Bilad Alrafidain Journal for Engineering Science and Technology
https://dx.doi.org/10.56990/bajest/2024.030212
ISSN: 2073-9524
Page: 160-165

# Effect of Lateral Load on the Behavior of Single Piles Subjected to Earthquake Load in Sand

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**Abstract**

In fact, piles usually carry static and dynamic loads at the same time, in the case of simulations lateral and dynamic loads are possible to occur. This case is not covered enough by previous research, especially by laboratory models. Therefore, the purpose of this study is to determine the extent to which altering the horizontal lateral loads impacts the behavior of individual piles during seismic events. An experimental test was devised using a physical model with an advanced shaking table that used the El Centro earthquake. Sandy soil with 65% relative density used the raining technique. Lateral loads were applied at levels of 0%, 50%, and 100% from allowable lateral load capacity. It was observed that when the lateral load increased from 0% to 50% and 100%, the lateral displacement response decreased by 32.10% and 49.59% respectively. Meanwhile, vertical displacement increased by 49.96% and 76.95%. Finally, the acceleration decreased by 34.39% and 41.03%. This is possibly due to the load acting at an angle opposite to the earthquake as a restraining factor for the pile. led to a decrease in lateral displacement, vertical displacement, and peak ground acceleration.

**Keywords**: Pile Foundation, Sandy Soil, Laterally Load, El Centro.

***Article history: Received:***9-6-2024***, Accepted:*** 10-7-2024***, Published:*** 15-9-2024



## 1. Introduction

Seismic stability and safety are very important in the whole building service. Thus, understanding the behavior of individual piles under seismic loads is very justified. Single piles during seismic events have to deal with various challenges like compressive axial loads and lateral forces [1]. However, there are several things that may be taken into account when designing single piles for seismic performance including soil type, pile material, and loading characteristics. The general capacity to resist earthquake induced lateral loads greatly depends on the number of piles as well as their arrangement [2].

Single pile structures are usually cylindrical columns that can either be solid or hollow filled with concrete sometimes reinforced with steel bars or other materials to increase their load carrying capacity [3]. Thus, in areas prone to earthquakes it is necessary to determine resistance capacities considering both the types of soils and levels of seismic hazards [4]. Many investigations have been done on how individual piles perform under strong motions caused by ground shaking during an earthquake, particularly on their ability to resist horizontal forces in different circumstances [5].

Vertical piles are commonly used in foundation systems especially where there is a high risk of earthquakes due to their capability to provide structural stability against dynamic actions such as strong ground motions generated by this natural disaster. However, these advantages need further exploration through research aimed at enhancing design efficiency based on performance improvement measures taken from experiments

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https://dx.doi.org/10.56990/bajest/2024.030212 ISSN: 2073-9524
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carried out under varying conditions involving different dynamic loadings and soil states [6].

Further research should be done to ensure safety during construction projects in earthquake-prone areas as vertical piling is still one area of seismic engineering that lacks depth understanding [7]. The growing interest in using single piled foundations subjected to different inherent levels of horizontal lateral loads for bridge piers; and offshore platforms among others has shown how little knowledge is available about them when earthquakes occur nearby [8]. This study investigates the influence of horizontal lateral load value on single pile response under seismic excitation in sand.

## 2. Laboratory Work

### 2.1 Material Used

The laboratory experiments that were done on the sandy soil used in this study are summarized in Table 1. Such table describes the soil properties of Karbala, an Iraqi province. Different tests were carried out to give information to understand more about such soil.

**Table 1:** Results of laboratory tests for sandy soil.

| Properties | Value |
|---|---|
| Maximum, γd (max.) (kN /m$^3$) | 17.65 |
| Minimum, γd (min.) (kN /m$^3$) | 14.85 |
| Maximum void ratio, $e_{max}$ | 0.81 |
| In place void ratio, $e_0$ | 0.59 |
| Minimum void ratio, $e_{min}$ | 0.5 |
| Initial dry unit weight, γd (kN/m$^3$) | 16.56 |
| Relative density Dr. (%) | 65 |
| Effective size, D10 (mm) | 0.18 |
| D30 (mm) | 0.29 |
| Mean size, D50 (mm) | 0.41 |
| D60 (mm) | 0.47 |
| Coefficient of uniformity, Cu | 2.61 |
| Coefficient of curvature, Cc | 1.11 |
| Classification (USCS) | SP |
| Specific gravity, Gs | 2.67 |
| Angle of Internal Friction (Ø) | 36° |
| Cohesion (c) (kN/$m^2$) | 0 |

### 2.2 Soil Container

A 50x50x60 cm steel container was used during the work. The tank is made of a 4 mm thick steel plate and has been treated to prevent corrosion and lined with cork to stop sparks from flying out (2 cm). This container is shown in Fig.1 below.

