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Experimental Study on Seismic Response Characteristics of Soil On Building Models Using 1-D Shake-Table

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ABSTRACT. *This research investigates the impact of seismic response on the scaled 1:10 multi storey steel frame-model supported by isolated shallow footings placed on sand sample. One dimensional shake-table testing was carried out on four, three and two storeys steel Frame Model subjected to El-Centro 0.46pga Earthquake. Dynamic properties acceleration, displacement, natural frequency of the frame models on isolated footing with changing of storey height were measured. Moreover, it was found that acceleration responses and natural frequencies decreased with an increase in frame model height while displacement responses increased for a given foundation type with increased height. In conclusion, soil, the structure's height, and the materials properties all affect a structures seismic response during an earthquake.*

Keywords: Isolated Footing, Steel frame model, 1-D Shake table, Seismic Response.

1. INTRODUCTION

When tectonic plates are in motion. Plates collide with each other and due to these seismic waves are induced in the underlying soil. Seismic waves travel through earth layers as a result of large energies released during earthquakes. Due to seismic waves rocking, sliding and settlement of foundations and other ground structures are tremendously affected. Seismic waves are more intense at the places of epicenter. Soil types and parameters (Material damping, Shear modulus, and mass density) as well as the structure's height affect the seismic response of a soil-structure system during an earthquake. Structure shape and size, material properties, soil properties, and ground shaking severity influence damage caused by ground shaking of the frame. An effective seismic model testing technique is the shake table, which provides an in-depth understanding of foundation reaction, liquefaction, and dynamic horizontal earth pressure. It is true that these forecasts aren't easy to obtain, but seismic experimentation facilities can enable us to study different types of structures and materials. Since it is difficult to determine such parameters theoretically, shake table testing offers a broader investigation scope that includes determining the dynamic behavior of soils and structures by using physical models, in addition to tests which conclude that the development of new construction technologies or the creation of new devices that enhance the safety of structures.

Seismic waves have been studied numerically as well as experimentally in order to determine how they affect the behavior of structures. According to [1] numerical and experimental studies were conducted, including shaking table tests, to investigate the effects of SSI on building models. Based on their observation, the rigid base model's lateral deflection was amplified compared to the flexible base models. According to [2]. Using isolated shallow footings on loose Ganga sand, they investigated how soil-structure interactions affected low- and medium-rise steel-moment-resistant frames' dynamic behavior. In a three-storey structure placed on the Ganga sand bed, the roof displacement increased by twice and by 37% in a six-storey structure placed on the same sand bed. Energy dissipation by rocking movements was estimated to be 36% at 3-storey levels and 42.6% at 6-storey levels. According to [3] Based on shake table tests it was concluded that the effect of the SSI decreases with increasing foundation embedment depth.

According to [4] studied that the dynamic interaction between soil and high-rise structure by conducting shaking table experiment. Compared with a single isolated building, high-rise buildings respond less to accelerations when grouped together. According to their study, buildings with long periods of time respond more strongly to the El-Centro earthquake than those with short periods of time

According to [5] conducted a seismic analysis of buildings over sand soil using ABAQUS version 6.0. The effects of subsoil type (dense and loose sand), building height, and earthquake frequency have been studied on the soil-foundation interface for amplification, acceleration, and stress propagation.

Mexico City earthquake of 1985 and Christchurch earthquake of 2011 illustrate how the response of structures to earthquakes is greatly affected by soil properties in the region (New Zealand).

In this paper, the study investigates how building frame models respond to real earthquakes like El Centro in terms of their frequency, acceleration, and displacement responses. A four-storey, three-storey, and eight-storey steel building frame model on isolated footings was considered for the experiment.

2. EXPERIMENTAL PROGRAM

2.1. Model

The prototype model was designed considering similitude laws due to the limited size of the shake table in the lab. Buildings and foundations were modeled in 1:10 scale from full-scale models. For the experimental study, conventional steel frame buildings of three, four, and two stories were used as prototype superstructures.

The length and width 3 x3 m frame structure were taken as the basis for the frame-building models. Two-story, three-story and four-story frame models had heights of 0.6, 0.9, and 1.2 m, which corresponded to the 6, 9, and 12 m heights of a real structure, respectively. Fig-1 and Fig-3 illustrates steel Frame models.

