International Journal of Engineering

Journal Homepage: www.ije.ir

RESEARCH NOTE

Behavior of Raft Foundation Built on Layered Soil under Different Earthquake Excitation

A. H. Ali, H. O. Abbas*, S. H. Abed-Awn

Department of Civil Engineering, University of Diyala, Diyala, Iraq

PAPER INFO

Paper history:
Received 20 February 2022
Received in revised form 21 March 2022
Accepted30 March 2022

Keywords:
Earthquake
Raft
Layered Soil
Numerical

ABSTRACT

Achieving the stability of buildings and facilities against any external influence, such as winds, storms, or earthquakes, depends primarily on the foundations supporting them, which are responsible for transferring those loads to the soil layers beneath them. Accordingly, the design of the foundations to be safe withstand these static and dynamic loads without causing dangers or failures on these structures has recently become the focus of the attention of many researchers. The task of this paper is to predict the behavior of shallow raft foundations supporting loads of structures under the influence of earthquakes in Baquba city and what results from them from downfall and displacement risks. To simulate the soil-foundation model for the study, numerical modeling was used depending finite element approach. Different thickness of raft foundation under different earthquake acceleration-time records that simulate with a Linear Elastic model (LE) built on layered soil represented by Mohr-Coulomb model (MC). The results from this analysis showed properties of soil are used for this study play a vital role in the ground response to the propagation waves. Also observed from the results that an increase in both lateral and vertical displacement as the duration of earthquake increases and raft thickness decreases, but these displacements decreased when the thickness of raft foundation increased from 0.8m to 1.6m are about 9% and 68%, respectively.

doi: *10.5829/ije.2022.35.08b.07*

1. INTRODUCTION

Studying the behavior of shallow foundations under earthquake excitation, especially in active seismic areas has attracted the attention of several researchers in the last years. The phenomenon of earthquakes is considered one of the most dangerous natural disasters, that occurs without warning and causes the damage of any building or structure through settlement, ground cracking, and loss bearing capacity of soil-foundation. In comparison to the static case, the design of foundations in seismic areas necessitates special considerations. Seismic risk mitigation is one of the most difficult challenges in civil engineering, and geotechnical earthquake engineering can make an important contribution to this challenge [1]. The earthquake-related ground motion can have several effects on the shallow foundation: (i) During an earthquake, cyclic loss of soil strength could lead to bearing capacity collapse; (ii) The foundation may break due to a large horizontal inertial force caused by an earthquake, resulting in sliding or overturning; significant settlement and tilting; (iii) After an earthquake, the ground softens or fails due to pore water pressure redistribution, which might compromise the foundation's post-seismic stability [2]. In today's design practice, the geotechnical earthquake engineer is frequently in charge of delivering acceptable design ground motions to the structural engineer [3]. As a result, foundation engineers must keep abreast of technological advancements in these domains, or be well informed in these fields, to achieve cost-effective and safe designs. There is still a lot of work to be done in developing methodologies to evaluate seismic bearing capacity and earthquake-induced permanent displacements in shallow and deep foundations [4].

Many academic researchers have been interested in studying the real behavior of different types of foundations, raft foundations subjected to different

* Corresponding Author Email: temimi71@yahoo.com (H. O. Abbas)

Please cite this article as: A. H. Ali, H. O. Abbas, S. H. Abed-Awn, Behavior of Raft Foundation Built on Layered Soil under Different Earthquake Excitation, ***International Journal of Engineering, Transactions B: Applications***, Vol. 35, No. 08, (2022) 1509-1515