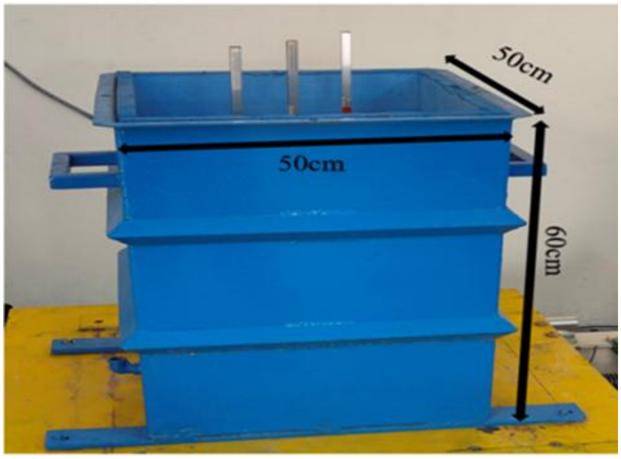


**Fig. 1** Soil container

### 2.3 Pile

Fig. 2 shows the use of hollow circular aluminum tubes, 1.6 cm in diameter and 44.8 cm in entire length, as single piles with an L/D ratio of 28. Whereas, Experimental details of the machine foundation and shaking table device are displayed in Fig. 3.

**Fig. 2** Pile used

### 2.4 Model apparatuses

The model apparatus used during this study consists of the following:

1. Steel container with dimension (50*50*60) cm.
2. Piles model.
3. Sensors to measure vertical displacement (two Lvdt).
4. Sensors to measure lateral displacement.
5. Hoper raining sand.
6. Shaking table device.
7. Lateral load application.
8. A sensor to measure the pile acceleration

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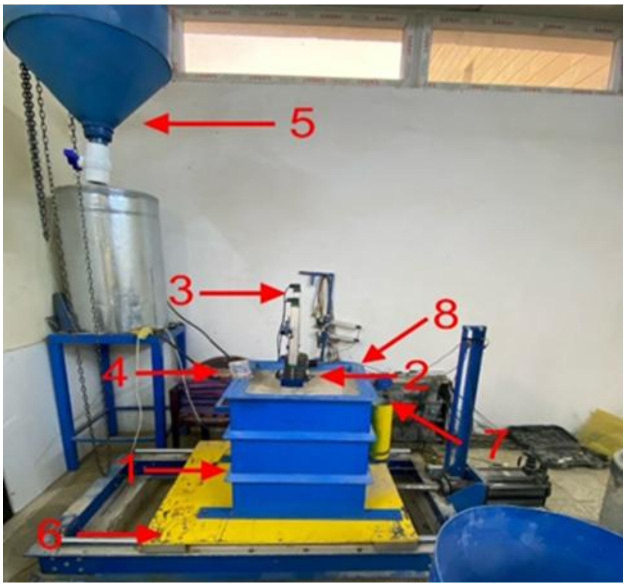


**Fig 3.** Experimental details of the machine foundation and shaking table device

### 2.5 Testing Apparatus

The container was placed on a shaking table apparatus and securely fastened with screws to prevent displacement during seismic testing. The sand-raining hopper method, as described by Vaid and Negussey [9], Rad and Tumay [10], and LoPresti et al. [11], was utilized. The sand was poured into the container from the hopper at a fixed height of 115 cm, with the hopper then raised 10 cm above the final sand level inside the container. This process continued until the desired level was reached. In this study, the lateral loading was set to be equal to 20% of the applied axial loading for all types of piles, following ASTM D3966-07 (2013) [12] standards. Consequently, an axial load of 50% is 5 kg was applied, with an applied lateral load of 0 kg, 2.5 kg, and 5 kg which represents 0%, 50%, and 100% of the ultimate derived lateral load capacity respectively. The lateral load equals 20% times the axial load.