A mild steel sheet with dimensions of 300mmx25mmx2mm was used as the column of the steel frame model to increase its flexibility. In the steel frame model, the slab was made of steel plates of dimensions 300mmx300mmx2.5mm. The bolt connection was used for the slab to column & footing to column connection.
In the actual building, the isolated footing was four meters by four meters. For the steel frame model, the isolated footing was made of reinforced concrete of dimensions 125 mm by 125 mm by 50 mm with a 1:2:4 proportion of materials. The particle size of coarse aggregate use sieve pass of 10mm and retained of 4.75 sieve. & Fine aggregate less than sieve pass 4.75mm

Fig. 1: Pictorial view of Frame models &isolated Footing on shake table

2.2. Properties soil sample:

The sand sample used for the research is lawrencpur Attock Punjab Pakistan. Manually sand sample is collected and stored in bags. Geotechnical properties of the sample were found in laboratory of soil mechanics and foundation engineering civil department Uet Taxila [6]. The index properties of sand used in the container as shown in Table1.

Table-1: Physical properties of sand sample

Specific gravity, G_S	2.67
Effective size, D_{10} (mm)	0.62

Max. void ratio, e_{max}	0.82
Min. void ratio, e_{min}	0.5
Maximum Dry Density ($kg/m3$)	1779.53
Minimum Dry Density ($kg/m3$)	1471.71
Uniformity coefficient, C_U	2.33
Coefficient of curvature, C_C	1.19
Angle of internal frication(ϕ)	34

2.3. Instrumentation and test setups: -

The experimental studies were performed on one-dimensional Shake-table electro dynamically operated. Which is available in soil mechanics and foundation engineering Lab University of Engineering Taxila. The shaking table is connected with a glass jar, sensors, a supporting system, a servo motor, and a mechanical linear drive [7].

Data acquisitions system700, control software & four accelerometers equipment were used to record all the Test data as shown in Fig-2(a-b).

First Medium sand were layered inside the box container & each layered of sample was manually compacted in box container of shake table. Then frame model were placed on isolated through bolts connection inside the box container of the shake table. Then sand sample filled to the plinth level of frame model. Two accelerometers were installed at various top floor level of frame model & two accelerometer were fix on container box and plinth level of frame model

Fig-2a: Pictorial view of a shake-table in Uet Taxila, Pakistan.

Fig-2b: Pictorial view of a shake-table in Uet Taxila, Pakistan.

(a) (b) (c)

Fig-3: Steel Models set up on shake-table: (a) 4 - storeys, (b) 3 - storeys, and (c) 2 - storeys.

2.4. Input Motion

A seismic shaking table was driven using the acceleration time history and response values of the 1979 El-Centro Earthquake (Horizontal component RSN183_IMPVALL.H_H-E08-UP-PEER strong motion database). The Magnitude of Earthquake 6.53, peak acceleration of this record is, 0.46 g, peak velocity is 36 cm/sec and peak displacement is 33.88 cm. In order to investigate how seismic waves, affect the Steel Model, which is a highly unpredictable earthquake has been considered. Fig.3 shows El-Centro's acceleration time history**.** The input signal was applied with a time interval of 0.01 s and for 36 seconds.