earthquake values to evaluate and interpret their performance using various methods. Conducted research by Roy [5] on strength considerations, which essentially entails ensuring that foundation loads remain well below those dictated by the allowable bearing capacity under seismic conditions, and serviceability is ensured by designing the substructure for the estimated permanent ground deformation. Uncomplicated procedures are presented for assessment bearing capacity and permanent ground deformation below earthquake conditions. Numerical simulation performed by Vali [6] to assess the settlement and safety factor of a reinforced marine soil-footing system on marine soft soil layers on Qeshm Island in the presence of a water table with finite element method used for this study, because of the erratic fluctuations in the water table on such poor soils; it was found the settlement was reduced while the safety factor of the soil-footing system was increased by lowering the water table. Numerical analysis by finite element was conducted by Shafiqu and Abdulrasool [7] to predict the behavior of raft foundation during different excitation of earthquakes, taking into consideration the influence of some parameters, such as raft stiffness and thickness, the maximum lateral displacement of soil under the foundation, vertical settlement, and influence the earthquake acceleration-time records. Plaxis 3d computer program is used in this study. The results of the parametric study for all sites showed that the settlement caused by the earthquake can be decreased by about 72% by increasing the thickness from 0.5 m to 1.5m. Also, it was founded that the value of the maximum lateral displacement and vertical settlement depends on the magnitude of the seismic wave and the peak ground acceleration of the earthquake. Another study was conducted by Al-Ameri et al. [8] to explain the effect of the earthquake (California, El-Centro earthquake is used) on the vertical and lateral displacement of the foundation numerically using the finite element analysis Abaqus program. The thickness of the foundation was studied in three different values which were (0.5, 1, and 2 m), as well as the depth of the soil layer under the foundation was taken (10, 20, and 40 m), and the soil stiffness ratio studied too. They concluded that as the earthquake's duration increases, so does the vertical displacement. In addition, as the depth of the soil layer beneath the foundation increases, both vertical and horizontal displacements diminish. They also discovered that increasing the foundation thickness minimizes lateral movement while having no discernible effect on vertical displacement. The reason for this is that the earthquake force is directed perpendicular to the foundation's base, and this displacement diminishes as the earthquake force increases. Increasing the distance between the wave's beginning point and the base is due to an increase in the influence of soil damping on earthquake forces. Srilakshmi and Rekha [9] investigated the MAT foundation. However, theoretical studies on the MAT foundation are relatively scarce. Furthermore, traditional methods for analyzing MAT foundations, such as the rigid method and the flexible method, are cumbersome and time-consuming. To overcome these limitations, the authors of these papers attempted to analyze the MAT foundation using the Finite Element Method. When compared to all other methods, FEM is the most efficient for complex boundaries and nonlinear material properties. ANSYS finite element software was used to analyze the MAT foundation in this work. The scope of this paper is limited to 2-D axisymmetric nonlinear analysis in medium sand concerning geometric features such as MAT foundation size and thickness under compression. While the MAT is treated as linear, the soil and soil-mat interface is treated as nonlinear, with the Drucker-Prager constitutive model used for the soil. The nonlinear analysis is a mixed method that is incremental and iterative, resulting in greater accuracy. The findings of this analysis will continue to pique the interest of MAT foundation designers. Bearing capacity's behavior and the resulting settlement for the rectangular, circular, and square shallow footing foundation were studied by Lwti et al. [10]. In addition, It is used in this study three modes of (D/B) ratios (0, 1/3, and 2/3) with three cases of footing depth (rested on the ground surface, below the ground surface with 0.5 and 1m) under earthquake loading by the numerical simulation using finite element analysis. The results indicate that the square shape was less settlement and high bearing than other shapes of footings, a linear relationship between the depth of footing and settlement under the effect of earthquake loading, and the magnitude of dynamic bearing capacity and settlement has been affected by the footing shape.As Iraq's seismicity has increased in a general and discernible way from south to north and West to East [11]. After a major 7.3 magnitude earthquake struck the Iraq-Iran border in November 2017, killing more people and injuring thousands more [12]. Accordingly, it became necessary to investigate the behavior of the soil-foundation system under these seismic activities due to a direct and destructive effect on the foundations of the buildings.Therefore, the objective of this paper is to predict the behavior of the raft foundation on silty soil subjected to different waves of earthquakes, considering the effect of raft thickness on the maximum settlement of the foundation, PLAXIS 3D 2020 finite element has been used for this axisymmetric simulation in Baquba city, Iraq [13].