A shaking table is a tool that replicates earthquakes to see how they affect piles in sandy soil. Five main parts make up this instrument: a strong steel frame, a base table with an immovable steel container inside it, the horizontal motion control servo motor, the ball screw mechanism that changes rotational motion into linear displacement and is driven by a servo drive controlled by complicated software. Accelerometers and linear variable displacement transducers are among the sensors used for measuring and calibrating the performance of this machine so as to achieve accurate replication of seismic events. The input earthquake utilized in this study (El - Centro) is shown in Fig. 4.

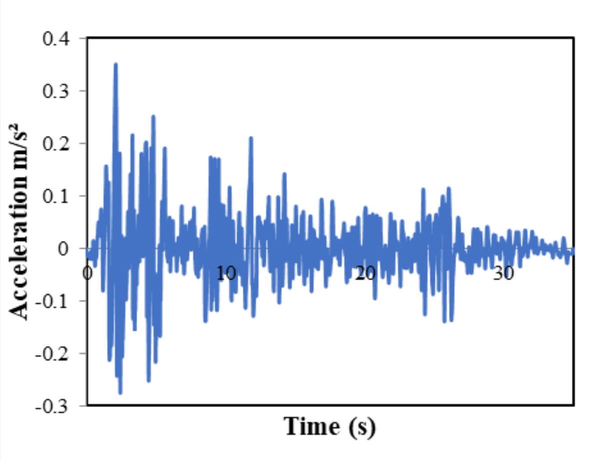


**Fig. 4** El-Centro input motion

The raining technique was applied to get a relative density of 65% in the study area. Fig. 5 shows the experimental curve derived from these calculations.

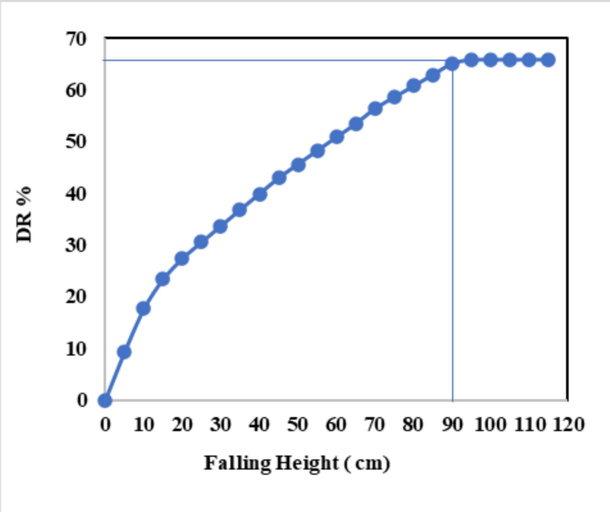


**Fig 5.** The curve of relative density and falling height of sandy soil

### 2.6 Testing Program

The testing program consists of several steps, these steps is displayed in Fig. 6 below.

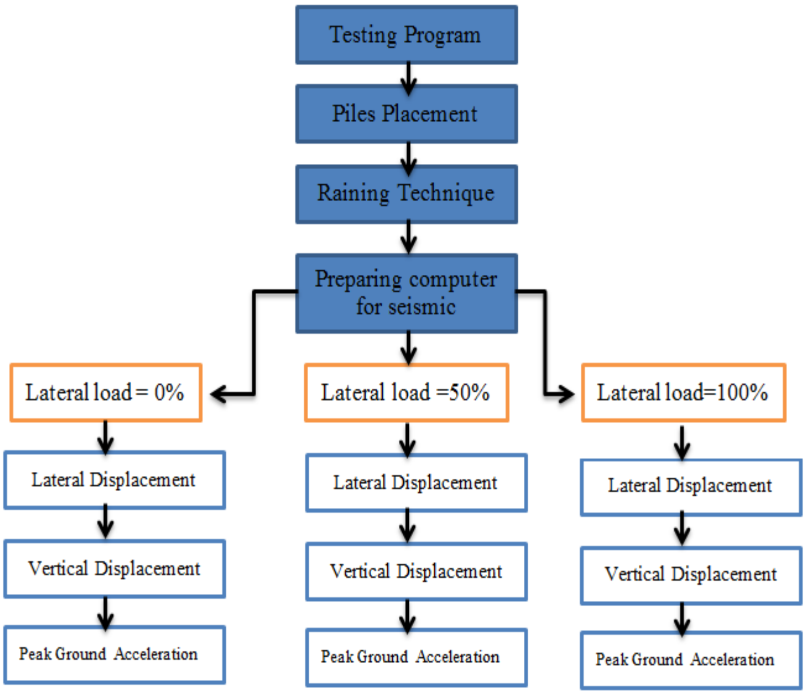


**Fig. 6** Testing Program Flow Chart for this Study.

## 3. Results and Discussion

### 3.1 Lateral Displacement Response of Pile

Fig. 7 Shows the relationship between the amount of shake and how far a single pile head moves side to side during an earthquake at different values of lateral load. For the first five seconds, nothing seems to be happening. Then all at once, after three seconds, there's a big peak. Finally, it levels off again and doesn't change much from there. This can be attributed to the transformation of sandy soil from (medium) to (dense) due to the effect of shaking.