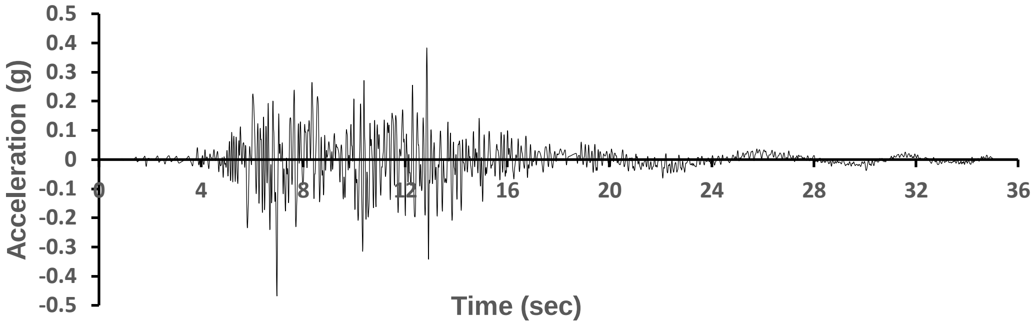

Fig-3a: El-Centro acceleration time history

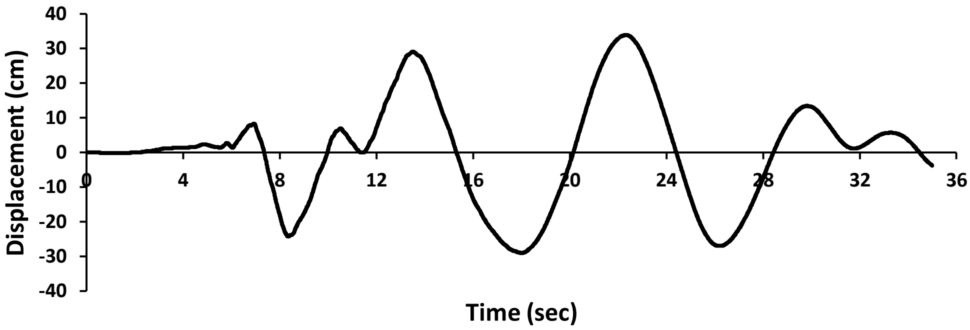

Fig-3b: El-Centro displacement response

2.5. Processing of shake table test data:

All the dynamic seismic responses were obtained and recorded using the data acquisition system 7000 and computer software available. The output acceleration of seismosignal software, the output accelerations were used to determine dynamic response of steel frame-model on isolated footing. The Seism Signal was also used for the filtering and base-line correction of the data recorded in each test.

3. Results and Discussion:

3.1. Peak seismic response acceleration

In Frame Models, the responses recorded by accelerometers at the 4th storey, 3rd storey, and 2nd storey model were plotted over time. The Fig-4 (a-c) illustrate the responses acceleration of isolated footings when the shaking table was excited by 0.46 PGA input acceleration of 1978 El Centro earthquake records.

It was seen from analysis that for the same input seismic acceleration of 0.46g on the isolated footing .The peak seismic acceleration response on different storey model decreases with increase of storey height as shown in Fig-4d. It is also found that the minimum acceleration takes place in Fourth storey model in case in isolated footing system.

