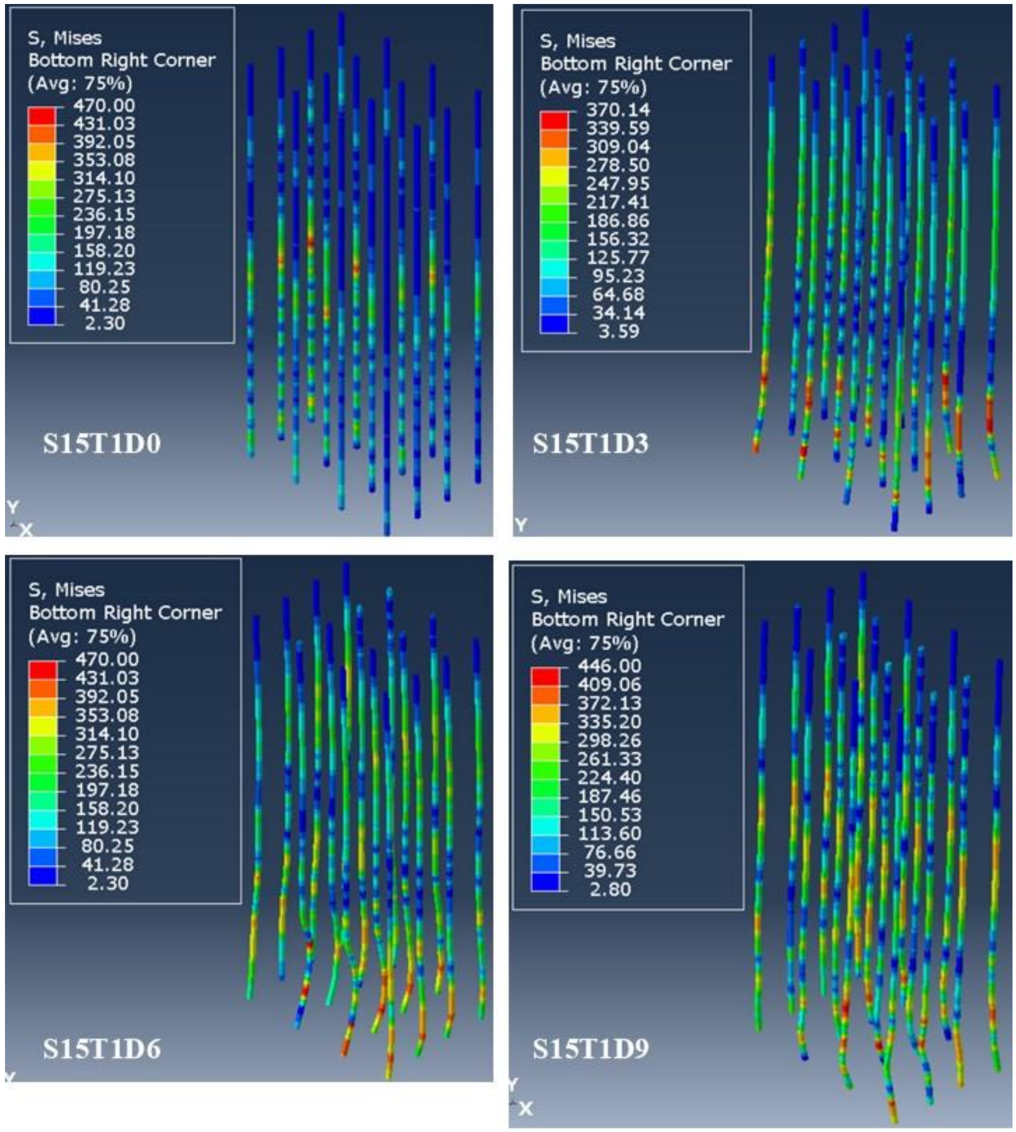

Figure 8: *The effect of foundation depth on stress contour in 15-story columns*

According to the above figure, it seems that with increasing the depth of the foundation burial, the deformation in the columns and finally the stress in the columns has increased. It seems that the deformations of the soil, which are caused by the forces exerted on it by the structure placed on it, cause the displacement of the structure, cut and anchor of the foundation, as well as the stress in the beams and columns, to change.