2. FINITE ELEMENT ANALYSIS FOR CASE STUDY

A three-dimensional analysis for a soil-foundation system of a four-multi-story building located in Baquba city in the Diyala governorate in Iraq, Northeast of

Baghdad. All the geotechnical reports, data, and important properties were available and listed in PLAXIS 3D Manual [13]. The geometry model for this study consists of raft foundation with square shape is suggested for analysis with dimensions (18.5x18.5x0.8 m) embedded in a (40x40x30 m) soil media is used as a type of shallow foundation to evaluate the behavior of shallow foundation under earthquakes in Baquba soils. A common geometry of the model, soil layers together with raft foundation, surface loads (dead and live load) 70 kN/m^{2,} and multiplier loading of the earthquake as shown in Figure1.

2. 1. Constitutive Models For Simulating Material

In general, the model of this study includes two parts of material soil and raft foundation. soil domain with square two layers represented by an elastic perfectly plastic (Mohr-Coulomb model). The failure envelope demonstrates that the points of stress under the line represent elastic behavior, and when the stress circles contact the failure line, the soil behavior changes from elastic to plastic. Mohr-Coulomb is commonly used for mostly geotechnical problems than other models as considered simple, easily used, and computations are relatively quick [14, 15]. Another part of the concrete foundation is molded by (thelinear elastic model), based on isotropic elasticity Hook's law. The flow is fed by several cases. The deformation analysis in PLAXIS software, the soil drained response of long time analysis, the soil undrained response of short term without considering the development of pore pressure, as the change of stress (the loading and unloading), excess pore water pressure will generate as a combination with time. As water level lies 1.5m below the ground surface, which can be represented in plaxis software of clay soil with short-term behavior (undrained A) in which the properties ineffective state and sand soil with long-term behavior (drained) high permeability. The properties for the foundation materials and soils are summarized Tables 1 and 2.

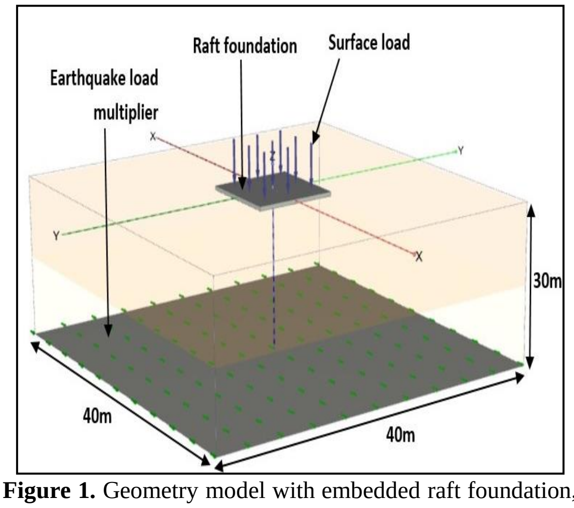

Figure 1. Geometry model with embedded raft foundation, surface load, and load multiplier of the earthquake

2. 2. Elements and Meshing

After completing the geometry model, PLAXIS 3D allows for a fully automatic to generate mesh, that is a collection of the finite element by dividing the model into volume elements taking full account soil stratigraphy, all structural objects, loads, and even boundary conditions. There is more than one selection of degree mesh start from very coarse to very fine, it is used in this study tetrahedral elements with 10 nodes, according to PLAXIS 3D Manual [13] strain is constant in the element and for accuracy results used with very fine mesh, but to avoid lengthy calculations time used medium-mesh as demonstrated in Figure 2. The relationship between the foundation and soil surrounding is rigid that delineates soil-foundation interaction, which means there is no relative displacement between these two materials. Raft

TABLE 1. Properties of the concrete foundation

Property	Unit	Value
Elastic Modulus	(kN\m^2)	3x10^7
Unit Weight	(kN\m^3)	34
Poisson's Ratio	-	0.15

TABLE 2. Properties of soil layers.

