Volume: 22, Issue: 1
Page: 102-114
2023

International Journal of Science and Business

Journal homepage: ijsab.com/ijsb

IJSAB International

Simplified Analytical Model and Shaking Table Test Validation for Seismic Analysis of Piled Raft Foundation

Mustafa Yasen Nama, Lubna Abdulrahman Salem & Ahmed Mancy Mosa

Abstract

This study adopted development of a shaking table to simulate real earthquake loadings in the laboratory. It is a platform excited with a type of mechanical loading to provide periodic or random motions. Currently, it is the only experimental method to simulate different types of motion such as earthquakes, ground motions, and sine sweeps directly. In order to perform dynamic testing to simulate seismic loading, a large, effective, and practical shaking table was designed and manufactured in this study. The developed shaking table is capable to move in horizontal and vertical direction forward and backward and combination of those. Several researches utilized shaking tables in geotechnical engineering under seismic loads to evaluate miscellaneous parameters. Although these researches that developed excellent shaking tables, there is a high demand to design and manufacturing a shaking table capable to simulate the seismic load and its effects on the buildings. To attain this objective, this study aims to develop a novel shaking table that can simulate the manner of the real earthquake. The shaking table proposed in this study capable to mimic an earthquake that starts from a high energy then the energy decreases gradually until reach the zero. In addition, the proposed shaking table can implement simulated earthquake for time similar to that occurs in the nature. Therefore, this study can fill the research gap in this domain. The proposed shaking table work was verified and validated by testing based on repeated operating.

IJSB
Accepted 14 April 2023
Published 16 April 2023
DOI: 10.58970/IJSB.2098

ISSN: 2520-4750 (Online) 2521-3040 (Print)

Keywords: *Shaking Table, Seismic Load, Earthquake, Testing, Validation.*

About Author (s)

Mustafa Yasen Nama (corresponding author), Directorate of Education of Babylon, Ministry of Education, Babylon, Iraq.
Lubna Abdulrahman Salem, Digital Media Department, Al-Mansour University College, Baghdad, Iraq.
Ahmed Mancy Mosa, Civil Engineering Department, Al-Mansour University College, Baghdad, Iraq.

