

**INVESTIGATION OF THE IMPACT OF EXCAVATION (REINFORCED) ON THE
SEISMIC BEHAVIOR OF ADJACENT STEEL STRUCTURES UNDER THE
INFLUENCE OF NEAR-FAULT AND FAR-FAULT EARTHQUAKES**

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ABSTRACT

Every year, as a result of earthquake, abundant losses may be created as result of roof motion and sliding and rupture. Under normal conditions, the ground and soils forming the ground tolerate and transfer the existing stresses and any kind of action like excavation and release of trench and applying dynamic load could distort the balance of stresses and endanger stability of roof. In this study, behavior of a steel building in adjacency of excavation is studied. The pit is stabled using hybrid system of pinching and anchoring and is studied before and after excavation under the effect of far and near-fault earthquakes with regard to soil-structure interaction. The results obtained from nonlinear dynamic analysis of time history of two said spectrums showed that the momentum of floor in the structure after excavation is increased compared to the time before excavation. The momentum of floor in the desired structure in near-fault earthquake has been increased compared to far-fault earthquake before excavation compared to the time after excavation. However, the overall drift of floors in the structure before excavation in near-fault earthquakes has been increased more than far-fault earthquakes.

Keywords: excavation, earthquake, far and near-fault zone, dynamic behavior, soil-structure interaction, steel structure

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INTRODUCTION

Increasing growth of urban activities has led to more and more use of underground spaces to provide urban services. Subway transportation, parking lot spaces or other engineering activities needing designation of deep excavation near the buildings are among these activities. Excavation includes inevitably considerable changes in stress and strain of sections of soil around them and hence, it could make permanent drift in foundation and structure and cause serious damages for potentially. With the development of cities and growth of population, necessity of making tall buildings and deep excavation to implement them is being felt more than before (10). Technical issues such as removing the weak soil and reaching to suitable soil, creating sub-surface sections, preserving balance of the forces applied on the soil and protection of foundations against climatic conditions make people use a space under the ground in construction. Limitation of lands in cities and necessity of supplying parking lot and limitation of building height are other factors making it necessary to use underground space. Although the pits are temporary, they face problem of stability of wall in excavation, controlling the deformations of ground around the foundation and implementation of building and the walls should be supported using suitable bracing systems. Lots of unproductive excavation activities done without observance of technical principles and executive plans and supervision of experienced engineer could cause accidents such as soil rupture and fall of the adjacent structure or damages caused by deformations caused by excavation in the buildings around the foundation such as damage of underground facilities. These problems clear the necessity of research and education in field of excavation and supervision on good implementation of foundations in small and large scale (2). While excavation, reduced soil stiffness and change in stress of the excavated soil could lead to creation of deformation in the wall of foundation of surrounding lands as a result of soil exploration. All decisions made in controlling deformations of a foundation are to prevent their large scale deformation (5 and 6). The cases of dangerous nature of excavation include weakness or sensitiveness of excavation including weakness of sensitivity of adjacent building, depth of foundation, the time that foundation remains open and the level of surface and underground water (3). The effect of building weight in classic calculations and finite element has entered to the engineering literature as a clear phenomenon and the displacements are increased and the reliability coefficient of stability is reduced with increased weight. The geometry of structure in terms of dimensions and its distance from the foundation wall could play key role in the displacements of the environment. Accurate estimation of ground motion is essential in each step of excavation (4). Failure of large number of buildings and the

financial and life losses has increased the importance of estimating and controlling the failure of adjacent buildings of the foundation, so that measurement of seismic behavior of buildings in adjacency of a deep foundation is common in majority of countries (9 and 11). Local measurement in implementation of excavation has two advantages: considerable reduction of project risk and reliable estimation of behavior of building in adjacency of foundation (8). In many engineering projects, because of various factors such as unavailability of required instruments, it is impossible to have local measurements. Hence, the stresses and other changes created in structure should be predicted properly using geotechnical software or other methods, so that the unpredicted undesirable effects of excavation could be minimized. Hence, it is essential to make comprehensive investigation of geotechnical properties of the place, necessity of using capable software, suitable models for simulation of foundations elements such as foundation and maintenance system and considering all environmental conditions for simulation of excavation and obtaining exact results. According to the mentioned, the aim of this study is to investigate the effect of excavation on seismic behavior of adjacent structures using numerical modeling.

