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Dynamic responses of shallow foundations on saturated soil under impact loadings

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Abstract. In civil engineering, there are many problems related to the transmission of pressure waves through the soil due to dynamic loads. The objective of this investigation is to research the dynamic soil properties. In industrial applications, these vibrations remain often caused by the impact of weights on the foundation machine. This study investigates how saturated soft clay soil responds to a single impulsive load. Deflectometry via falling weights was conducted to produce single pulse energy by dropping different weights from various elevations. Usually, these dynamic foundations have a greater effect on the surface than various depths of the same foundation. Soil surface responses were studied, then the effects occurring at the depth of the soil surface and causing these responses were studied, which include vertical displacements, velocities, and accelerations. Using the same impact weight (5 kg) at both drop heights (250 mm and 500 mm), the average percentage change in the maximum impact force generated at the contact surface increased by 33 %. This decreased the maximum displacement response of the clay soil model by 25 %, and the maximum displacements increased with increasing operational frequency and dynamic loads.

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1. *Introduction*

Dynamic response is one of the primary parameters used to describe the soil behavior under dynamic loads. The machine foundation's behavior is affected by different factors such as soil properties, the weight of machine and foundations, the magnitude of the unbalanced force of machine, contact zone between foundations and soils, and static soil pressure. For these reasons, the most critical step in the design to get a successful machine foundation can be relied an analyzing technique for dynamic responding and it should not surpass the limit given to a machine designer. Anyway, before starting the acceptable limits of the settlement of the machine foundation, it is very important to explain that the failure of the vibrating foundations is reached when the motion exceeds a limiting value, which is usually expressed as displacement of the foundation at specified frequencies [1].

The mechanics of saturated clay are more complex than those of single-phase materials due to the coupling of the responses of their many constituents. For saturated clay, the soil pores are filled with water, which causes the permeability to be low and transient loading to be fast. To properly measure how earth buildings and foundations behave, this connection should be taken into account [2].

Many researchers have investigated the dynamic response under machinery. Additionally, several researches investigated the vertical vibrating manner for surface footing Soil reaction under impacting forces is determined by dynamical soil characteristics. Estimating the activity soil characteristics by monitoring the reactions to impact loading. In dynamic research, stiffness, damping ratio, and unit weight are considered [3–5].

The impacts of surface depth and loading frequency on the modeling of circular shallow foundations in stiff clay soil are investigated. Additionally, impact loads and excess pore water pressure are measured at the foundation’s soil surface. It was shown that maximum displacements rise with operating frequency increases with dynamic load and no measured effects of pore water pressures on the model of stiff clay soil. The seismic response of locations is subjective to the dynamical properties of the surface soil. This response affects the performance of embedded or superimposed structures. Identification and inverse problem solution approaches are required for determining in-situ soil variables and calibrating models of soil dynamical loads. The increased availability of high-quality laboratory and field data has led to an increase in soil investigation system identification research [6].

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In [8] several natural and forced vertical vibration models performed on surface and embedding modeling for footings on dry and moist poorly graded sand were investigated. Similar findings were presented in [9], indicating that as the footing base area increases, the natural frequency and amplitude The dynamic behavior of the soil-foundation systems is the most important aspect of a machine’s successful functioning. The essential objective of the design of a machine’s foundation is to restrict its motion to amplitudes that neither endanger the machine’s operation nor disturb surrounding personnel. Hence, the engineering study of the footings’ response to the projected dynamical force created by the usage of the equipment is a crucial component of a solid foundation design. In addition, when large movements of an existing footing impede the functioning of supported machinery, an investigation must be done to determine the root causes of the issue. Therefore, in an investigation, soil-structure interaction (SSI) phenomena that are exposed to impact load are studied [10]. Firstly, dynamic soil-structure interaction subject to impact forces is tested using vibrating impacts then were explored by contrasting the soil-structure system with a solid footing condition. After that, a mathematical analysis that passes the SSI tests is given. The nonlinear behavior of soil in the finite element simulation is modeled independently using a boundary surfaces deformation method and a related linear approach. The boundary surface plasticity model’s estimation outcomes prove to be more accurate than those of the experiments [11].

Modern industry has brought massive machinery that affects the foundation’s performance and the soil below, causing another sort of vibration stress. All machine foundations, regardless of dimension and type, should be considered engineering problems, and their designs should be founded on solid engineering methods [12].

Many researchers look into how machinery moves, for instance, the authors of [13–14] and other researchers looked into how vertical vibrations affect surface footings.

When the applied loads from the structure of testing increase and exceed the cracking load, the damaged supporter of individual groups exhibits a relatively high ratio of stiffness drop [15] as an outcome of a portion of the pre-stressing force, which rises the rate of cracking and displacements. Most studies absorbed the dynamic load caused to earthquakes and offshore waves.

The majority of solutions model the machine's base as a block resting on the surface of an elastic earth. Typically, the actual foundations are inserted, which significantly affects the dynamic behavior of the foundation [16].

The primary aims of this study are to evaluate the soil’s response to impact loads. The dampening of waves caused by impact stresses via the soil will be emphasized. A decision was made to experiment on clayey soils to identify how to analyze the performance of these soils below the influence of impact loads with variable applied kinetic energy, taking into account the embedment and distance of the footing as well as the impact force.

2. Methods and Materials

The tests were conducted under the standards for identifying the physical and chemical properties of soil, the specifics of these requirements are detailed in Table 1. A sample of clayey soil was taken from a depth of 1.0 m from the soil subsurface of a brick factory site in Al-Nahrawan city (54 km east of Baghdad) [2].

For soft clay conditions, a compliant consolidation test was performed. Table 2 displays the soft clay consolidation test results, and the testing programs are shown in Table 3.

Table 1. Comparison of displacement value with maximum impact loads from the present study area in Iraq.