1. Introduction

Increase in global population increases the demand on infrastructures, housing buildings, and other facilities required for the humankind (Mosa, Al-Dahlaki, & Salem, 2021; Mosa, Atiq, Raihantaha, & Ismail, 2011a, 2011b; Mosa, Rahmat, Ismail, & Taha, 2013; Mosa, Salem, & Banyhussan, 2021; A. M. Mosa, L. A. Salem, & Q. S. Banyhussan, 2022; Ahmed Mancy Mosa, Lubna Abdulrahman Salem, & Qais Sahib Banyhussan, 2022; Mosa, Taha, Ismail, & Rahmat, 2013; Salem, Taher, Mosa, & Banyhussan, 2020). Earthquakes, if occur, has a disastrous effects on these facilities (Huang & Liu, 2023). During earthquakes, the dynamic behavior of a piled-foundation is related to the inertial force generated from building as well as to the deformations of the surrounding ground. Therefore, the behavior of piled- foundation under seismic loading must be understood. This objective can be attained effectively and accurately using full-scale loading tests. However, this is very costly and time-consuming technique. Numerical simulation can help in understanding of piled-foundation behaviors under the mentioned conditions (Bao, Morikawa, Kondo, Nakamura, & Zhang, 2012). However, experimental test using shaking table and down-scaled model is, also, an effective technique to attain the mentioned objective. Therefore, this study adopted development of a shaking table for this purpose. The shaking table is essential testing equipment to simulate real earthquake loadings in the laboratory. It is a platform excited with a type of mechanical loading to provide periodic or random motions. Currently, it is the only experimental method to simulate different types of motion such as earthquakes, ground motions, and sine sweeps directly (Severn, 2011). In order to perform dynamic testing to simulate seismic loading, a large, effective, and practical shaking table was designed and manufactured in this study. The developed shaking table is capable to move in horizontal and vertical direction forward and backward and combination of those. One of the earliest shaking tables was developed by Japanizes in 19th century. It is a hand-power driven (Severn, 2011). Stanford University developed shaking tables with an electric motor to implementing-directional frequent motion in the beginning of 20th century. The responses of the tests piece were collected using mechanical pens on rotary drums. The developed tables had uni-directional movement based on rails, excited using pendulums strikes at uni-end; the second end rests on designed springs or using wheels with a mass of eccentric-center attached to the table (Severn, Stoten, & Tagawa, 2012).University of California developed a shaking table similar to that developed by Stanford University in the 1950s. However, the supporting means are represented by one-directional flexible vertical bars. The responses were recorded using electrical facilities. Simultaneously, shaking tables were developed in Italy based on pendulums excitation. Other types of shaking tables were developed in Japan to simulate seismic loading by inducing the motion based on release of compressed springs. The released power is transferred to a platform supported on springs, flexible arms, rails, and combination of those. After Long Beach earthquake which occurred in 1933, shaking tables with oil-filled pistons and platform suspended by wires were developed. Innovations analogue devices and motion-control were very important at that time. These innovations support utilizing the real earthquake records as inputs. The development of electronic facilities and digital computation supported the improvement of recent shaking tables' control. Simple oscillatory motion shaker was developed in Japan in 1890. This shaker is a hand-driven machine involves a railway truck device produces oscillatory motion by a bar connected with eccentric manner to wheels. The responses are collected using pens on rotary drums. Similar principles were adopted by Stanford University in 1906 to develop a more complex shaking table (Severn, et al., 2012). Shakers excited with springs and pendulums can be utilized to excite motion similar to that excited by earthquakes in the laboratory with aid of other means. These principles were adopted by Jacobsen in 1934 to develop a shaking table (Severn, 2011). A number of shaking tables were recently developed. Most of the studies were implemented under one-dimensional loading (Boulanger, Curras, Kutter, Wilson, & Abghari, 1999; Iiba, Tamori, & Kitagawa, 2003; Shirato, Nonomura, Fukui, & Nakatani, 2008; Tamura, Miyazaki, Fujii, Tsuchiya, & Tokimatsu, 2001; Kohji Tokimatsu, Suzuki, & Sato, 2005). However, few studies were implemented under multi-dimensional loading conditions that it is actually occurred in the field (Hijikata et al., 2004).A number of researches were performed in this domain. (Gohl & Finn, 1991) utilized a shaking table to test a small scale model using single pile and group of piles embedded in dry sand foundations. (Meymand, 1998) developed a shaking table for modeling of a nonlinear soil-pile- superstructure interaction rest on soft clay. (Iiba, et al., 2003) used a shaking table to study the sway-rocking motion effects on pile stresses and its distributions. (Prasad, Towhata, Chandradhara, & Nanjundaswamy, 2004) utilized 1-g shaking table and manual shaking table with laminar box in order to study ground conditions under dynamic loading. (K Tokimatsu, Suzuki, Tabata, & Sato, 2007) developed a huge shaking table to evaluate the effects of dynamic interaction between soil, piles and buildings (Suzuki, Tokimatsu, Sato, & Tabata, 2008; Tabata & Sato, 2006).(Bajad & Sahu, 2008) used a 1g shaking table to investigate load sharing and settlement reduction of piled raft resting on soft clay soil. Several researches utilized shaking tables in geotechnical engineering under seismic loads to evaluate miscellaneous parameters (Ahn, Park, Yoon, Han, & Jung, 2021; Anastasopoulos, Georgarakos, Georgiannou, Drosos, & Kourkoulis, 2010; Bathurst, Zarnani, & Gaskin, 2007; Chau, Shen, & Guo, 2009; Cubrinovski, Kokusho, & Ishihara, 2006; Dungca et al., 2006; Guoxing, Enquan, Zhihua, Binghui, & Xiaojun, 2016; Guoxing et al., 2015; Haiyang et al., 2019; Haiyang, Xu, Chao, & Dandan, 2014; Lee, Wei, & Kuo, 2012; Maugeri, Musumeci, Novità, & Taylor, 2000; Pitilakis, Dietz, Wood, Clouteau, & Modaressi, 2008; Turan, Hinchberger, & El Naggar, 2009; Ueng, 2010; Ueng, Wu, Cheng, & Chen, 2010; Wang, Guo, Du, & Yu, 2022; Wu, Ge, Yuan, Ding, & Anastasopoulos, 2020; Zhang, Wei, & Qin, 2017; Zheng et al., 2018). Although these researches that developed excellent shaking tables, there is a high demand to design and manufacturing a shaking table capable to simulate the seismic load and its effects on the buildings. To attain this objective, this study aims to develop a novel shaking table that can simulate the manner of the real earthquake. The shaking table proposed in this study capable to mimic an earthquake that starts from a high energy then the energy decreases gradually until reach the zero. In addition, the proposed shaking table can implement simulated earthquake for time similar to that occurs in the nature. Therefore, this study can fill the research gap in this domain.