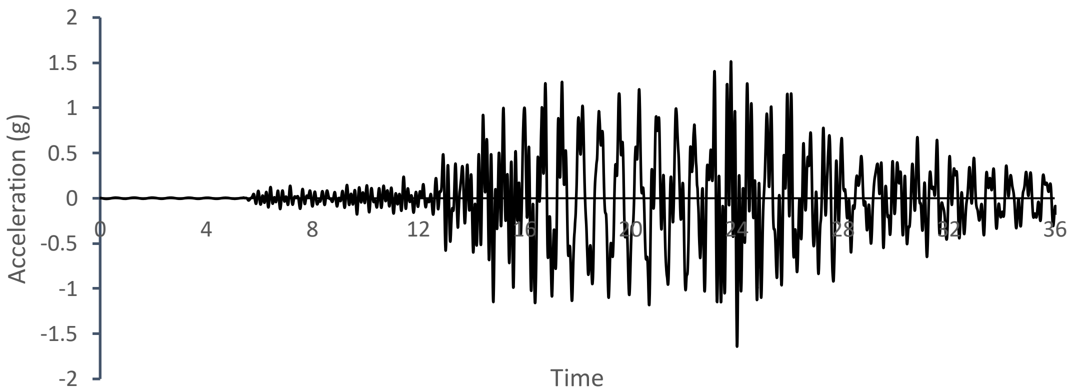

Fig-4a: Four storey model acceleration response

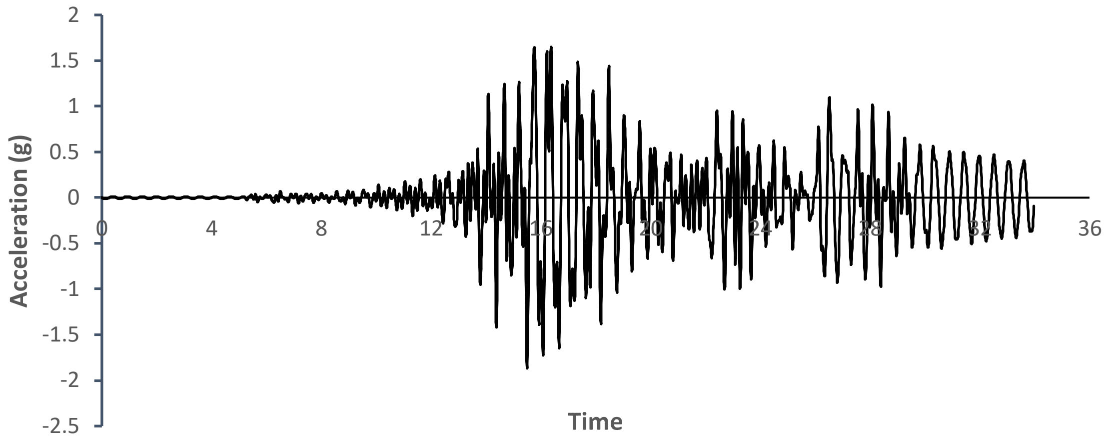

Fig-4b: Three storey model acceleration response

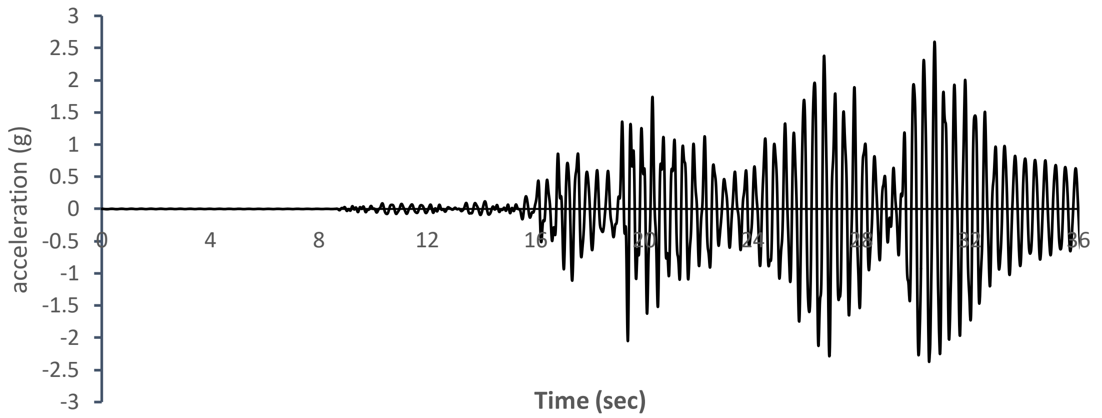

Fig-4c: Second storey model acceleration response

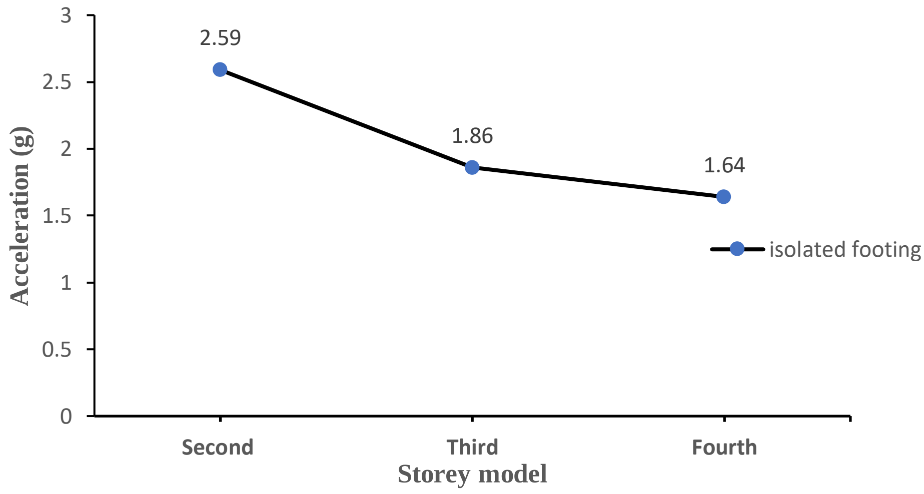

Fig-4d: Peak value of acceleration response of four, three and two steel frame model

3.2. Peak Displacement Response:

In this study, Seismosignal Software was used to calculate the output displacement seismic response of Frame models based on El-Centro earthquake input motion for isolated footings.

Fig-5 (a-d) shows seismic response displacement vs time curves when Four, Third, Second Storey, and plinth level were on isolated footing. In addition, it has been found that the maximum displacement recorded in Fourth storey level in case of isolated footing system.

For more clarity The Maximum Displacement values have also been plotted in Fig-5e and it was observed that optimum displacements for all building heights tends to increase the order of plinth-First-second-Third-Fourth storey Systems and this increase is almost at a at specific interval.