No.	Author	Year	Study area	Soil type	Soil depth	Displacement value with maximum impact loads
1	Adnan F. et al..	2016	Karbala city	Dry-dense sand	Embedment depth	40–50%
2	Adnan F. et al.	2016	Karbala city	Dry-medium sand	Embedment depth	35–40%
3	Adnan F. et al.	2016	Karbala city	Dry-loose sand	Embedment depth	25–35%
4	Adnan F. et al.	2016	Karbala city	Saturated sand	At surface depth	30–60%
5	Ahmed B.A. et al.	2022	Al-Nahrawan city	Saturated soft clay	At surface depth	50%
6	Ahmed B.A. et al.	2022	Al-Nahrawan city	Saturated stiff clay	At surface depth	80%
7	Rasheed A.H. et al.	2023	Al-Nahrawan city	Saturated soft clay	At surface depth	50%
8	Rasheed A.H. et al.	2023	Al-Nahrawan city	Saturated stiff clay	At surface depth	80%

Table 2. Physical and chemical properties of soil under using standards.

Property	Value	Standard of the test
Specific Gravity, Gs	2.71	ASTM D854
Gravel (> 4.75 mm) %	0	ASTM D422
Sand (4.75–0.075 mm) %	3	
Silt (0.075–0.005 mm) %	40	
Clay (< 0.005 mm) %	57	
Liquid limit (LL)	39	ASTM D4318
Plastic limit (PL)	22	
Plasticity index	17	
Gypsum content ($CaSO_4$ $2H_2O$) %	0.23	BS 1377-3
Total dissolved salts (TDS) %	0.39	ASTM D5907
SO_3 content, %	0.19	BS 1377-3
Organic matter (OM) %	0.2	ASTM D2974
pH value	9.18	ASTM D4972
Classification according to USCS	CL	ASTM D2487

Table 3. Consolidation test results for soft clay.

Parameter	Soft clay state
Cu	20–25 kN/m^2
e_o	0.73
γ_{dry}	16.45 kN/m^2
γ_{sat}	19.4 kN/m^2
Compression index, Cc	0.19
Expansion index, Cr	0.11

Eight experiments were performed on soft clay soil with impact loads from various sources and measurement of the energy at the soil's surface using two separate footing dimensions (where B is the diameter of the foundations). Fig. 1 shows the tests. A falling weight deflectometer (FWD) was used to apply impact loads to a modeling technique with a ground baseplate of two sizes that remained measured as a surface footing on the topsoil underneath the impactor. It also included a steel with walls made of plating 2 mm thick and a base that represented a soil container. The two portions of the steel container have dimensions of 1200 × 1200 × 800 mm. Test runs were conducted before beginning the process of prepping the soil. Fig. 2 shows a relationship between the water content and liquidity index to get the soil's undrained shear strength. Following are the preparation steps for the soil layers in the steel container:

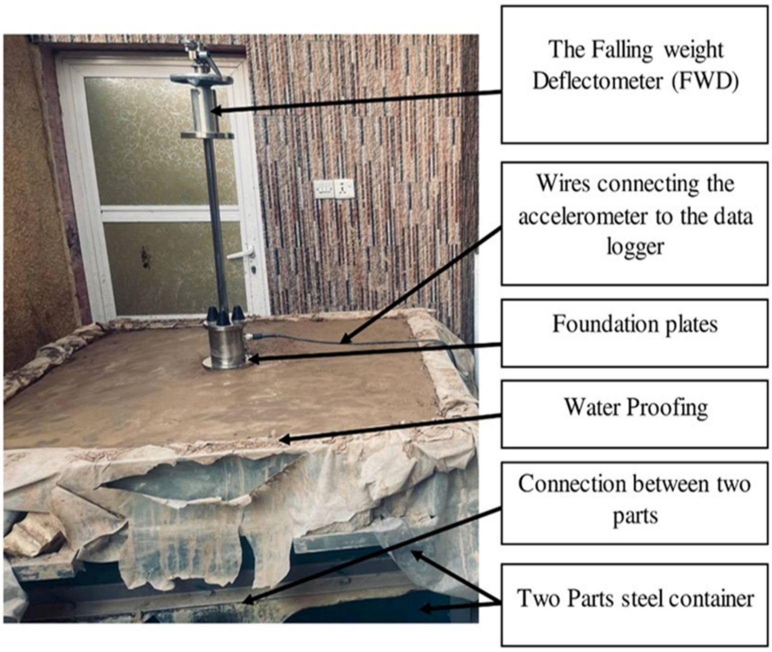


Figure 1. The experimental soil model's setup.

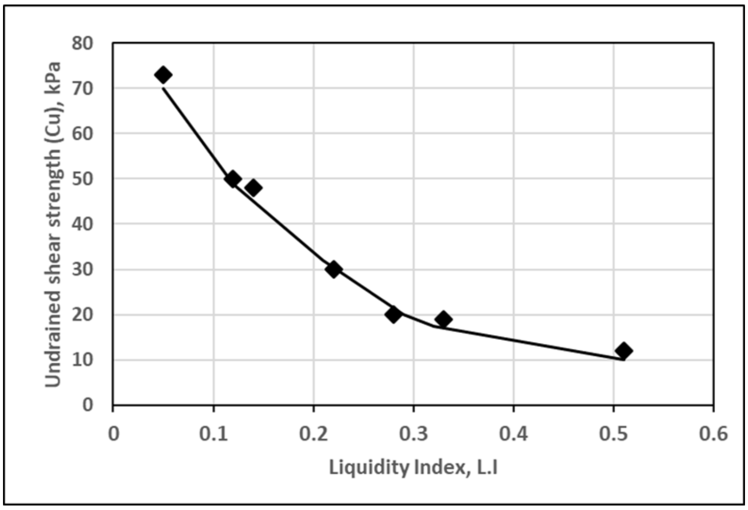


Figure 2. Relations between shear strength and liquidity index.