2. Building of the Shaking Table

The developed shaking table (Figure 1) in the present study was built using high quality parts to ensure efficiency and durability as the developed shaking table can be used in several researches in miscellaneous branches of civil engineering. Generally, the developed shaking table is operated hydraulically by tight hydraulic system and consists of two parts. The first part is responsible of producing the hydraulic pressure required for motion; whereas, the second part utilized the produced motion and translates it into oscillatory (vibratory) motion. The hydraulic pressure is driven by an electrical motor connected to a gearbox amplifies the power from 8.5 kW into 32.7 kW and decrease the speed form 2800 rpm into 0-727 rpm. The gearbox transfers the power into an eccentric system. The eccentric action stimulates the pressure in the four hydraulic cylinders at the first part of the shaking table (first set of hydraulic cylinders). As the eccentric system moves in an oscillatory manner, the hydraulic jack operates in the same manner by confined hydraulic system. The eccentric system is adjustable to control the transferred motion. The vibration is transferred to the second part of the shaking table via steel pipes and pneumatic tubes hydraulically. The second part of the table involved four 2-way hydraulic cylinders responsible of moving the shaking platform; one at each corner. To ensure equilibrium in oscillatory pressure among the four cylinders, an adjustment system was utilized. The adjustment system consists of eight hydraulic containers; each with capacity up to 400 cc. adjusting of oil quantity in each container controls the pressure leading to the required equilibrium. This equilibrium ensures equal displacements in the four hydraulic cylinders responsible of shaking at the second part of the shaking table. The hydraulic system produces stable vibration with constant frequency. However, this manner does not simulate the seismic loading. Therefore, a damping system was installed to simulate the seismic loading. The damping system consists of an electrical jack and eight hydraulic containers. The electrical jack pulls the pistons of the eight hydraulic containers gradually to increase the available volume in the hydraulic system to decrease the motion of the second set of the hydraulic cylinders leading to decrease in the frequency of the vibration from the maximum value to zero regardless of the operation of the motor. This manner is capable efficiently to simulate the seismic loading. The quantity of oil in the hydraulic system was calculated accurately to ensure efficient damping. The hydraulic containers volume is adjustable. The entire operation is controlled electronically using two complex AC-Drives. The AC-Drives control the motor speed, the hydraulic jack pulling speed, and the timing of the entire process. An electrical board was installed to control electricity feeding and to ensure safe operating. Several other parts are utilized to connect the entire system: steel casing, steel base plates, steel shafts, steel ball bearing units, steel brackets, and steel connectors. All the parts are supported on a tight steel frame and fastened tightly using steel screws. The details of the shaking table parts are described in the following sections.

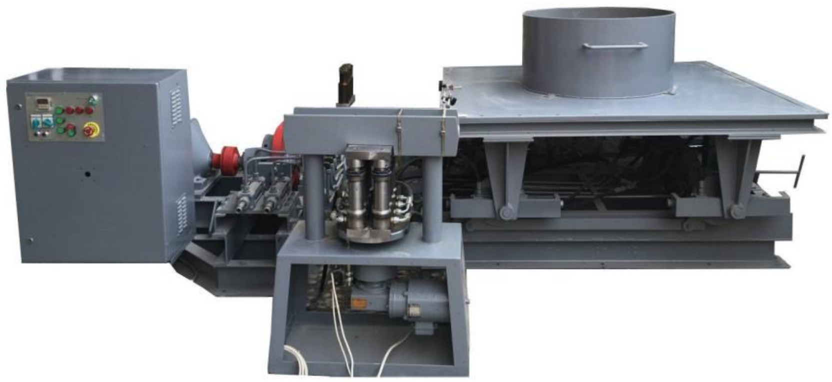

Figure 1. A photo for the developed shaking table

3. The Main Frame

The shaking table parts are supported on a tight steel frame with 4 m in length, 2 m in width and 1 m in height. The base of the shaking table consists of C150×12.2 steel sections (152.4 mm in height, 55 mm in width, and 5.1 mm in thickness). Two sections were installed as a double section and welded tightly to ensure stability and durability as well as high load bearing. The upper layer of the frame consists of C75×6.1steel sections (76.2 mm in height, 35 mm in width, and 4.3 mm in thickness). This layer supports a steel plate with thickness of 3 mm works as a platform for the steel laminate box which contains the soil and the model. The upper part is supported on the main base using four flexible steel arms with 5 mm in thickness. The flexible arms provide a high degree of freedom to facilitate the displacement of the shaker.