LITERATURE REVIEW

Ghahreman (2004) has used advanced hypoplastic model for simulation of the soil behavior in analysis of numerical parameters of foundation and the issues studied in the research have been soil-structure interaction around the deep foundation in sand. This work is implemented in ABAQUS software. The investigations have been performed in two form of with and without presence of building. Moreover, the effect of parameters such as soil density, lateral bracing stiffness, foundation wall stiffness, bracing pre-loading and bracing space were studied.

Liu et al (2015) studied the foundation controlled by diaphragm wall with depth of 15.5m related to the Shanghai station in soft clay. The bracings were made of reinforced concrete in two ends of the plate and in other plates, the steel pipes were pre-stressed. The study showed that the initial measured stress is not reliable. Hence, Liu et al studied only the process of measurements. Because of depreciation of horizontal stress caused by drift of wall to inside the foundation, the ground stress is reduced gradually in steps 2-4. In steps 5-6 of excavation, increased stress was observe din depths of 4 and 14m and Liu has attributed the stresses to pre-stressed nature of steel bracing in this step. For comparison, the pack design in soft clay is also presented. It should be mentioned that the pack results are mostly related to the flexible walls with bracings without pre-stressed force. It is observed that the ground lateral stress in

Shanghai is lower than push pack stresses in depths less than 10m and is higher than it in depth more than 8m.

Kaunda et al (2015) have studied the deformation behavior of the wall and ground caused by braced foundations in the construction of Subway No.8 of Issaquah. The width of foundation was 16.8m and the final depth of the foundation was 21m. to prevent inefficient section of wall, the soil optimization close to the place is taken after the depth of 1.5m and the initial values of each observed data are attributed to the values after the first step of excavation. It was observed that the back ground moves toward the foundation and the lower section is slid along a circle following the drift of wall and its effect is extended to the ground. The ground surface precipitation near the wall is reduced as a result of friction between wall and the surrounding ground and the maximum precipitation happens in a distance from wall in level of 8-60° from lower section of wall. The ground deformation is reduced with increased distance from wall.

Fadavi M (2015) has studied the effect of deep foundations on seismic vulnerability of adjacent concrete structures. In this study, the effects of deep excavation on seismic vulnerability of existing buildings are studied. In this study, a finite element model is used, in which the nonlinear behavior of soil, geology issues, dead and live loads, boundary conditions and soil-structure interaction are studied. According to an accelerogram, the dynamic response of reinforced concrete frame and the status before and after excavation are evaluated. The results obtained from the study showed that significant changes have been created in seismic vulnerability, so that in the state after excavation, the inter-floor drift is increased under horizontal loads and seismic event compared to states before excavation. The momentum was measured before and after excavation and it was increased after excavation. When seismic spectrum was used before and after excavation operations, the momentum caused by earthquake was also increased after excavation and the nonlinear dynamic response also showed that beams have been failed after excavation in some sections and the columns have faced seismic damages in first level.

Modeling

In this study, a braced foundation with nailing system by Plaxis software v8 is used. Plaxis is a 2-D finite element software used to do stability analysis and deformation in various geotechnical uses. Although the applicability of 6 and 15-node elements is available in Plaxis software, 15-node element is used to enhance accuracy of results in this study. Moreover, to model the foundation wall and nails under flat strain conditions, plate element is used with

two main features including bending strength (EI) and axial strength (EA). Therefore, to model the nails, equivalent stiffness should be applied. The information of the foundation and bracing system and shotcrete are presented in tables 1 and 2.