In other words, the results of this study show that the deformation of the columns, which is caused by the forces exerted by the structure placed on it, causes the displacement of the structure, the cutting and the anchor of the foundation, as well as the stress in the beams and columns, to change.

In other words, it seems that the rocking motion has a significant effect on the seismic behavior of the structure, so that it leads to the transfer of the focus of deformations from the upper floors to the first floor. Subsequently, the structure enters into a nonlinear behavior in less pier shear, and the corresponding displacement of the maximum pier shear is mainly increased.

According to the above and the change in damping, rotation time and displacement of the structure due to the phenomenon of soil-structure interaction and due to the increase in the buried depth of the foundation, it can be safely stated that if this phenomenon is not applied in the analyses, the response of the system may be significantly different from the reality and the analysis performed may have been errord.

According to the above figure and from the study of this research, it can be concluded that the greater the depth of the buried foundation of a structure, regardless of the type of structure, the damping of the system and consequently its effect on the response of the system to the stimulation will be reduced and the maximum displacement of the structure will increase. The greater the depth of the burial, the more the frequency of resonance of the system and consequently its period increases, and the structure reaches a state of stagnation later. With the increase in the depth of the burial, the damping of the system decreases rapidly, and the structure reaches a state of stagnation later. It seems that the cause of this phenomenon is the increase in the rocking motion with the increase in the buried depth of the foundation. In the figure below, the maximum floor drift for a 5-story structure is shown.

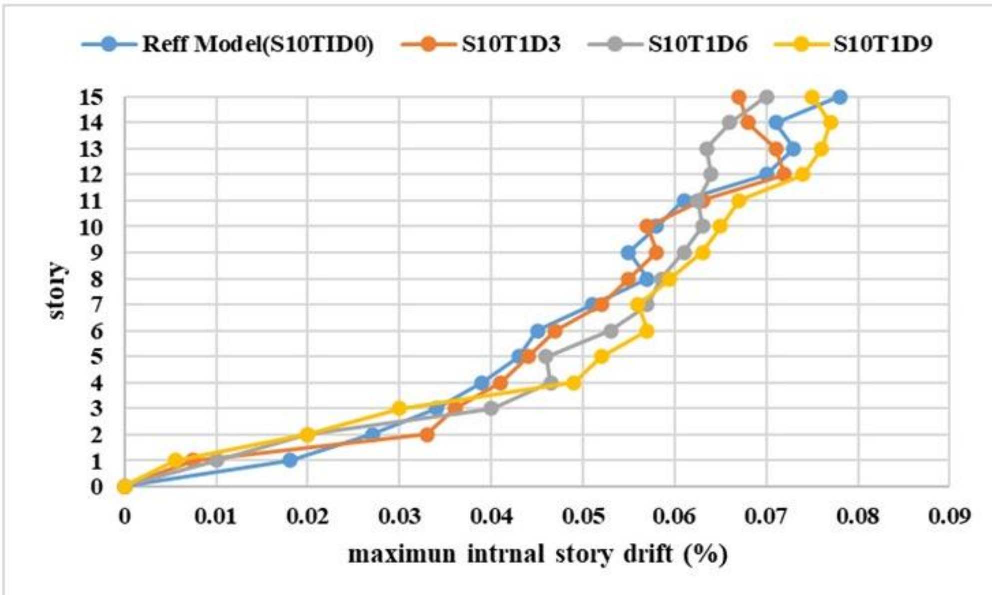

Figure 9: *The Effect of Foundation Depth on the Maximum Floor Drift for a 15-Story Structure*

According to the figure above, on the higher floors, the maximum drift of the floors has increased by increasing the depth of the foundation burial increases. While on the lower floors, the maximum drift of the floors decreases with the increase in the depth of the burial.

As can be seen, in the part of the structure that has been buried, the drift of the floors is less than the drift of the unburied structure. Also, based on the figure above, it can be said that the effect of increasing the buried depth of the foundation is more than the elastic area by considering the interaction of the soil of the structure in the non-elastic area, which means that by increasing the buried depth of the foundation, we see a greater increase in the elastic force created in the structureAnd for this reason, in the upper floors of the ground, the drift of floors has increased.