4. Servo Motor

The servo motor is most important part in the movement system as it initiates and keeps the motion. The present shaking table involves an active motor from ABB brand which is a well-known brand. Table 1 presents the properties of the motor. The power produced by the servo motor is amplified by a gearbox from 8.5 kW into 32.7 kW and decrease the speed form 2800 rpm into 727 rpm**.**

Table 1. Technical Properties of the Main Servo-Motor

Brand	ABB	Rated Current	30 A
Type	Servo-Motor	Rated Speed	2800 rpm
Frequency	50 Hz	Rated Torque	60 N.m
Output Power	8.5 kW	Peak Torque	180 N.m
Protection	Water Proof	Voltage Constant	0.1 V/r/min
Number of Phases	3-Phases	Moment Coefficient	1.5 N.m/A
Rated Power	8.5 kW	Rotor Inertia	0.4 kg/cm^2
Rated Voltage	380 V	Weight	125 kg

5. Hydraulic Cylinders

The hydraulic system of the developed shaking table involves two sets of hydraulic cylinder; each set includes four 2-way hydraulic cylinders (Figure 2). The first set is located in the first part of the shaking table; whereas, the second set is located in the second part. The hydraulic cylinders consist of a piston moves inside a barrel forward and backward under the pressure of the oil. The barrels are opened at both ends to facilitate the motion of the piston rod forward and backward. Both sets are from high quality brand to ensure effective operation as well as durability. Table 2 includes the manufacture properties. Each pair of hydraulic cylinder in the first set is assembled to the main frame using a steel base plate with a 100 mm in diameter and fastened with tight screws to ensure stability. Each hydraulic cylinder in the second set is assembled to a steel case with 100 mm in diameter and supported by a circular steel flange to the main shafts. This tight supporting ensures stability as well as equilibrium in motion. Equilibrium of motion of the four cylinders in the second part of the shaking table is very important to ensure equal displacement at every corner of the shaking platform in both horizontal and vertical displacement as well as any combination of them. This manner provides correct simulation of seismic loading. Each assembly in the second set (hydraulic cylinder, steel case, and circular flange) is connected to the adjustable arm to facilitate the required degree of freedom. The cylinders obtained the hydraulic pressure from the hydraulic system via pneumatic pipes with pressure capacity of 240 bars. The cylinders use this pressure to move forward and backward to simulate the required vibration. They can provide horizontal displacement up to 30 mm in both ways and vertical displacement up to 30 mm.

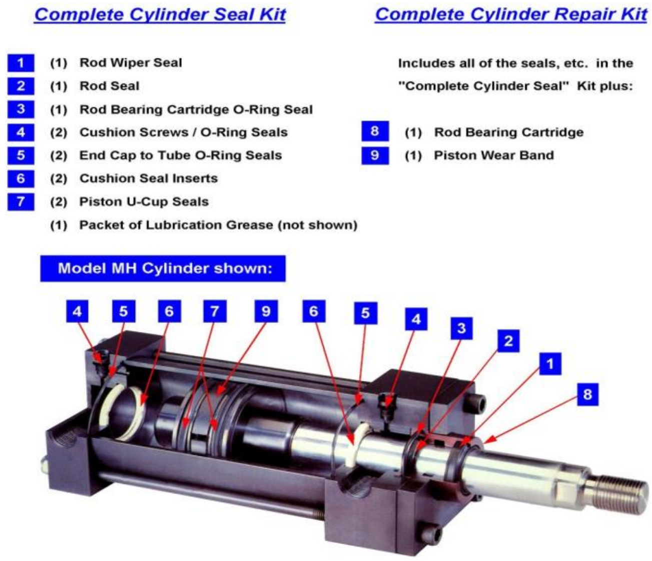

Figure 2. The hydraulic cylinder details

Table 2. The properties of the Hydraulic Cylinders

	The set	
The property	First Set	Second Set
Brand	Mecman	Mecman
Series	251 H Mod A	SD 27 A
Reference	FS BS	FS BS
Inner Diameter	50 mm	55 mm
Stroke	100 mm	120 mm
Piston rod diameter	25 mm	25 mm
Maximum operating pressure	160 bar	190 bar
Test Pressure	240 bar	300 bar

6. Ball Bearing Units

The shaking table involves 6 ball bearing units contained in a tight steel brackets contribute in smooth, stable, and uniform motion**.** Two units are installed in the first part of the shaking table. They are responsible of supporting the main shaft which transfers the rotary motion from the motor to the eccentric system. The second set consists of four ball bearing units located in the second part of the shaking table. This set supports the four hydraulic cylinders. This set includes two pairs; each supports one shaft and two hydraulic cylinders. These units are high quality units manufactured by SKF Company.