Table 1. Information of foundation and bracing system

Parameters	Values
Foundation depth H (m)	15
Diameter of drilling hole D_{DH} (mm)	10
Nail diameter d (mm)	32
Nail length L (m)	8.14
Nail angle to horizon ($^{\circ}$)	10
Nail yield stress (MPa)	400
Grout yield stress (MPa)	20
Nail elasticity modulation E_n (GPa)	210
Grout elasticity modulation E_g (GPa)	22
Nail Poisson coefficient	0.2
Grout Poisson coefficient	0.2
Nail spaces $S_v * S_h$ (m*m)	1.5*1.5

Table 2. Information of shotcrete for modeling in Plaxis

Parameters	Values
Materials	Elastic
Overall shotcrete height	15
Shotcrete thickness t (mm)	200
Shotcrete yield stress (MPa)	30
Shotcrete elasticity modulation E_{sh} (GPa)	27
Shotcrete Poisson coefficient	0.2

Moreover, in this study, nonlinear analysis is applied with regard to soil-structure interaction before and after excavation and the aim by this action has been analysis of the effects caused by excavation in distribution of seismic waves in defined range. The studied steel structure in this study has moment frame lateral load and 5 stories. The said structure has been designed

in accordance with the Code 2800 (third edition) and National Construction Regulations (chapter 10) using authorized stress method and using ITEX software. The analysis done in this structure is in kind of linear time history analysis, so that the described structures have been analyzed with use of earthquake records in the mode before excavation. The ceiling of the structures is made of block joist with weight of 600kg/m² of dead load and 200kg of live load. The applied sections for beam and column are extracted from the sections available in software library (EURO.PRO). To scale the records, the method mentioned in Standard 2800 is used. To use nonlinear analysis in software, plastic joint method is used. Figure 1 illustrates the modeled structure and table 3 presents the information of materials for the analysis.