In general, increasing the buried depth of the foundation decreases the behavior coefficient of the structure. Reducing the behavior coefficient means that in order not to exceed a certain ductility, we are allowed to reduce the elastic force created in the structure for design. Increasing the depth of foundation burial increases the behavior coefficient, because increasing the depth of foundation burial causes a greater increase in the elastic force created in the structure.

4.3. Comparison of Seismic Behavior of 5, 10, and 15-Story Structures Considering the Effect of Buried Depth of Foundation

The analytical solution of the problem of the interaction of soil and structure has always been considered by researchers, this problem has special complexities due to the many and different parameters of the soil and the structure on it, although the important aspects of the problem can be properly modeled and logical results can be extracted from them, but according to the type of soil behavior, which is a completely nonlinear behavior, the accurate analytical solution of the problem of soil interaction and the structure is not possible. Today, with the extensive studies of researchers in this field and the growth of nonlinear methods of solving the problem of soil and structure, which has been made possible by the development of software, we have witnessed a significant growth in the field of more accurate solutions to this problem. The dynamic reaction of the soil and structure complex, when affected by dynamic loading, is a function of the dynamic model of the system, the dynamic characteristics, the forces, and the stimuli induced in the system.

Based on the contour of permanent displacement, with increasing the number of floors of the structure, the permanent displacement in the structure increases, and also with increasing the depth of the buried foundation, the permanent displacement of the floors increases.

The results of this study show that in 5, 10, and 15-story structures, the amount of deformation and stress in the columns increases with increasing depth of foundation burial, and with increasing number of floors, the amount of deformation and stress in the columns increases.

In all numerical models, the equivalent plastic strain in the concrete in the foundation has increased by increasing the buried depth of the foundation, and also with increasing the number of floors, the equivalent plastic strain in the foundation concrete has increased.

As can be seen, with increasing depth of the foundation, the amount of plastic strain in the foundation increases, and in all numerical models, the highest plastic strain is observed in the outer and lower parts of the foundation. Also, for lower buried depth ratios, the rupture mechanism within the edge is more probable, and the discrepancies are high.

The deformations of the soil, which are caused by the forces exerted by the structure on it, cause the displacement of the structure, the cutting and anchoring of the foundation, as well as the stress in the beams and columns, to change.

According to previous studies, when a wave is radiated from a source into the soil environment, its nature changes depending on the type of medium, and two important points should be considered in modifying this wave: first, the movement of the free field in the desired place in the absence of the structure is strongly affected and changed, and second, the presence of the structure on the soil causes the desired dynamic system to be a system. It should not be rigid with the foundation, and the structure in question shows an interaction behavior with the soil around it, which affects the movement applied to the base of this structure. Therefore, in general, by increasing the effect of buried depth of the foundation and considering the interaction of the soil of the structure, the elastic force created in the structure increases. Reducing the thickness of the structure causes a further decrease in the elastic force. In Al-Ghar structures, calculating the induction of the foundation due to kinematic interaction and applying it to the foot of the soil system instead of stimulating the free field of the soil increases the elastic force created in the structure.

In general, the interaction of the soil of the structure may increase, decrease or not change the forces created in the structure, but based on the results of this research in the structures of 5, 10 and 15 floors, increasing the buried depth of the foundation has increased the forces created in the columns and has caused the formation of plastic joints in the higher floors. For this reason, It is not possible to design the structure in the design of the structure without considering the effect of increasing the depth of the foundation and assuming that the structure is located on a rigid substrate.

According to the results of this study, the performance of sloped foundations is more similar to the behavior of semi-deep foundations than buried foundations. Especially in cases where the slope length is smaller, due to less soil deformations within the slopes, the behavior of sloped foundations is more inclined to semi-deep foundations. In addition, according to the results of this study, in short buildings (5 floors), the effects of horizontal and cradle movement in the interaction of soil and structure are almost the same, but with increasing the height of the structure, the share of rocking movement prevails, so that in tall buildings (15 floors and above), more than 90% of the changes in the structural period are due to this movement. Usually, increasing the rotation time also increases the displacement, which increases Δ –It will increase the effects of P.