- A total of 25 kg of dry soil was divided up into groups.
- To achieve an undrained shear strength (Cu) between 20 and 25 kPa, as specified by engineering standards, the soil model was mixed in mixing with sufficient water contents and various proportions. The moisture content value then was chosen from Fig. 3.
- The clay soil was combined with water and placed in parts of the steel container. Each level was then compacted using a specific hardwood tamping hammer measuring 150 × 150 mm. Each layer's outcome was around 50 mm. The operation continued until the clay bed reached its maximum depth.
- After completing the preparations for the clay layers, they were covered with nylon sheets and left for 96 hours to cure.
- Using a portable vane shear apparatus, the undrained shear strength was measured daily to get the closest shear strength value displayed in Fig. 4.

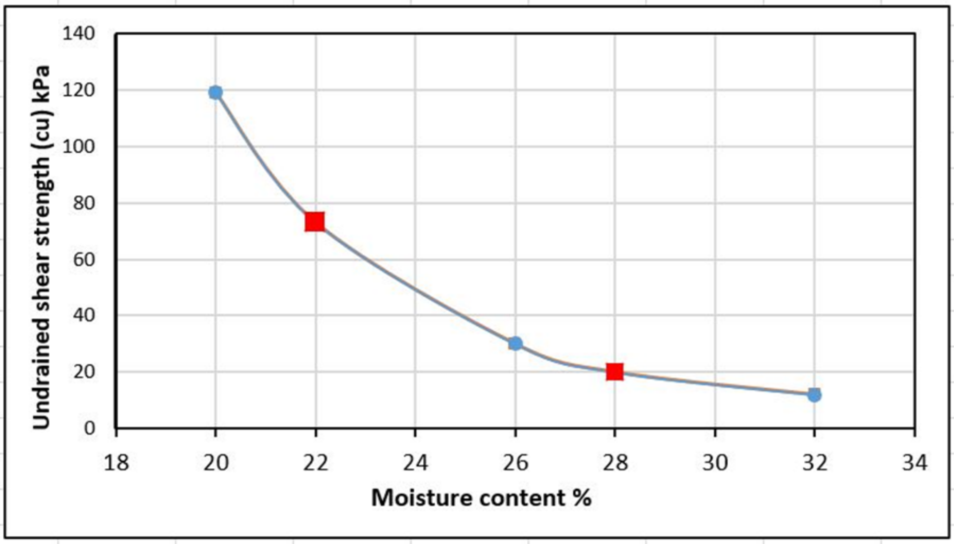


Figure 3. Variation of undrained shear strength vs moisture content.

Figure 4. A portable vane shear device is used to control the undrained shear strength.

2.1. Measuring Instruments

The supporting plates were placed directly upon the surface of the ground, and thus the falling weights utilized to transfer the soil model to the vertical impact dynamic loading were of varying weights (5 or 10 kg) and elevations to represent varying values (500 or 250 mm). Two sizes (100 and 150 mm) of foundation contacting plates are utilized to assess the reaction of the soil surface to an impact force. Then, two pore water pressure gauges are placed at a depth of B or 2B, depending on the size of the bearing plates, in the center of the clay layer in the vertical path under the midpoint of the supporting plates. The method of data collection was designed so that all information could be continually evaluated and collected. Using this method, it is possible to measure the transmitted impulse response, the displacement-time history, and the soil surface depths. Using an accelerometer transducer and surface levels for each test, the acceleration-time history was calculated. The fundamental construction of the FWD mechanism consists of a base structure with an integrated accelerometer and indicator unit. The card reader may record and store a wide range of computations. The sensors display the peak load value and the displacement value. Its storage card's data can be delivered directly to a laptop or through the indication. The software comprises a load cell and an accelerometer to measure the impact load and displacements after free-falling the system block of the falling weight deflectometer. The displacement is obtained by integrating the readings in the accelerometer double. The measurement/processing software is essential for a laptop-based system of units. Inside this approach, recorded data from the indicators is transferred directly from the indicators to the laptop. To identify acceleration within the clay.

2.2. *Testing Method*

The stages describe this test plan:

- Preparing the soft clay layers for a total depth of 800 mm (100 mm per level).
- Putting the accelerometer sensor in the midpoint of the clay soil in a vertical path under the center of the bearing surfaces plate at depths of B or 2B, depending on the size of the bearing surfaces.
- Putting the sensors on the ground horizontally at a depth of 10 mm.
- After putting the base for the model, mount the FWD in the center and ensure that it is perpendicular to the area of the model.
- The file collecting system, as seen in Fig. 5, will record the response to delivering the impacting mass and display the results on a laptop.
- The information of abbreviation for the verified models as well as a specimen of models identification is clarified in Table 4.

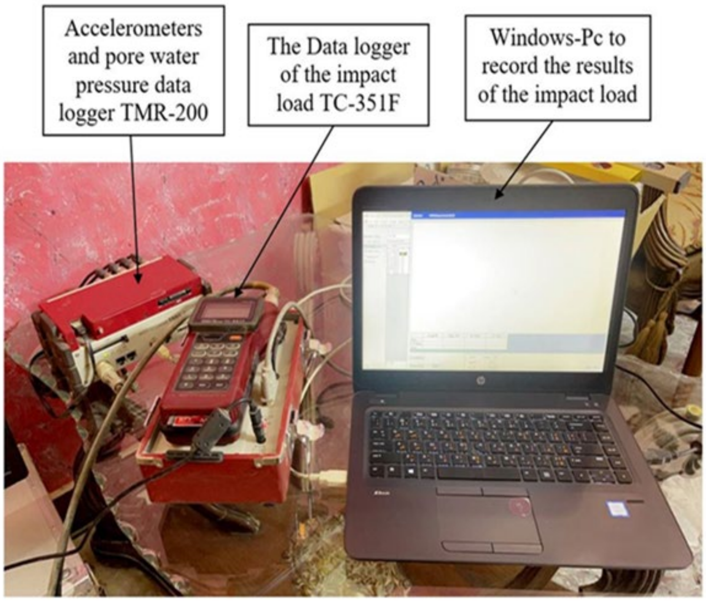


Figure 5. Data acquisition system.