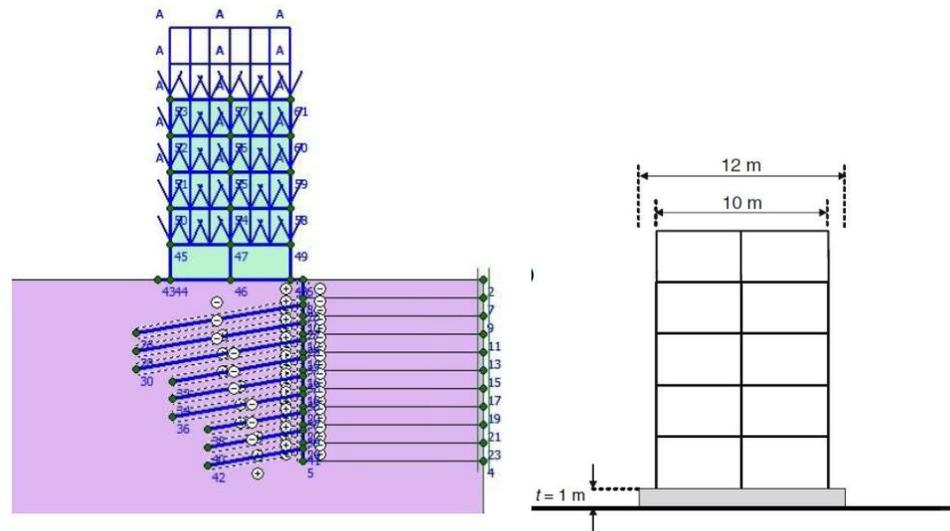


Fig.1. The modeled structure

Table 3. Information of materials for analysis

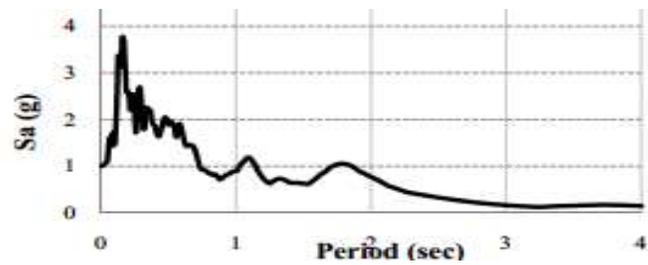
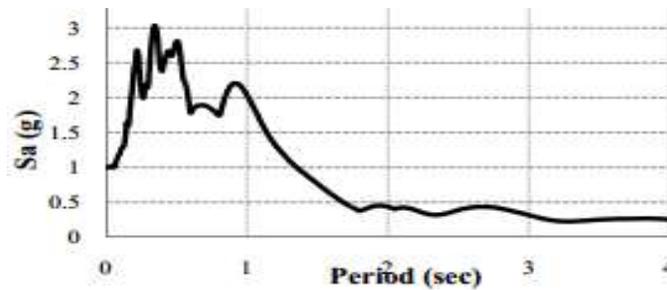
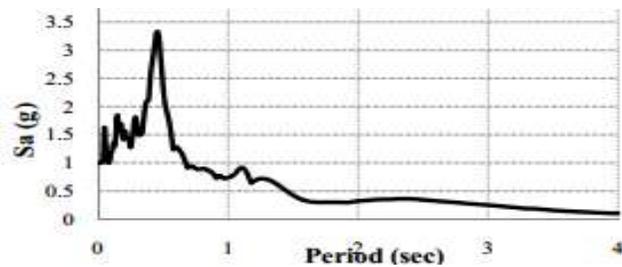
MC	Information
18.5	γ_{unsat} (kN/m ³)
20	γ_{sat} (kN/m ³)
35000	E (kN/m ²)
0.3	V
20	C (kN/m ²)
27	Φ (°)
0	Ψ (°)
-	E_{50}^{ref} (kN/m ²)
-	$E_{\text{oad}}^{\text{ref}}$ (kN/m ²)
-	$E_{\text{url}}^{\text{ref}}$ (kN/m ²)
-	G_0 (kN/m ²)
-	$\gamma_{0.7}$
-	P_{ref} (kN/m ²)
-	M
0.8	R_{inter}

Earthquake records

Selecting the earthquake records near the origin of earthquake is one of the most important parameters affecting the destruction caused by earthquakes. Phenomena such as directness of earthquake could be the effect of the nearness. Directedness caused by a strike emerged at the beginning of time history of earthquake is underlying. The investigations show that Iran's metropolises such as Tehran, Tabriz and many other residential areas like Kerman are located along the active faults and even the extension of these cities over the years has made faults pass throughout the cities (8). According to the mentioned and due to the importance of evaluating near-fault earthquakes, in this study, the desired structure has been firstly exposed to two ranges of near-fault earthquake accelerations and then, the seismic behavior of the structure to the far-fault earthquake range is obtained for better comparison of dynamic behavior of structure. Here, table 4 has presented the information of desired seismic spectra.

Table 4. Applied records

Earthquake	Station	Year	Max acceleration(g)	Type of area
Imperia1 vally	E1 Centro Array	1979	0/4273	Near-fault
Northridge	Sylmar Convertsr Sta	1994	0/3848	Near-fault
Chi Chi	HWA 053	1999	0/02732	Far-fault
Colding	Parkfield Chohame 3 E	1983	0/4432	Far-fault