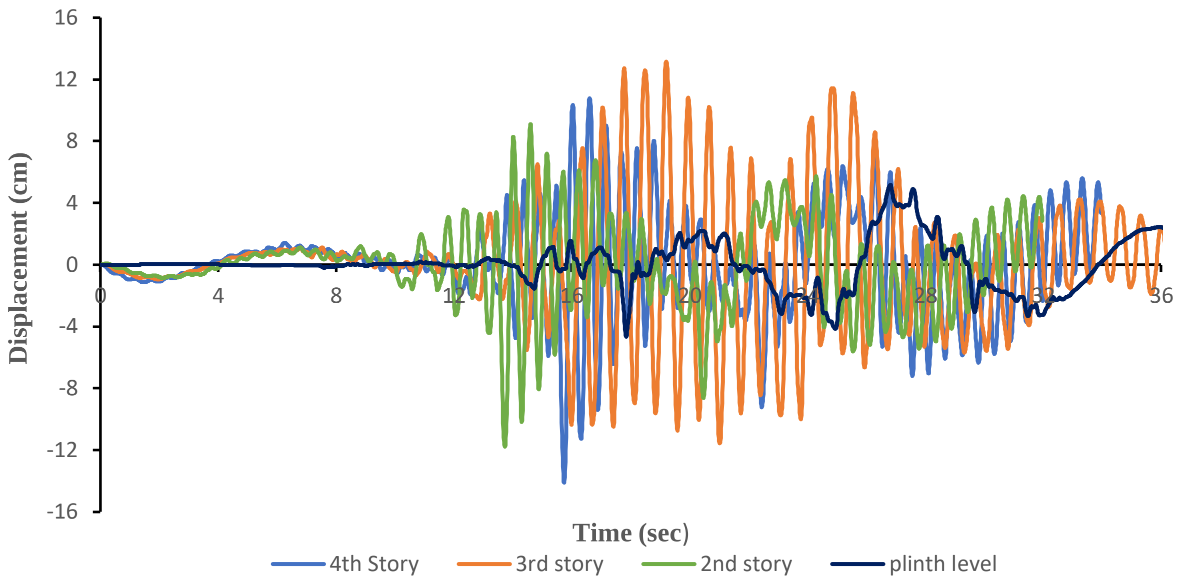

Fig-5: Steel frame-model displacement responses of a) four, b) three c) two storeys due to El-Centro for isolated footing.

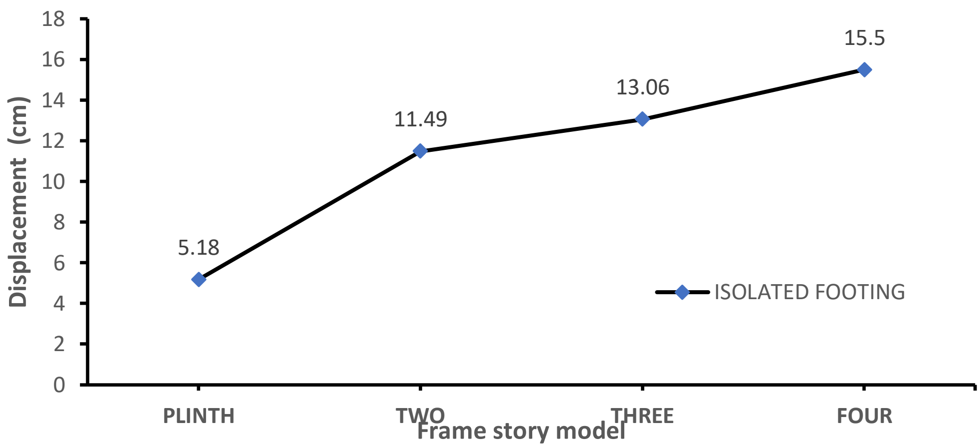

Fig-5e: Peak value of displacement response of four, three and two steel frame model

3.3. Fundamental period/frequency:

The response acceleration record was changed from the time domain to the frequency domain using Fourier transformation analysis to calculate the fundamental period/frequency. Based on the Fourier amplitude of acceleration versus frequency, Fig-6 shows the power spectral density (PSD) envelope curves for isolated footing models.

Table 2 shows that, for the isolated footing, the natural frequencies of frame models decrease with increase of height. It's observed that minimum frequency for all frame-model heights tends to decrease the order of second-Third-Fourth storey model and this increase is almost at a at specific interval. It is observed for a given isolated Footing Fourth storey building frame yields maximum frequency 2.7 Hz as shown in Table-2.