Table 4. Details of the testing program and test designation.

No.	Test designation	Soil state	Soil density	Impact loading state	Size of bearing plate (mm)	The dropping mass (kg)	The height of drop (mm)
1	SsoP100M5H25	Saturated	Soft	At surface	100	5	250
2	SsoP100M5H50	Saturated	Soft	At surface	100	5	500
3	SsoP100M10H25	Saturated	Soft	At surface	100	10	250
4	SsoP100M10H50	Saturated	Soft	At surface	100	10	500
5	SsoP150M5H25	Saturated	Soft	At surface	150	5	250
6	SsoP150M5H50	Saturated	Soft	At surface	150	5	500
7	SsoP150M10H25	Saturated	Soft	At surface	150	10	250
8	SsoP150M10H50	Saturated	Soft	At surface	150	10	500

3. *Results and Discussion*

Concerning the behavior of soft clay soil, it is essential to note that a range of loading conditions was utilized in impact testing on plates ranging in diameter from 100 to 150 mm, dependent on the supporting plates' location on the soil surface (0B). A weight of 5 or 10 kg was dropped from a height of 500 or 250 mm to produce the impact force. The results of dynamic analysis are shown in Fig. 6–9. The data are shown in sections (a), (b), (c), and (d) of each figure for each reaction, which contains the load history, displacements, accelerations, and velocity functions of time. All responses are observed directly beneath the surfaces. Variations in vertical displacement (beneath the plates) are depicted in section (c) of each figure.

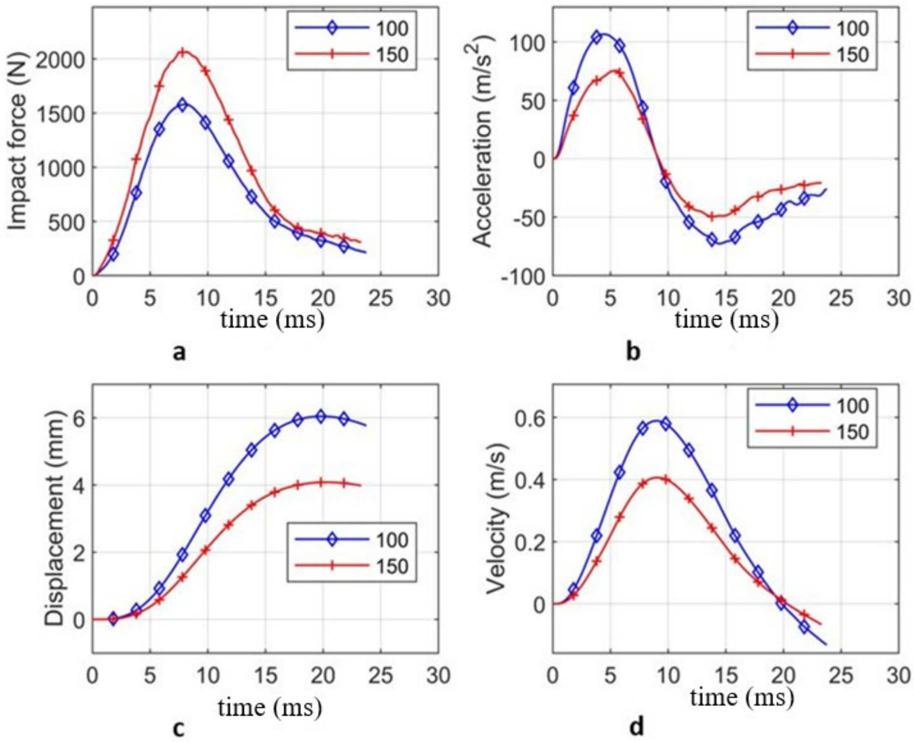


Figure 6. Dynamic test results for SsoPM5H25 model: (a) and (c) impact force-time history with displacements, (b) acceleration time history, (d) velocity time-history.