However, increasing the horizontal lateral load from 0% to 50% and 100% decreased maximum lateral displacement by 32.10% and 49.59% respectively. In addition, the percentage of such decrement from 50% to 100% is 25.76%. this can be attributed to the effect of lateral confinement. This is possibly due to the load acting at an angle opposite to the earthquake as a restraining factor for the pile. Leading to a decreased maximum lateral displacement.

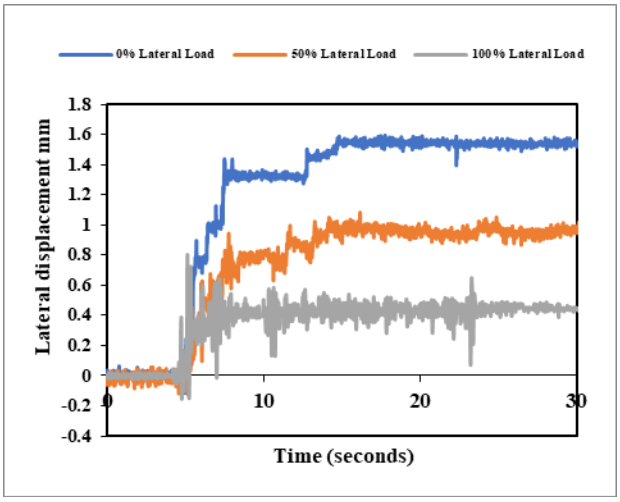


**Fig. 7** Lateral displacement response of pile

The reported results showed clearly that the presence of lateral load accompanied by an earthquake affects the resulting lateral displacement response.

### 3.2 Vertical Displacement Response of Pile

The effect of lateral load level on the vertical displacement response of a single pile head during earthquake motion is displayed in Fig. 8. It can be noted; for motion of El Centro, increasing such level

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from 0% to 50% and 100% increased maximum vertical displacement by 49.96% and 76.95% respectively. While such increment is reported as 18% from 50% to 100%. This can be ascribed by the relative accumulated disturbances of soil which increased as the lateral load increased.

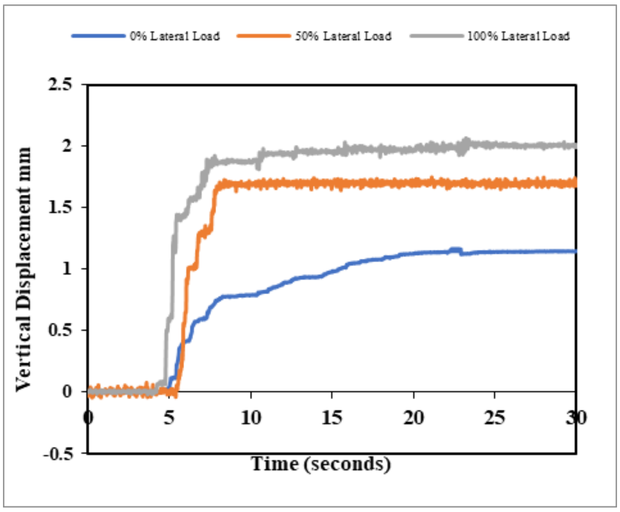
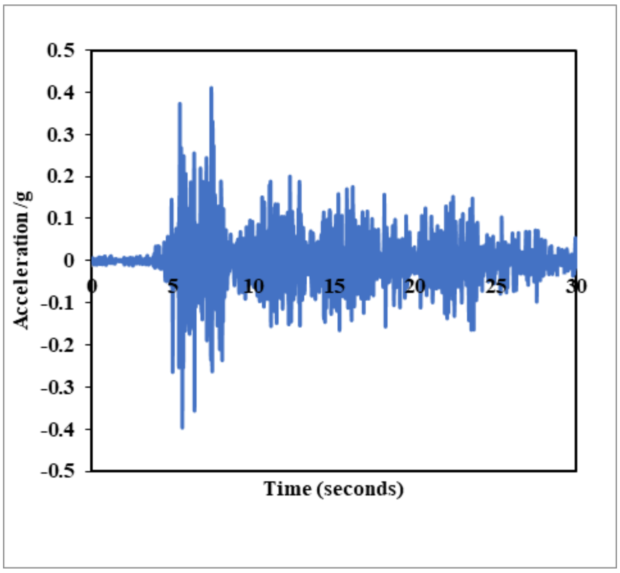