Table-2: Peak value of Frequency and time period response of four, three and two steel frame model

STORY	Time (sec)	FREQUENCY (hz)	Fourier Amplitude
Second	0.36	2.7	8.04
Third	0.53	1.85	4.6
Fourth	0.7	1.41	4.74

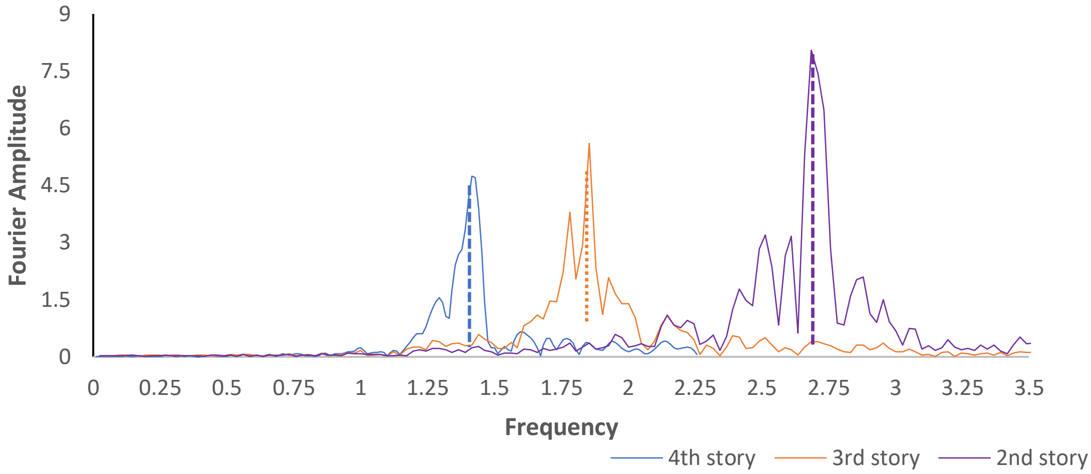

Fig-6: Frequency vs Fourier amplitude of Frame model

4. CONCLUSION

In this study we presented the seismic response 1:10 scaled-down steel frame model for isolated footing. Seismic shake table tests were conducted on Four, Three, Second Storey Frame models were being placed on Sand. The following conclusion has been summarized from the experimental study.

- The comparative study of Time period, natural frequencies, acceleration, and displacement responses for isolated footing, have been carried out on Frame Models.
- For the isolated type of footing, the natural frequency is minimum for the four-story model, then the third and second storey model, and while the time period of the frame model increase with increase of height.
- It has been found that Fourth storey offers maximum displacement response on isolated foundations. the displacement responses of structural frame models are increase with increase height for a given foundation type.
- It has been found that Fourth storey offers minimum acceleration response on isolated foundations. The acceleration responses of building frame models are decrease with increase height for a given foundation type.

REFERENCES

[1] Tabatabaiefar SHR, Fatahi B, Samali B. Numerical and experimental investigations on seismic response of building frames under influence of soil-structure interaction. Advances in structural Engineering. 2014;17(1):109-30.

[2] Vivek B, Raychowdhury P, editors. Effect of Soil-Structure Interaction on Low to Medium-Rise Steel Frames Through Shake Table Experiments. Experimental Vibration Analysis for Civil Structures: Testing, Sensing, Monitoring, and Control 7; 2018: Springer.

[3] Hosseinzadeh N, Davoodi M, Roknabadi ER, editors. Shake table study of soil structure interaction effects in surface and embedded foundations. Proceedings of the 15th World Conference in Earthquake Engineering, Lisbon, Portugal; 2012.

[4] Ge Q, Xiong F, Zhang J, Chen J. Shaking table test of dynamic interaction of soil–high-rise buildings. European Journal of Environmental and Civil Engineering. 2017;21(3):249-71.

[5] Matinmanesh H, Asheghabadi MS. Seismic analysis on soil-structure interaction of buildings over sandy soil. Procedia Engineering. 2011;14:1737-43.

[6] Kaleem A, Ahmad N, Khalid RA, Danish A, Safdar M, Butt F, et al. Characterization and Standardization of Sand for Geotechnical Research in Pakistan. Technical Journal. 2021;26(3):1-8.
[7] Danish A, Ahmad N, Salim MU. Manufacturing and performance of an economical 1-d shake table. Civil Engineering Journal. 2019;5(9):2019-28.