According to the results of this study, with increasing the depth of foundation burial, the strain of plastic at the edges around the foundation has increased. In other words, with increasing the depth of foundation burial, the damages and damage to the foundation has increased. Therefore, simplified assumptions should not be taken into account during the design of the foundation, because in the damage to the foundation, the depth of the foundation burial increases with increasing depth of the foundation. As the depth of the foundation increases, rocking and torsional movements are more likely due to the flexibility of the environment under the foundation.

Nowadays, most of the designs are based on the usual assumption of solid foundations. Previous studies show that the occurrence of rocking motion can mainly affect the behavior of the structure. The results indicate that the rocking motion has a significant effect on the behavior, so that it leads to the transfer of the focus of deformations from the upper floors to the first floor, and the corresponding displacement of the maximum base cut is mainly increased.

The results of this study show that in short buildings (5 floors), the share of horizontal and rocking movements in the response of the tip of the structure is almost equal, but in higher heights (10 floors and above), the share of rocking movement increases, and this increase is such that in buildings taller than 15 floors, the share of horizontal movement is negligible and can be ignored.

According to the above and the changes in the damping, rotation time, and displacement of the structure due to the phenomenon of soil-structure interaction, it can be safely stated that if this phenomenon is not applied in the analyses, the response of the system may be significantly different from reality, and the analysis may have been erroneous.

The deformations of the soil, which are caused by the forces exerted by the structure on it, cause the displacement of the structure, the cutting and anchoring of the foundation, as well as the stress in the beams and columns, to change.

Based on the results of this study, it seems that the flexibility of the foundation, which is caused by the deformation of the soil underneath it, increases the period of the structure and changes in the displacement of the floors and the shear of the foundation compared to the fixed state of the foundation. In some structures, this change appears as an increase in the displacement of floors and a decrease in the shear of the foundation and the anchor of the foundation, and in others, it may be quite the opposite, although in a particular structure, these changes are unstable and depend on the soil conditions and the type of dynamic loading. When a wave is radiated from a source into the soil environment, depending on the type of environment, the nature of the change is changed, and two important points should be considered in modifying this wave: first, the movement of the free field in the desired location is strongly affected and changed in the absence of the structure, and secondly, the presence of the structure on the soil causes the desired dynamic system to no longer be a rigid-based system And the structure in question shows an interaction behavior with the soil around it, which affects the movement applied to the base of this structure. The interaction of soil and structure in the case of the foundation with the depth of burial may lead to the formation of rocking and twisting movements that are very likely due to the flexibility of the environment under the foundation.

The difference between the hardness of the foundation and the soil beneath it causes the foundation to change its position relative to the free surface, and is different from the state of the foundation on the bedrock.

A very small period caused by the rocking movement of the structure can have a significant effect on the displacement of the structure, which in turn changes the response of the structural system in a major way. As mentioned earlier, the main mechanism of interaction between the soil and the structure is related to the horizontal and cradle movements of the APs, in a system of a free degree, as shown in the following figure, the contribution of the horizontal movement of the foundation to the lateral movement can be The roof roof of the structure was considered from the difference between the horizontal movement of the foundation and the free area, as well as the contribution of the rocking movement of the foundation in the lateral movement of the roof of the structure equal to h.