**Imperia1 vally****Chi Chi****Colding**

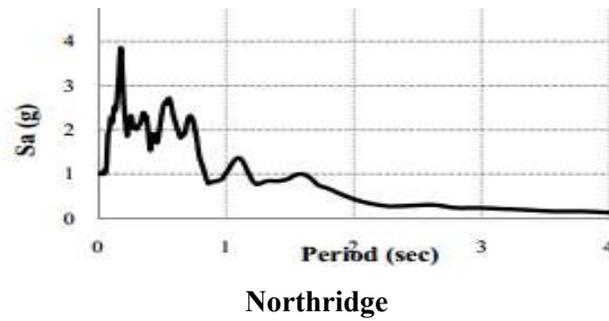


Fig.2. Records of applied earthquakes

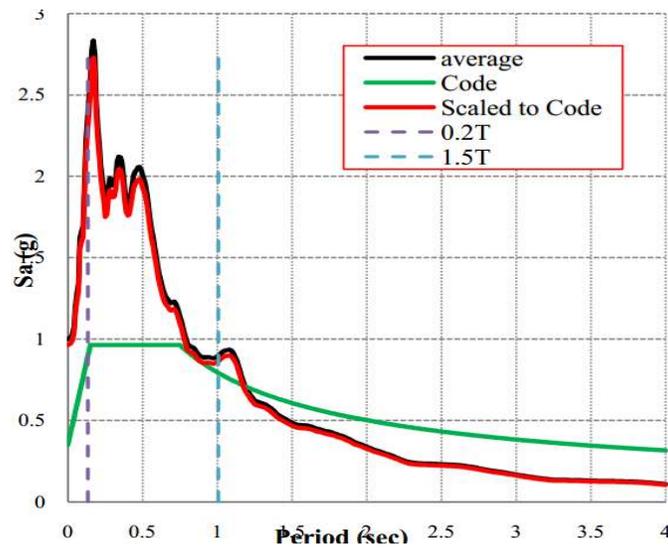


Fig.3. Scaling accelerograms in studied model

RESULTS

Dynamic response of structure under near-fault earthquakes

In this study, the said structure was modeled in SAP software and was exposed to near and far-fault records before and after excavation and maximum lateral deformation of foundation and stories was evaluated. The results obtained from the study are presented in tables 5-8.

Table 5. Dynamic responses of structure before excavation of near-fault Imperial Vally (near-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	0	0
Storey 1	1.03	508.87
Storey 2	2.1	654.66
Storey 3	2.65	876.34
Storey 4	2.98	934.3

Table 6. Dynamic response of structure after excavation under seismic spectrum of Imperial Vally (near-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	25.3	336.35
Storey 1	26.08	331.87
Storey 2	26.9	332.45
Storey 3	27.3	333.34
Storey 4	27.78	334.3

Table 7. Dynamic response of structure before excavation under seismic spectrum Imperial Vally (near-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	0	0
Storey 1	15.3	768.32
Storey 2	2.87	931.43
Storey 3	3.89	1123.35
Storey 4	4.45	1214.12
Storey 5	4.97	1296.14

Table 8. Dynamic response of structure after excavation under seismic spectrum of Northridge (near-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	47.43	501.36
Storey 1	48.08	476.65
Storey 2	50.1	487.35
Storey 3	51.45	523.90
Storey 4	60.18	553.42
Storey 5	64.88	571.58

Dynamic response of structure under far-fault earthquake areas

In this study, the said structure was modeled in SAP software and was exposed to far-fault records in modes before and after excavation and maximum lateral drift of base and floors was evaluated. The results are presented in tables 9-12.

Table 9. Dynamic response of structure before excavation under Chi Chi seismic spectrum (far-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	47.43	501.36
Storey 1	0	23.8
Storey 2	0.2	50.32
Storey 3	0.2	64.39
Storey 4	0.24	73.9
Storey 5	0.27	79.65

Table 10. Dynamic response of structure after excavation under Chi Chi seismic spectrum
(far-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	0.5	27.64
Storey 1	0.6	31.7
Storey 2	0.7	38.4
Storey 3	0.7	41.31
Storey 4	0.8	44.3
Storey 5	0.8	48.23

Table 11. Dynamic response of structure before excavation under Colding seismic spectrum
(far-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	0	0
Storey 1	0.2	71.7
Storey 2	0.3	105.4
Storey 3	0.4	121.34
Storey 4	0.5	133.93
Storey 5	0.6	143.14

Table 12. Dynamic response of structure after excavation under Colding seismic spectrum
(far-fault)

Stories	Max lateral drift(mm)	Max absolute momentum of floors cm/s^2
Base	1.9	94.3
Storey 1	2.1	104.77
Storey 2	2.3	106.99
Storey 3	2.3	111.04

Storey 4	2.5	123.13
Storey 5	2.6	131.19

CONCLUSION

In this study, through modeling the soil in excavated mode stabled conventionally using nailing system in adjacency of a 5-storey steel building and using Plaxis software by use of soil surface records before and after excavation, the 5-storey steel structure was designed and the structure responses were derived through applying soil surface records before and after excavation. Then, the structures were compared under far and near fault earthquakes in two modes of before and after excavation. The results obtained from the study are as follows:

- 1- In the mode after excavation, in case of applying near-fault area accelerograms, the drift of floors was equal to 0.32%; although in case of applying far-fault area accelerograms, insignificant change was created in relative drift in some floors.
- 2- The excavation caused increased lateral drift of floors compared to the mode before excavation and the increase in near-fault area was more than far-fault area.
- 3- Before excavation and under the mode of applying accelerograms of near-fault area, the maximum absolute acceleration of floors reached 43.5% and in mode of applying far-fault accelerograms, maximum absolute acceleration of floors reached 22.3% in some floors.

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