7. Adjustment System

The adjustment system consists of eight hydraulic containers each with capacity up to 400 cc (Figure 3 and 4). They are installed on two steel bases tightened and stiffened with screws. The system rely the quantity of oil provided to second set of the hydraulic cylinders to control the hydraulic quantity and adjust the displacement of them. This action controls the required vibration magnitude and frequency. The quantity of oil can be increased or decreased as required. This manner ensures high flexibility and practicality in this study as well as future studies.

Figure 3. The adjustment system (front view)

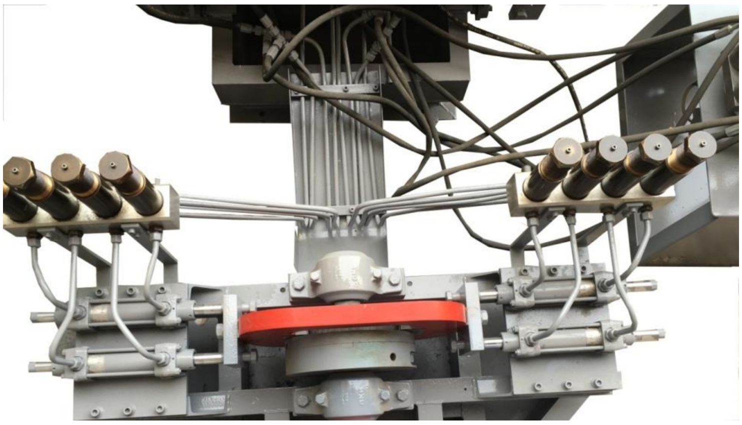

Figure 4. The adjustment system (front view)

8. Damping System

The damping system is one of the most essential parts in the shaking table (Figure 5). It is responsible of decreasing the vibration from the maximum value to zero to simulate the real earthquake action. This system consists of eight hydraulic containers each with capacity up to 600 cc. The quantity of hydraulic in the containers is relied by a hydraulic jack which is operated by a servo-motor. The system decreases the vibration gradually from maximum value to zero by absorbing the oil from the hydraulic cylinders causing decrease in their pressure and as a result decrease in their displacement which inhabits the vibration gradually. The quantity of oil in the entire hydraulic system was designed accurately to ensure vibration inhabiting from the maximum to zero within the volume of the eight oil containers. The speed of inhabiting is controlled electronically by an AC- Drive device. The technical properties of the servo-motor and the hydraulic jack are presented in Table 3 and Table 4 respectively.

Figure 5. The damping system

Table 3. Technical properties of the servo-motor of the damping system

Brand	Stephan-Werke Hameln	Rated Current	5 A
Type	Servo-Motor	Rated Speed	1500 rpm
Frequency	50 Hz	Rated Torque	12N.m
Output Power	2 kW	Peak Torque	36N.m
Protection	Water Proof	Voltage Constant	0.1 V/r/min
Number of Phases	3-Phases	Moment Coefficient	1N.m/A
Rated Power	2 kW	Rotor Inertia	0.1 kg/cm^2
Rated Voltage	380 V	Weight	15 kg

Table 4. The properties of the hydraulic jacks in the damping system

Brand	MAZ-Bruchsal
Series	71D S14
Diameter	50 mm
Stroke	100 mm
Piston rod diameter	25 mm
Maximum operating pressure	160 bar
Test Pressure	240 bar

9. Control System of the Displacement Direction

The developed shaking table can operate horizontally, vertically, and any combination of both directions. To control the required motion, an adjustment system was installed in the second part of the shaking table (Figure 6). The direction adjustment system consists of a mechanical motor connected by a steel chain to the steel shaft that connects the second pair of the hydraulic cylinders. The mechanical motor can be operated manually by means of a rotating arm. The rotating arm can be rotated clockwise or counterclockwise to obtain the required angle. The system is provided with a mechanical lock to ensure stable direction during operating. Table 5 presents the technical properties of the mechanical motor.

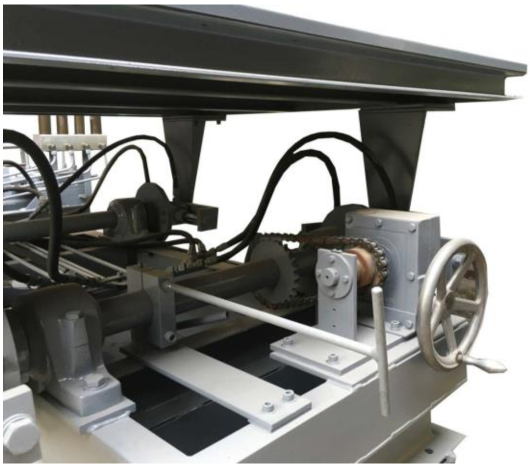

Figure 6. Control system of the displacement direction

Table 5. The properties of the mechanical motor

Brand	Albin Motors AB
Series	ASV 70 20.1
Operating Type	Mechanical
Control	Manual
Dimensions	20 mm x 20 mm x 70 mm