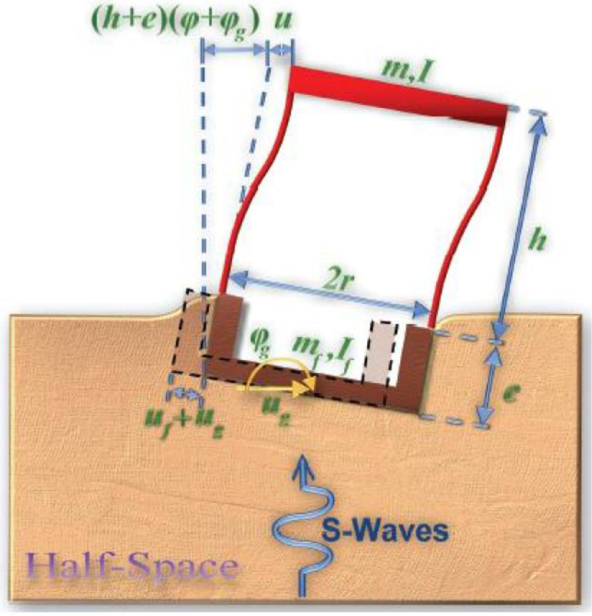

Figure 10: *Structure with foundation buried in soil(Bapir et al., 2023; Dhadse et al., 2021)*

According to the above and the changes in the damping, rotation time, and displacement of the structure due to the phenomenon of soil-structure interaction, it can be safely stated that if this phenomenon is not applied in the analyses, the response of the system may be significantly different from reality, and the analysis may have been erroneous. The deformations of the soil, which are caused by the forces exerted by the structure on it, cause the displacement of the structure, the cutting and anchoring of the foundation, as well as the stress in the beams and columns, to change. On the other hand, the seismic waves that reach the structure after passing through different layers of soil change their nature according to the type and height of the soil layers that are in their path. The soil under the structure acts like a filter and does not allow some of the earthquake waves that have a high frequency to pass. In the past, most of the regulations considered the effects of the sequential behavior on the response of the structure to be approximated by modifying the main vibration period and the damping ratio of the structure. However, these simple approximations are not suitable for studying the effects of soil and structure.

According to the results of this study, the flexibility of the foundation, which is caused by the deformation of the soil underneath it, increases the period of the structure and changes in the displacement of the floors and the shear of the foundation compared to the fixed state of the foundation. In some structures, this change appears in the form of an increase in the displacement of the floors and a decrease in the shear of the foundation and the anchor of the foundation, and in others it may be quite the opposite, although in a particular structure, these changes are unstable and depend on the soil conditions And it depends on the type of dynamic loading. Of course, most of these researches are limited to single-degree or multi-degree freedom systems placed on the soil with linear characteristics, and in many cases, two-dimensional models or soil damping have not been considered. However, the actual behavior of the soil is nonlinear and depends a lot on the loading. Equivalence of the structure with a system of one degree of freedom or a few degrees of simple freedom also has a lot of approximation and may sometimes make the results appear completely inverted. Also, soil damping has a great impact on the results and should be applied appropriately.

Considering the effect of the buried depth of the foundation, in general, the interaction of the soil with the structure may increase, decrease, or not change the forces created in the structure. However, in general, for ordinary structures, the interaction decreases the design forces compared to the rigid bed state.

In general, considering the effect of buried depth of the foundation on the interaction of the soil of the structure decreases the behavior coefficient of the structure. Reducing the behavior coefficient means that in order not to exceed a certain ductility, we are allowed to reduce the elasticity of the structure for design. Increasing the depth of foundation burial increases the behavior coefficient, because increasing the depth of foundation burial causes a greater increase in the elasticity of the structure than the yield strength required by the structure. The effect of structural soil interaction in the elastic area is greater than in the non-elastic area, which means that by increasing this effect, we see a greater decrease in the elastic force created in the structure than in the yield strength required by the structure.

In the design of structures, considering the interaction of the soil of the structure along with considering the effect of the buried depth of the foundation, if the support of the structure is fixed, the effects of the interaction can be ignored, but if the flexibility of the foundation is considered, the effect of the interaction of soil and structure should be considered. By the valid international regulations, if the structure is located on one of the types III lands, II, I, and Annex 5 of the International Valid Regulations can be used for analysis. If the structure has a wide or deep foundation and is located at a depth of the ground and the dimensions of the building and foundation are such that the propagation and return of the earthquake wave from the soil body is possible, according to the relative hardness of the structure and the foundation soil, the seismic interaction of the soil and the foundation should be considered through appropriate analytical methods. For ordinary structures and common dimensions whose basement depth does not exceed two floors, there is no need to consider their interaction.