Type of soil	Soft clay	Silty sand
Interface	Rigid	Rigid
Elastic Modulus(kN/m^2)	7000	49000
UnitWeight of Soil(kN/m^3)	20	19
Poisson's Ratio	0.4	0.3
The angle of internal friction	-	40
Cohesion(kN/m^2)	28	-

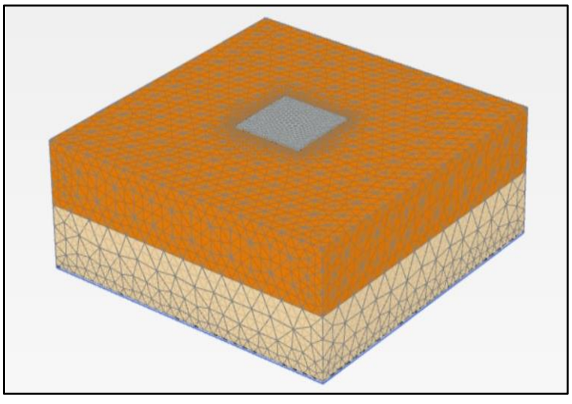

Figure 2. Medium mesh of raft footing and soils

foundation elements in full contact with soil elements [13]. Therefore, the interface element used has zero thickness.

2. 3. Definition of Earthquake and Boundary Condition The input motion used in this study is defined as dynamic surface load (load multipliers) at the bedrock level of the model as illustrated in Figure 3. The acceleration time history for three earthquakes selection in this search EL-Centro, Ali-Gharib, and Halabja that applied along the X-direction at the bottom boundary of the 3-D model in m/s^2 and s, respectively. In reality, the seismic waves propagate to infinity within the soil, according to this fact, and to prevent the sudden reflection of these waves on the model boundaries. Absorbent boundaries (viscous boundaries) are defined in Xmax, Xmin, and Zmin of the soil domain to absorb the incoming wave energy and a free move in all directions of the ground surface.

3. RESULTS AND DISCUSSION

The results of the numerical analysis of the model after completing all calculations of stage construction including excavation, raft construction, static and dynamic loads, that developed for this paper using the finite element method. The analysis is conducted to predict the behavior of raft foundation lateral displacement and vertical settlement under different distractive earthquakes: the first one is the EL-Centro earthquake 1940 with a local magnitude of 6.9, other earthquakes, 2017 Halabja earthquake with ML=7.3 was a record on Richter scale in the north of Iraq and Ali Al-Gharbi earthquake with ML=4.8 in the south of Iraq. In addition, the effect of raft thickness with (0.8m,1m,1.2m,1.4m and 1.6m), that discussion in the following section:

3. 1. Free Vibration of Soil The results of the free field analysis or as known free vibration of the soil deposits under the input earthquake motion as illustrated in Figure 4. This analysis describes the distribution and propagation of the seismic waves from bedrock to the surface soil, to get the response of soil layers of the model without any structure on or within it. It can be noted from the figure, the maximum lateral displacement occurs at the end of each one of the applied earthquakes and the minimum value at the start of wave propagation, this reason is related to the geophysical and mechanical properties of the soil layers under the foundation, that means the soil layers are silty sand (SH) to upper layers lean clay (CL) soft clay make the values of shear (V_s) and compression waves (V_p) lower than sandy soils. The second reason is when the duration of an earthquake increases the lateral displacement of soil increases with a reduction of the bearing capacity of those soil.