10. AC-Drive

The operation of shaking table is controlled by two effective and accurate electronic AC-Drives. The AC-Drives synchronizes all the operations during shaking. The first AC-Drive controls the damping system operation. The second AC-Drive controls the shaking operation. It initiates the operating, feeds the main motor with required power, control the timing, and shutdown the system at the programmed time. The AC- Drives are flexible and can be programmed to obtain the required vibration (magnitude and frequency) and the shaking time. The technical properties of the AC-Drives are presented in Table 6.

Table 6. The technical properties of the AC-Drive

	AC-Drive 1	Ac-Drive 2
Brand	Lust	LSIS
Series	Fu 2000	iG5A
Power	3kw	20kw
Input Phases	3 Phases	3 Phases
Input Voltage	340-420 V	340-420 V
Output Phases	3 Phases	3 Phases
Output Voltage	0-380 V	0-380 V
Input Current	15 A	85 A
Output Current	10 A	60 A
Frequency	0-400 Hz	0-400 Hz
Operation Mode	Analog and Digital Input	Analog and Digital Input
Function	Programmable	Programmable

11. Shaking Table Operating and Testing

The manufactured shaking table was tested by repeated operating for hundred times to ensure its efficiency and accuracy. Several adjustments were implemented during testing process. At last, the results verified and validated the shaking table work.

12. Conclusions

Preparation of effective instruments and tools is the key for successful research. This study involved manufacturing and employment of an effective shaking table to simulate the effects of seismic loading caused by earthquakes. The developed shaking table differs from other tables as it is capable to implement simulated earthquake starts from high energy then decreases gradually until reaching the zero value. The shaking table was designed based on scientific principals and manufactured accurately to ensure attaining its objective. The manufacturing process involved using heavy duty parts with high quality to ensure long service life. The work of the shaking table was verified and validated by testing based on repeated operating. Several adjustments were made during testing and validation process to overcome all problems. The shaking table can be used in wide domain of researches in the field of civil engineering especially the structures and geotechnical engineering. The large platform of the proposed shaking table enables testing large scale models which facilities the scientific research in different domains.

References

Ahn, S., Park, G., Yoon, H., Han, J.-H., & Jung, J. (2021). Evaluation of soil–structure interaction in structure models via shaking table test. Sustainability, 13(9), 4995.

Anastasopoulos, I., Georgarakos, T., Georgiannou, V., Drosos, V., & Kourkoulis, R. (2010). Seismic performance of bar-mat reinforced-soil retaining wall: Shaking table testing versus numerical analysis with modified kinematic hardening constitutive model. Soil Dynamics and Earthquake Engineering, 30(10), 1089-1105.

Bajad, S., & Sahu, R. (2008). An experimental study on the behaviour of vertically loaded piled raft on soft clay. Paper presented at the The 12th international conference of international association for computer methods and advances in geomechanics (IACMAG).

Bao, X., Morikawa, Y., Kondo, Y., Nakamura, K., & Zhang, F. (2012). Shaking table test on reinforcement effect of partial ground improvement for group-pile foundation and its numericalsimulation. Soils and foundations, 52(6), 1043-1061.

Bathurst, R. J., Zarnani, S., & Gaskin, A. (2007). Shaking table testing of geofoam seismic buffers. Soil Dynamics and Earthquake Engineering, 27(4), 324-332.

Boulanger, R. W., Curras, C. J., Kutter, B. L., Wilson, D. W., & Abghari, A. (1999). Seismic soil-pile-structure interaction experiments and analyses. Journal of geotechnical and geoenvironmental engineering, 125(9), 750-759.

Chau, K. T., Shen, C., & Guo, X. (2009). Nonlinear seismic soil–pile–structure interactions: shaking table tests and FEM analyses. Soil Dynamics and Earthquake Engineering, 29(2), 300-310.

Cubrinovski, M., Kokusho, T., & Ishihara, K. (2006). Interpretation from large-scale shake table tests on piles undergoing lateral spreading in liquefied soils. Soil Dynamics and Earthquake Engineering, 26(2-4), 275-286.

Dungca, J. R., Kuwano, J., Takahashi, A., Saruwatari, T., Izawa, J., Suzuki, H., & Tokimatsu, K. (2006). Shaking table tests on the lateral response of a pile buried in liquefied sand. Soil Dynamics and Earthquake Engineering, 26(2-4), 287-295.