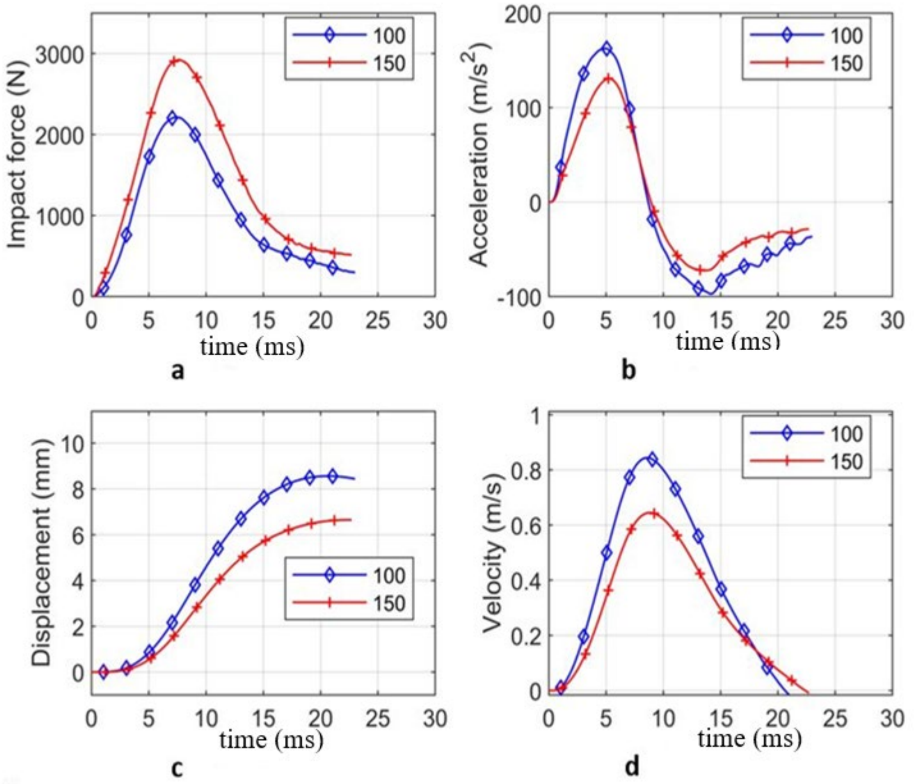
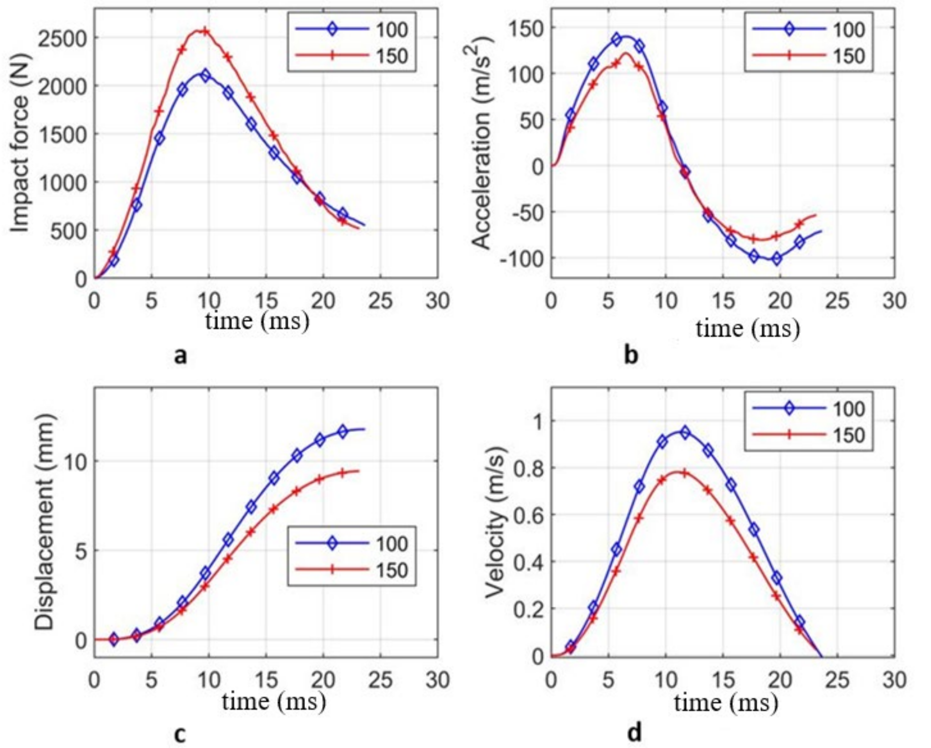


Figure 7. Dynamic test results for SsoPM5H50 model: (a) and (c) impact force-time history with displacements, (b) acceleration time history, (d) velocity time-history.



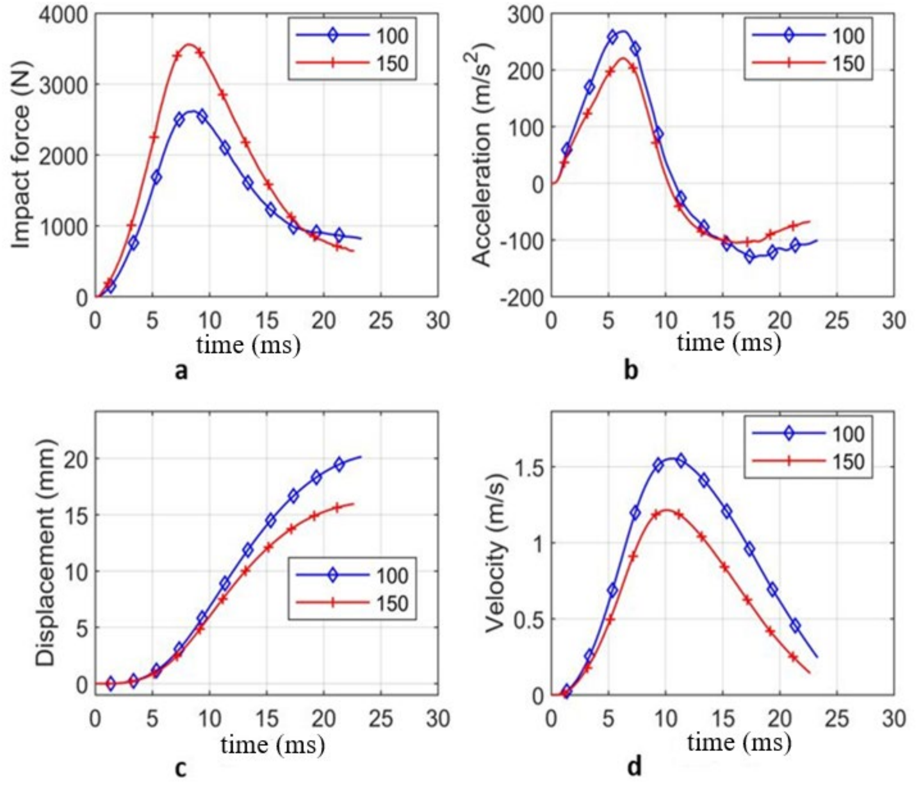
a

b

c

d

Figure 8. Dynamic test results for SsoPM10H25 model: (a) and (c) impact force-time history with displacements, (b) acceleration time history, (d) velocity time-history.



a

b

c

d

Figure 9. Dynamic test results for SsoPM10H50 model: (a) and (c) impact force-time history with displacements, (b) acceleration time history, (d) velocity time-history.