3. 2. Earthquake Loading The earthquake loading was applied to the raft foundation set above two layers of soil. Three situations of the earthquake were studied: the first one, the El-Centro earthquake (PGA) of intensity 0.35g was applied horizontally to the soil model while the foundation was subjected to surface load; and in the second situation, the Halabja earthquake (PGA) of intensity 0.1g; in the final situation, Ali AL-Gharbi (PGA) also of intensity 0.1g. Figure 5 shows the amount of lateral displacement resulting from EL-Centro load is higher than both of Halabja and Ali Al-Gharbi

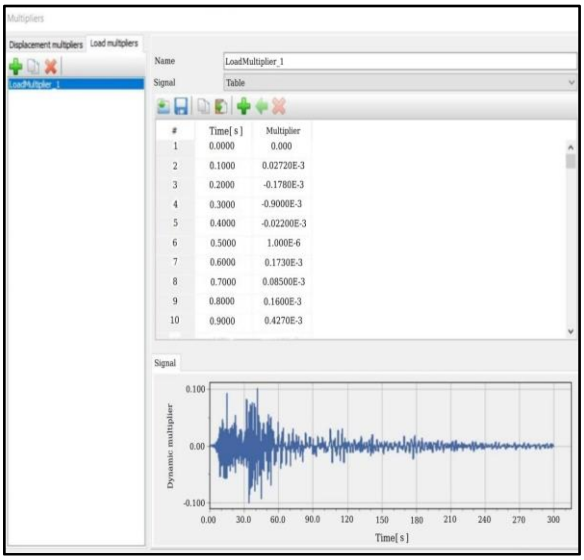

Figure 3. Acceleration –time history of Halabja earthquake

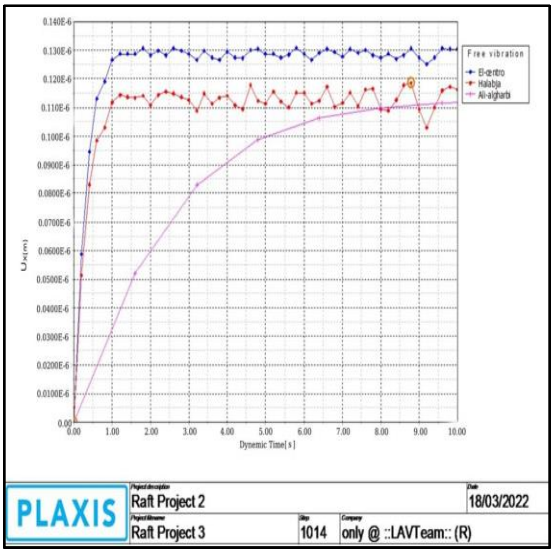

Figure 4. Lateral displacement of soil with time under different earthquakes

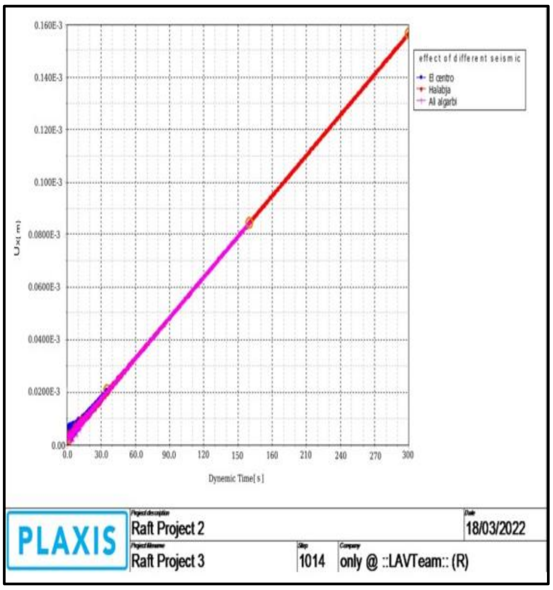

Figure 5. Dynamic time versus lateral displacement on foundation under different earthquakes