Based on the stress contour and equivalent plastic strain contour in foundation rebars, it is concluded that ignoring the effect of structural soil interaction in the design of structures located on a flexible bed leads to unconservative results. It has also been concluded that ignoring the depth of foundation burial and the effect of kinematic interaction in the design of tall structures with deep buried foundations also leads to unconservative results.

It is concluded from this study that the greater the depth of the buried foundation of a structure, regardless of the type of structure, the damping of the system and consequently its effect on the response of the system to the stimulation will be greater and the maximum displacement of the structure will be reduced. As the depth of the buried increases, the frequency of resonance of the system and consequently its period decreases, and the structure reaches a state of stagnation sooner. With the increase in the depth of the burial, the damping of the system increases rapidly, and the structure quickly reaches a state of stagnation.

4. Conclusion

In the analysis of structures, it is assumed that the soil located under the structure is rigid and the effect of the interaction of the soil with the structure is ignored. However, the soil is not rigid in reality, and the existence of the foundation with the depth of burial in the structure, and also the presence of soil in the substructure, changes the dynamic properties of the structure and consequently its response. On the other hand, the placement of the relatively rigid foundation of the structure in the soil causes a change in the input stimuli to the system. The soil becomes a structure. Which is more important in structures with buried and deep foundations? Therefore, for a more accurate analysis, it is necessary to consider the effect of the interaction of the soil structure. In this study, we investigated three buildings of 5, 10, and 15 floors that are located on a foundation in four different levels (buried depth) of 0, 3, 6, and 9 meters using Abakus finite element software. The results indicate that:

1- Based on the contour of permanent displacement, with increasing the number of floors of the structure increases, the permanent displacement in the structure increases, and also with increasing the depth of the buried foundation increases, the permanent displacement of the floors increases.
2- The results of this study show that in 5, 10, and 15-story structures, the amount of deformation and stress in the columns increases with increasing depth of foundation burial, and with increasing the number of floors, the amount of deformation and stress in the columns increases.
3- The performance of sloped foundations is more similar to the behavior of semi-deep foundations than buried foundations. Especially in cases where the slope length is smaller, due to less soil deformations within the slopes, the sloped foundation behavior is more inclined to semi-deep foundations. In addition, according to the results of this study, in short buildings (5 floors), the effects of horizontal and cradle movement in the interaction of soil and structure are almost the same, but with increasing the height of the structure, the share of rocking movement prevails, so that in tall buildings (15 floors and above), more than 90% of the changes in the structural period are due to this movement. Usually, increasing the rotation time also increases the displacement, which increases Δ –It will increase the effects of P.
4- In other words, with increasing the depth of the foundation burial, the damages and damage to the foundation has increased. Therefore, simplified assumptions should not be taken into account during the design of the foundation, because in the damage to the foundation, the buried depth of the foundation increases with the increase in the depth of the foundation. In

other words, with the increase in the depth of the foundation, the Rocking and torsional movements are very likely due to the flexibility of the environment under the foundation.

5- In short buildings (5 floors), the share of horizontal and rocking movements in response to the tip of the structure is almost equal, but in higher heights (10 floors and above), the share of rocking movement increases, and this increase is such that in buildings taller than 15 floors, the share of horizontal movement is negligible and can be ignored.
6- In all numerical models, the equivalent plastic strain in the concrete in the foundation has increased by increasing the buried depth of the foundation, and also with increasing the number of floors, the equivalent plastic strain in the foundation concrete has increased.
7- As can be seen, with increasing depth of the foundation, the amount of plastic strain in the foundation increases, and in all numerical models, the highest plastic strain is observed in the outer and lower parts of the foundation. Also, for lower buried depth ratios, the rupture mechanism within the edge is more probable, and the discrepancies are high.
8- The deformations of the soil, which are caused by the forces exerted by the structure on it, cause the displacement of the structure, the cutting and anchoring of the foundation, as well as the stress in the beams and columns, to be changed.
9- Considering the effect of the buried depth of the foundation, in general, the interaction of the soil of the structure may increase, decrease, or not change the forces created in the structure. However, in general, for ordinary structures, the interaction decreases the design forces compared to the rigid bed state.

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