3.1. Impacts and Displacements Reactions

The reaction is related to displacements of the soil surface layer under vertical impacts of energies (measured under the impact plate's middle under surface depth only); these reactions were represented in the bottom section of component (c) of Fig. 6–9. The following are examples of common effects features:

- The highest impacting loading and highest displacements for soft clay occurred only when the impacts plate is placed at the soil surface of the foundations' area (100 mm) and the impactor plate (10 kg) is elevated to a height of 500 mm as seen in Fig. 9.
- It is not possible to predict the highest impact load and highest displacements of soft clay soil according to the modeling data results compared with different soil models. To indicate the excess pore water pressure-time histories gathered by pore water pressure sensors located at levels B and 2B below the middle of the testing bearing surface, two piezometers were placed under the plates to measure the pore water pressure through impact.

The following behavior is shown by a soil-foundations system:

- According to design models, it was observed that the resultant impulse waves have a smaller value in all cases under investigation when the water content of soft clay soil is reduced.
- The maximum displacement responses in the case of the soil model as shown in Fig. 9, have always been found to be greater as the kinetic energy of the dropping hammer increased (mass and level of fall). When either the mass of the hammering or the height of the fall is increased by a factor of doubled (from 5 to 10 kg or from 250 to 500 mm, respectively).
- As a result of a reduction in the water content ratio and a rise in the density of clay particles, as indicated by the soil model, it has been shown that the excess pore water pressure of the soft clay model has measurable complete effect.
- The vertical displacements of the footing block caused by the initial hammer blows were computed using the fatigue damage model proposed in this research and compared with the analytical results [18–21]. It can be shown that the simulation findings for vertical displacement are in good arrangement with the analytical results.
- When comparing the amplitude of displacement for saturated sand with time as a test result for the investigated outcome [22], it can be seen that each test's findings have a different character in the relationship between displacement and time. Concerning the test conditions and reaction of the dynamic behavior of the soil, it seemed that high measurement values at the beginning and end of the test for a low amplitude load. Thus, when a low load amplitude was applied, a large displacement magnitude was detected and remained constant for a lengthy period of testing before the load was released, at which point there was a noticeable decrease in the magnitude of displacement. Therefore, it is clear that the displacement values change over time as the amplitude of the load increases. It follows that a high loading percentage would also have a high displacement and settling value.
- As the soil required time to regain its resistance, the displacement may be higher or lesser than the prior displacement if the loading rate is not uniform [23-25].

Two piezometers were put under experimental bearing plates to monitor the pore water pressure during the impacts. Fig. 10–16 represent the excess pore water pressure-time histories recorded by pore water pressure sensors positioned at levels B and 2B underneath the bearing plate's center. A soil-foundations system displays the following behavior:

- For the soft clay state, based on increasing the water content, it was determined that the resultant impulse waves have a higher peak when increasing the mass energies.
- The peak displacement reactions inside soft clay soil having risen in reactions were seen to be higher when the falling hammer's kinetic energy increased (mass and level of fall). When either the mass of the hammer or the elevation of the fall is doubled (from 5 to 10 kg or from 250 to 500 mm, respectively).
- The vertical displacements for the largest plates (150 mm) are decreasing by 60 % at the depth of the topsoil surface.
- The excess pore water pressure inside the topsoil is shown as a result of three important parameters: impact energy (hammer weight and elevation of drop), size of foundations exposed to the impactor, and soil type. For soft clay soils with constant impact energy, increasing the impact area causes the excess pore water pressure to decrease. In that instance, a 125 % increase in the plate area (from 100 to 150 mm in diameter) causes a 30–40 % drop in the pore water pressure.

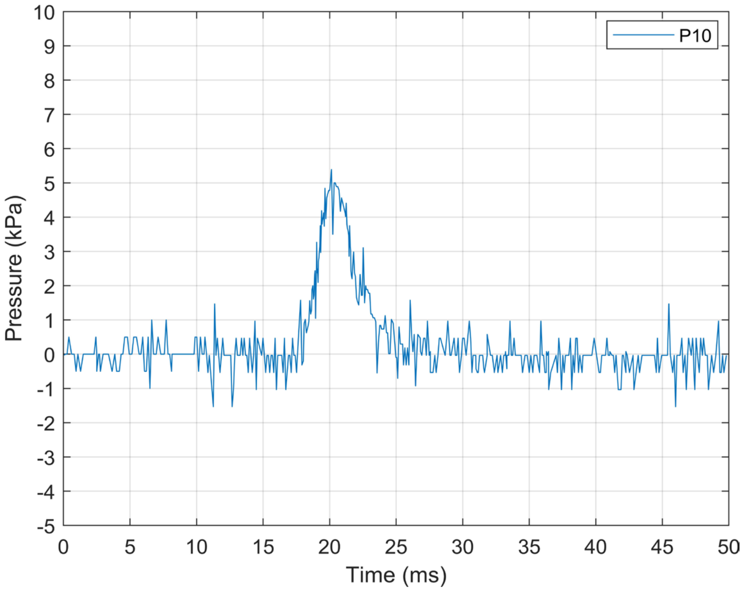


Figure 10. Pressure-time history of excess pore water at depth B for the SsoP100M5H25 model.