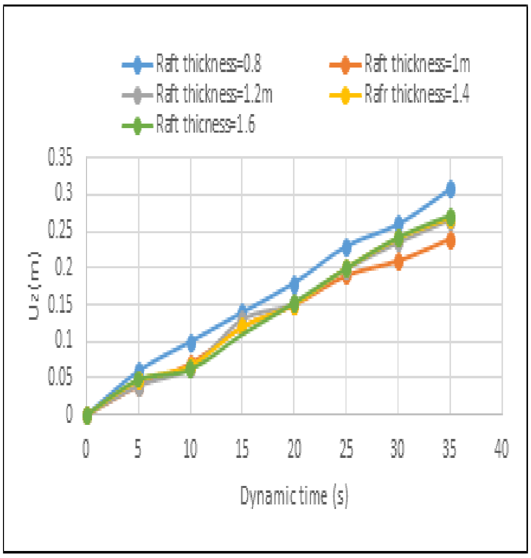

Figure 6. Vertical settlement versus dynamic time with different thicknesses placed on soil layers under El-Centro earthquake

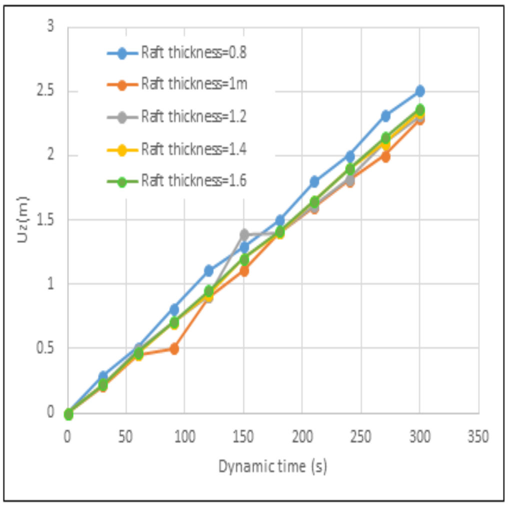

Figure 7. Vertical settlement versus dynamic time with different thicknesses placed on soil layers under Halabja earthquake

earthquakes at the beginning of loading, after the end of the EL-Centro earthquake period the oscillation of displacement with time is constant for values and start to increase with time acceleration of the other earthquakes to values about 5% from the previous increase. This may be to the displacement depending on the duration of the seismic waves and magnitude [16], in addition to the peak ground acceleration of the earthquake.

3. 3. Effect of Raft Foundation on Displacement

The influence of different raft thicknesses (i.e., T=0.8, 1, 1.2, 1.4 and 1.6m) which is embedded in soil models with two layers of soil lean clay and silty sand, concerning the vertical settlement and lateral displacement under different earthquake excitation is studied. In general, it can be noticed from the results, the maximum value of vertical settlement occurred in the lowest thickness of foundation (0.8m) under the Halabja earthquake is about 89% more than the value that occurred under the El-Centro earthquake and more than that under the Ali Al-Gharbi about 47%. As shown in Figures 6 to 8, the vertical settlement represents the highest values with 0.8m thickness for all earthquakes loading and being to reduce to 9% when gradually, the thickness of raft foundation increases even (1.6m). Also with every increase of raft thickness, the settlement was been at lower values with the beginning of the earthquake and increases with time of it, this response was generated due to an increases in the duration of an earthquake application on the model of study, an increase in the displacement foundation and, in addition to the state of soil layer beneath the foundation as soft clay soil that means has low strength properties to resist the application of earthquake loading. The lateral displacement of soil under the foundation has the same behavior pattern as vertical displacement because affected by changing the multiplier of the input motion of earthquakes, but the lateral displacement decreased by more than vertical, which is about 68% when the thickness of the raft foundation changed from (0.8 m) to (1.6m). From the above literature survey and the findings obtained are that there is a good agreement with data reported by Shafiqu and Abdulrasool [7] and Al-Ameri et al. [8] in different proportions due to the nature of each study that was