Gohl, W., & Finn, W. (1991). Use of piezoceramic bender elements in soil dynamics testing. Paper presented at the Recent advances in instrumentation, data acquisition and testing in soil dynamics.

Guoxing, C., Enquan, Z., Zhihua, W., Binghui, W., & Xiaojun, L. (2016). Experimental investigation on fluid characteristics of medium dense saturated fine sand in pre-and post-liquefaction. Bulletin of Earthquake Engineering, 14, 2185-2212.

Guoxing, C., Su, C., Xi, Z., Xiuli, D., Chengzhi, Q., & Zhihua, W. (2015). Shaking-table tests and numerical simulations on a subway structure in soft soil. Soil Dynamics and Earthquake Engineering, 76, 13-28.

Haiyang, Z., Xu, W., Yu, M., Erlei, Y., Su, C., Bin, R., & Guoxing, C. (2019). Seismic responses of a subway station and tunnel in a slightly inclined liquefiable ground through shaking table test. Soil Dynamics and Earthquake Engineering, 116, 371-385.

Haiyang, Z., Xu, Y., Chao, Z., & Dandan, J. (2014). Shaking table tests for the seismic response of a base-isolated structure with the SSI effect. Soil Dynamics and Earthquake Engineering, 67, 208-218.

Hijikata, K., Ishida, T., Tanaka, H., Koyamada, K., Miyamoto, Y., Kontani, O., & Nigbor, R. (2004). Experimental study on soil-pile-structure interaction in liquefiable sand subjected to blast-induced ground motion. Paper presented at the Proceeding of the 13th World Conference on Earthquake Engineering (13WCEE), Vancouver, BC, Canada.

Huang, S., & Liu, C. (2023). A computational framework for fluid–structure interaction with applications on stability evaluation of breakwater under combined tsunami–earthquake activity. Computer-Aided Civil and Infrastructure Engineering, 38(3), 325-352.

Iiba, M., Tamori, S., & Kitagawa, Y. (2003). Fundamental characteristics on seismic effect to pile foundation by shaking table test for model of building-soil interaction system. Journal of Structural and Construction Engineering(566), 29-36.

Lee, C.-J., Wei, Y.-C., & Kuo, Y.-C. (2012). Boundary effects of a laminar container in centrifuge shaking table tests. Soil Dynamics and Earthquake Engineering, 34(1), 37-51.

Maugeri, M., Musumeci, G., Novità, D., & Taylor, C. (2000). Shaking table test of failure of a shallow foundation subjected to an eccentric load. Soil Dynamics and Earthquake Engineering, 20(5-8), 435-444.

Meymand, P. J. (1998). Shaking table scale model tests of nonlinear soil-pile-superstructure interaction in soft clay: University of California, Berkeley.

Mosa, A. M., Al-Dahlaki, M. H., & Salem, L. A. (2021). Modification of roadbed soil by crushed glass wastes. Periodicals of Engineering and Natural Sciences (PEN), 9(2), 1038-1045.

Mosa, A. M., Atiq, R., Raihantaha, M., & Ismail, A. (2011a). Classification of construction problems in rigid highway pavements. Australian Journal of Basic and Applied Sciences, 5(3), 378-395.

Mosa, A. M., Atiq, R., Raihantaha, M., & Ismail, A. (2011b). A knowledge base system to control construction problems in rigid highway pavements. Australian Journal of Basic and Applied Sciences, 5(6), 1126-1136.

Mosa, A. M., Rahmat, R. A. O. K., Ismail, A., & Taha, M. R. (2013). Expert System to Control Construction Problems in Flexible Pavements. Computer-Aided Civil and Infrastructure Engineering, 28(4), 307-323. doi: 10.1111/mice.12001

Mosa, A. M., Salem, L. A., & Banyhussan, Q. S. (2021). Overcoming Concreting Problems of Rigid Pavements using Knowledge-Based System. Civil Engineering Beyond Limits, 2(3), 12-17.

Mosa, A. M., Salem, L. A., & Banyhussan, Q. S. (2022). Chemical influence of magnesium oxide on the engineering properties of clayey soils used as road subgrade. [Article]. Journal of Engineering Science and Technology, 17(4), 2615-2630.

Mosa, A. M., Salem, L. A., & Banyhussan, Q. S. (2022). Treatment of cracking in rigid highway pavements using knowledge-based System. International Journal of Innovation in Engineering, 2(1), 68-77.