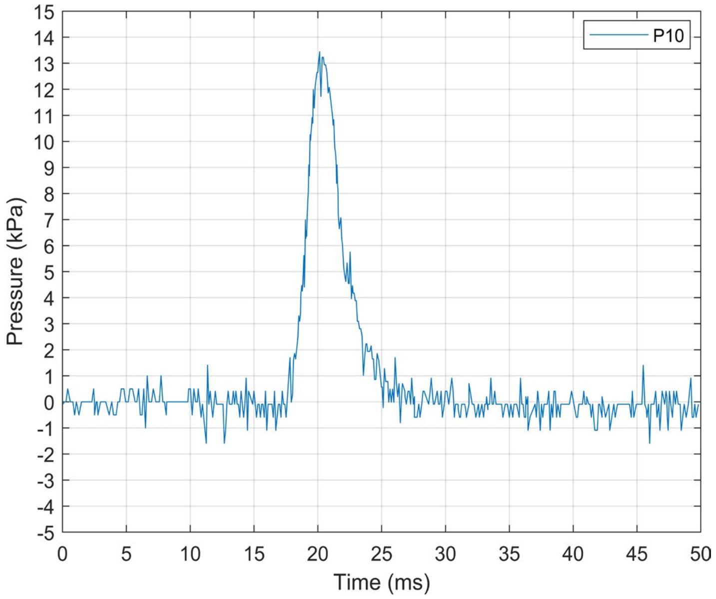


Figure 11. Pressure-time history of excess pore water at depth B for the SsoP100M5H50 model.

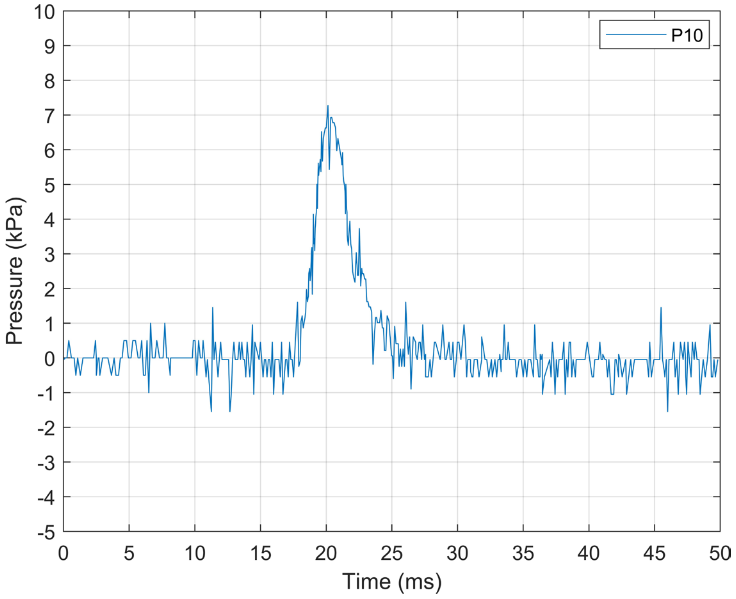


Figure 12. Pressure-time history of excess pore water at depth B for the SsoP100M10H25 model.

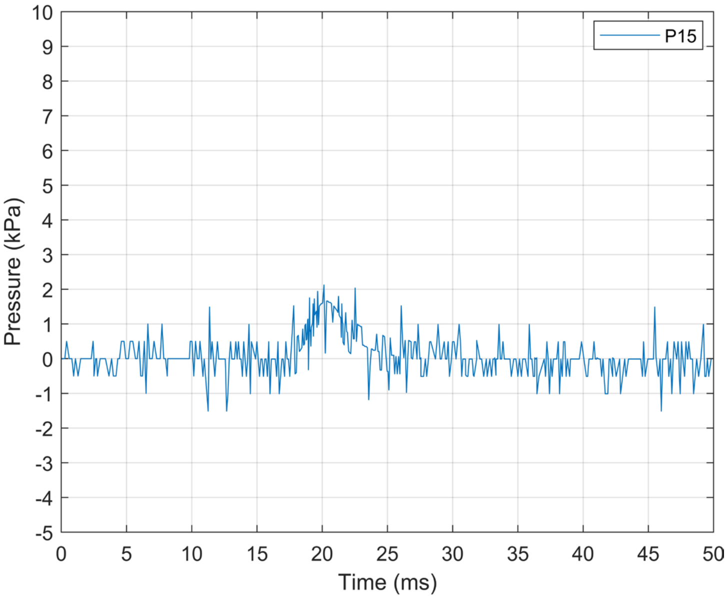


Figure 13. Pressure-time history of excess pore water at depth B for the SsoP100M10H50 model.

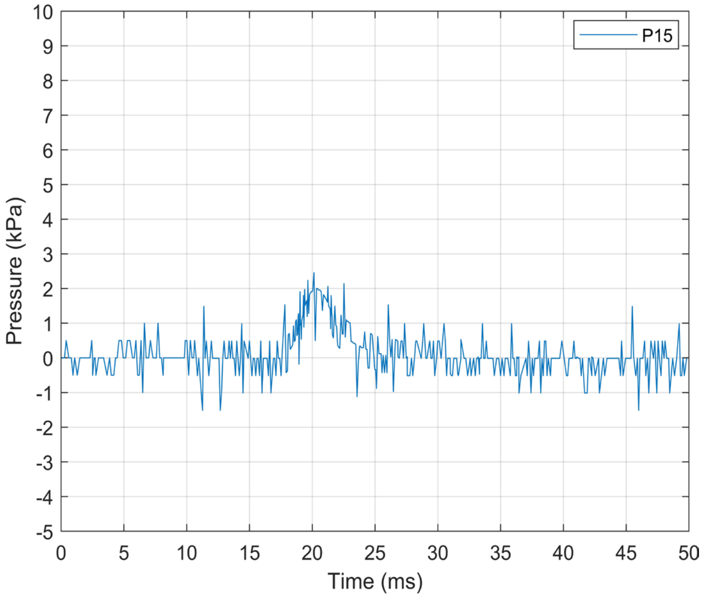


Figure 14. Pressure-time history of excess pore water at depth B for the SsoP150M5H50 model.