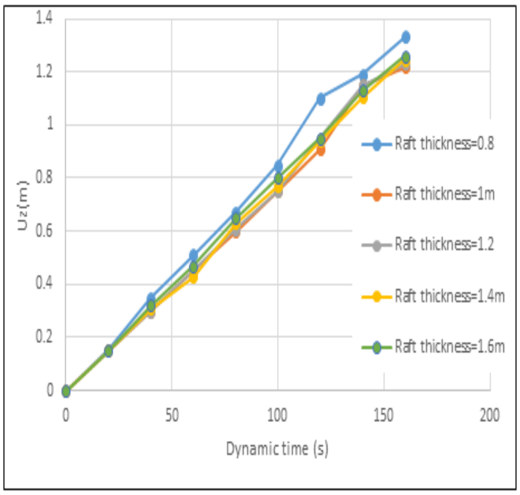

Figure 8. Vertical settlement versus dynamic time with different thicknesses placed on soil layers under the Ali Al-Gharbi earthquake

conducted according to different criteria. This agreement concluded that changing the thickness of the foundation under the same study conditions towards higher values than 0.8m reduces the displacement, and when PGA increases the displacement increases.

4. CONCLUSIONS

In this paper, three-dimensional numerical simulations were carried out for the dynamic behavior of the raft foundation on layered soil under different earthquake excitation. The most important observations from this simulation are the following points that can be derived from the study′s findings.

1. The geotechnical and geophysical properties of soil are used with constitutive MC model for this study play a vital role in the ground response to the propagation waves.

2. The maximum and minimum lateral displacement of the raft foundation is 3mm and 0.35mm, respectively. The values are found under the influence of the Halabja earthquake, at 0.8m thickness, the higher value and 1m thickness the less value.

3. The vertical and lateral displacement of the foundation increases as the duration of the earthquake increase, and decrease when the thickness of the foundation increases. The vertical decreased about 9%, but the lateral displacement decreased by more than vertical is about 68% when the thickness of the raft foundation changed from (0.8 m) to (1.6m).

4. It can be noticed that the results of the vertical displacement from the Halabja earthquake applied with local magnitude (7.3) are greater is about 89% than from the El-Centro with (6.9ML), and 47% than Ali Al-Gharbi earthquake with (4.8ML).