Mosa, A. M., Taha, M. R., Ismail, A., & Rahmat, R. A. O. K. (2013). A diagnostic expert system to overcome construction problems in rigid highway pavement. Journal of Civil Engineering and Management, 19(6), 846-861. doi: 10.3846/13923730.2013.801905

Pitilakis, D., Dietz, M., Wood, D. M., Clouteau, D., & Modaressi, A. (2008). Numerical simulation of dynamic soil–structure interaction in shaking table testing. Soil Dynamics and Earthquake Engineering, 28(6), 453-467.

Prasad, S., Towhata, I., Chandradhara, G., & Nanjundaswamy, P. (2004). Shaking table tests in earthquake geotechnical engineering. Current science, 1398-1404.

Salem, L. A., Taher, A. H., Mosa, A. M., & Banyhussan, Q. S. (2020). Chemical influence of nano-magnesium-oxide on properties of soft subgrade soil. Periodicals of Engineering and Natural Sciences, 8(1), 533-541.

Severn, R. (2011). The development of shaking tables–a historical note. Earthquake engineering & structural dynamics, 40(2), 195-213.

Severn, R., Stoten, D., & Tagawa, Y. (2012). The contribution of shaking tables to earthquake engineering. Paper presented at the World Conference on Earthquake Engineering.

Shirato, M., Nonomura, Y., Fukui, J., & Nakatani, S. (2008). Large-scale shake table experiment and numerical simulation on the nonlinear behavior of pile-groups subjected to large-scale earthquakes. Soils and foundations, 48(3), 375-396.

Suzuki, H., Tokimatsu, K., Sato, M., & Tabata, K. (2008). Soil-pile-structure interaction in liquefiable ground through multi-dimensional shaking table tests using E-Defense facility. Paper presented at the 14th World Conference on Earthquake Engineering, Beijing, China.

Tabata, K., & Sato, M. (2006). Report of special project for earthquake disaster mitigation in urban areas. Ministry of Education, Culture. Sports Science and Technology, 489-554.

Tamura, S., Miyazaki, M., Fujii, S., Tsuchiya, T., & Tokimatsu, K. (2001). Earth Pressure Acting on Embedded Footing During Soil Liquefaction by Large-Scaling Shaking Table Test.

Tokimatsu, K., Suzuki, H., & Sato, M. (2005). Effects of inertial and kinematic interaction on seismic behavior of pile with embedded foundation. Soil Dynamics and Earthquake Engineering, 25(7-10), 753-762.

Tokimatsu, K., Suzuki, H., Tabata, K., & Sato, M. (2007). Three-dimensional shaking table tests on soil-pile-structure models using E-Defense facility. Paper presented at the 4th international conference on earthquake engineering, June.

Turan, A., Hinchberger, S. D., & El Naggar, H. (2009). Design and commissioning of a laminar soil container for use on small shaking tables. Soil Dynamics and Earthquake Engineering, 29(2), 404-414.

Ueng, T. (2010). Shaking table tests for studies of soil liquefaction and soil-pile interaction. Geotechnical Engineering, 41(1), 29.

Ueng, T., Wu, C., Cheng, H., & Chen, C. (2010). Settlements of saturated clean sand deposits in shaking table tests. Soil Dynamics and Earthquake Engineering, 30(1-2), 50-60.

Wang, J., Guo, T., Du, Z., & Yu, S. (2022). Shaking table tests and parametric analysis of dynamic interaction between soft soil and structure group. Engineering Structures, 256, 114041.

Wu, W., Ge, S., Yuan, Y., Ding, W., & Anastasopoulos, I. (2020). Seismic response of subway station in soft soil: Shaking table testing versus numerical analysis. Tunnelling and Underground Space Technology, 100, 103389.

Zhang, Z., Wei, H., & Qin, X. (2017). Experimental study on damping characteristics of soil-structure interaction system based on shaking table test. Soil Dynamics and Earthquake Engineering, 98, 183-190.

Zheng, Y., Sander, A. C., Rong, W., Fox, P. J., Shing, P. B., & McCartney, J. S. (2018). Shaking table test of a half-scale geosynthetic-reinforced soil bridge abutment. Geotechnical Testing Journal, 41(1), 20160268-20160268.

Cite this article:

Mustafa Yasen Nama, Lubna Abdulrahman Salem & Ahmed Mancy Mosa (2023). Simplified Analytical Model and Shaking Table Test Validation for Seismic Analysis of Piled Raft Foundation. *International Journal of Science and Business, 22*(1), 102-114. doi: https://doi.org/10.58970/IJSB.2098

Retrieved from http://ijsab.com/wp-content/uploads/2098.pdf

Published by

IJSAB International