**Fig. 8** The vertical displacement response of a single pile

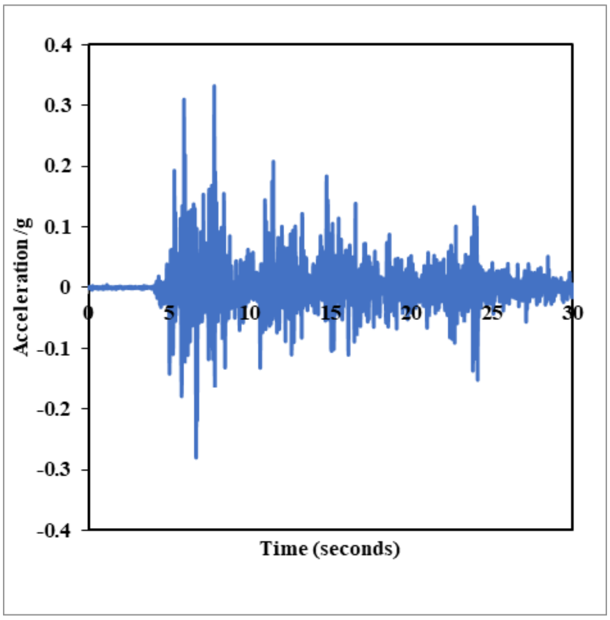
## 3.3 Peak Ground Acceleration Response of Pile

Effect of lateral load level to the peak ground - acceleration response of a single pile head during earthquake motion were displayed in Fig. 9. It can be noted; that for motion of El Centro, increasing such level from 0% to 50% and 100% decreased maximum peak ground - acceleration by 34.39% and 41.03% respectively. This is possibly due to the load acting at an angle opposite to the earthquake as a restraining factor for the pile. leading to a decreased maximum peak ground acceleration.

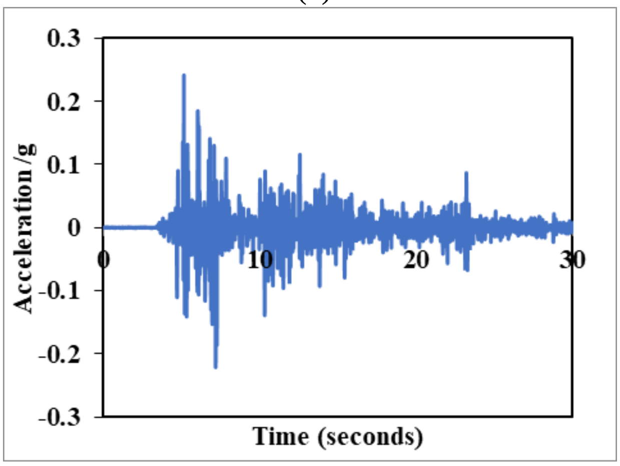
It is clear the peak ground-acceleration response reflects the same order between the load levels. Further research is needed to correlate the peak ground acceleration and the related lateral and vertical response under the same conditions.




(a)




(b)




(c)

**Fig. 8** Vertical displacement response

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## 4. Conclusions

The following are the main conclusions that can be drawn in this research:

1. Increasing the lateral load level decreased the maximum lateral displacement, vertical displacement, and maximum acceleration response.
2. In general, the response path of lateral displacement response is obvious where the peak values reached and the post peak phases illustrated relative stability due to the densification of sandy soil resulting from the seismic load.
3. The effect of lateral load levels on the load–lateral displacement, load – vertical displacement, and the consequent load acceleration histories is governed by the combined loading concept.
4. Increasing lateral load level from 0% to 50% and 100% decreased the related lateral displacement response by 32.10% and 49.59% respectively.
5. Increasing lateral load level from 0% to 50% and 100% decreased vertical displacement increased by 49.96% and 76.95%.
6. Increasing lateral load levels from 0% to 50% and 100% decreased the acceleration by 34.39% and 41.03%.

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