5. REFERENCES

1. Kulkarni, P.R. and Sambre, T.R., "Literature review on effects of/.,m87 lateral forces on shallow foundations", ***International Journal of Emerging Science and Engineering***, Vol. 3, No. 10, (2015), 10-14. ISSN: 2319–6378.
2. Puri, V.K. and Prakash, S., "Shallow foundations for seismic loads: Design considerations", In International Conference on Case Histories in Geotechnical Engineering, (2013), 1-16.
3. Hair, J.F., Black, W., Babin, B., Anderson, R. and Tatham, R., "Pearson new international edition: Multivariate data analysis", ***Exploratory Data Analysis in Business and Economics***, (2014), 23-60.
4. Fattah, M., Karim, H. and Al-Recaby, M., "Dynamic behavior of pile group model in two-layer sandy soil subjected to lateral earthquake excitation", ***Global Journal of Engineering Science and Research Management***, Vol. 3, No. 8, (2016), 57-80.
5. Roy, D., "Design of shallow and deep foundations for earthquakes", ***Journal of Geotechnical Earthquake Engineering***, (2013), 1-8.
6. Vali, R., "Water table effects on the behaviors of the reinforced marine soil-footing system", ***Journal of Human, Earth, and Future***, Vol. 2, No. 3, (2021), 296-305.
7. Shafiqu, Q.S.M. and Abdulrasool, M.A., "Finite element analysis of raft foundation on various soil types under earthquake loading", ***International Journal of Architectural and Environmental Engineering***, Vol. 12, No. 9, (2018), 799-809. https://doi.org/10.5281/zenodo.1474315
8. Al-Ameri, A., Jawad, F. and Fattah, M., "Vertical and lateral displacement response of foundation to earthquake loading", ***International Journal of Engineering***, ***Transactions A: Basics,*** Vol. 33, No. 10, (2020), 1864-1871. doi: 10.5829/IJE.2020.33.10A.05.
9. Srilakshmi, G. and Rekha, B., "Analysis of mat foundation using finite element method", ***International Journal of Earth Sciences and Engineering***, Vol. 4, No. 6, (2011), 113-115.
10. Lwti, N.K., Al-Hamdani, D.A., Abbas, M.F. and Albusoda, B.S., "Numerical studies of shallow footing subjected to earthquake loading", in AIP Conference Proceedings, AIP Publishing LLC. Vol. 2404, (2021), 080019. https://doi.org/10.1063/5.0070651
11. Abd Alridha, N. and Mohammed, H.J., "Seismicity study of khanaqin area", ***Iraqi Journal of Science***, Vol. 56, No. 1A, (2015).
12. Al-Taie, A.J. and Albusoda, B.S., "Earthquake hazard on iraqi soil: Halabjah earthquake as a case study", ***Geodesy and Geodynamics***, Vol. 10, No. 3, (2019), 196-204. https://doi.org/10.1016/j.geog.2019.03.004
13. Manual, T., "Plaxis 3d", Delt University of Technology &PLAXIS, Netherland, (2016).
14. Waheed, M. and Asmsil, N., "Study simulation of shallow foundation behavior using different finite element models", ***Journal of Advanced Civil Engineering Practice and Research***, Vol. 8, (2019), 4-9.
15. Lancellotta, R., "Geotechnical engineering, CRC Press, (2008).
16. Toh, J. and Pender, M., "Earthquake performance and permanent displacements of shallow foundations", in Proceedings of New Zealand National Society for Earthquake Engineering Annual Conference, Citeseer. (2008).

Persian Abstract

چکیده

دستیابی به پایداری ساختمان ها و تأسیسات در برابر هر گونه تأثیر خارجی مانند باد، طوفان یا زلزله، در درجه اول به پایه های نگهدارنده آنها بستگی دارد که وظیفه انتقال آن بارها به لایه های خاک زیر آنها را بر عهده دارند. بر این اساس، طراحی پی برای ایمن بودن در برابر این بارهای استاتیکی و دینامیکی بدون ایجاد خطر یا خرابی بر روی این سازه ها اخیراً مورد توجه بسیاری از محققین قرار گرفته است. وظیفه این مقاله پیش‌بینی رفتار پی‌های رافت کم عمقی است که بارهای سازه‌ها را تحت تأثیر زلزله در شهر بعقوبه نگه می‌دارند و آنچه که در نتیجه آنها از خطرات ریزش و جابجایی حاصل می‌شود. برای شبیه‌سازی مدل خاک–پی برای مطالعه، از مدل‌سازی عددی بسته به رویکرد اجزای محدود استفاده شد. ضخامت های مختلف پایه قایق تحت رکوردهای مختلف شتاب–زمان زلزله که با یک مدل الاستیک خطی (***LE***) ساخته شده بر روی خاک لایه ای شبیه سازی شده توسط مدل ***MC)Mohr-Coulomb***) شبیه سازی شده است. نتایج حاصل از این تجزیه و تحلیل نشان داد که خواص خاک برای این مطالعه استفاده شده است، نقش حیاتی در پاسخ زمین به امواج انتشار دارد. همچنین از نتایج مشاهده شد که با افزایش مدت زلزله و کاهش ضخامت کلک، افزایش جابجایی جانبی و عمودی افزایش می یابد، اما این جابجایی ها با افزایش ضخامت پی رافت از ۰.۸ متر به ۱.٦ متر، به ترتیب حدود ۹٪ و ٦۸٪ کاهش یافته است.