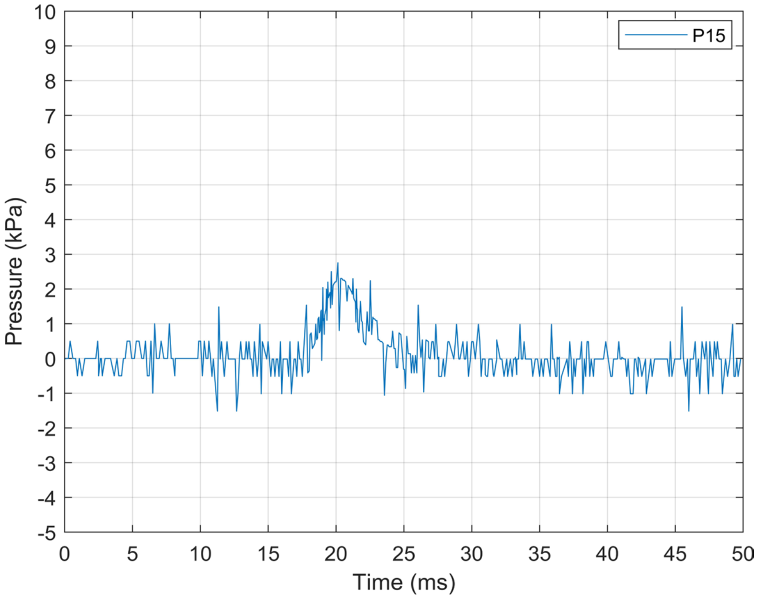


Figure 15. Pressure-time history of excess pore water at depth B for the SsoP150M10H25 model.

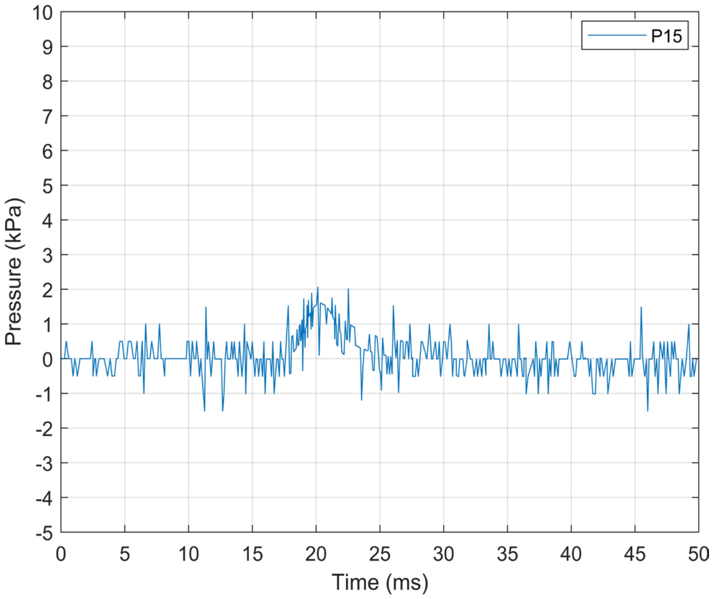


Figure 16. Pressure-time history of excess pore water at depth B for the SsoP150M10H50 model.

4. Conclusions

- The average percentage change in maximum impact forces generated in the contact surface increased by 33 % under the same impact loads (5 Kg) for both dropping heights (250 and 500 mm), which led to a reduction of 25 % in the maximum displacement reaction of the soft clay soil model.
- The amplitude of the force-time history in soft clay is reduced by 40–57 %. This reduction happens since the voids are filled with water, causing fewer contact points between particles.
- The amplitude of the force-time history for soil under impact stress is a single pulse.
- Once the operation frequency increases, the amplitude of displacements on the foundations, total stress, and pore water pressure increased for soft clay shallow foundations at the soil's surface.
- The maximum displacements increased with increasing operational frequency and dynamic loads.
- The dynamic response increases rapidly with the degree of damage, which in turn affects the transmission of damage in the foundation and the soil due to the higher stresses concentrating near the foundation regions. From the computational analysis of the dynamic features of soil damage, it can be observed that as damage rises, the effects of hammer blows on the surface and depth of the soil near the foundation become more important. This enables the development of a method for managing the damage and its progression in a damaged material, as well as the dynamic response of a damaged structure.

Following these conclusions, it is advised that pile foundations in saturated clay soils be used in future works with the same standard specifications. In addition to the possibility of studying the behavior of the plane runways-bearing soil, which is constantly exposed to impact loads at the moment the plane touches the ground.

References

1. Gazetas, G. Analysis of machine foundation vibrations: state of the art. International Journal of Soil Dynamics and Earthquake Engineering. 1983. 2(1). Pp. 2–42. DOI: 10.1016/0261-7277(83)90025-6

2. Abdulrasool, A.S., Fattah, M.Y., Salim, N.M. Experimental investigation for dynamic response of saturated clay under machine foundation. Modern Applications of Geotechnical Engineering and Construction. 2021. Pp. 365–374. DOI: 10.1007/978-981-15-9399-4_30

3. Pandya, S., Sachan, A. Experimental studies on the effect of load repetition on dynamic characteristics of saturated Ahmedabad cohesive soil. International Journal of Civil Engineering. 2019. 17(6). Pp. 781–792. DOI: 10.1007/s40999-019-00392-8

4. Pitilakis, D., Dietz, M., Wood, D.M., Chouteau, D., Modaressi, A. Numerical simulation of dynamic soil-structure interaction in shaking table testing. Soil dynamics and Earthquake Engineering. 2008. 28(6). Pp. 453–467. DOI: 10.1016/j.soildyn.2007.07.011

5. Chehab, A.G., El Naggar, M.H. Response of block foundations to impact loads. Journal of Sound and Vibration. 2004. 276(1-2). Pp. 293–310. DOI: 10.1016/j.jsv.2003.07.028

6. Jayawardana, P., Achuhan, R., De Silva, G.S., Thambiratnam, D.P. Use of in-filled trenches to screen ground vibration due to impact pile driving: experimental and numerical study. Heliyon. 2018. 4(8). e00726. DOI: 10.1016/j.heliyon.2018.e00726

7. Costa, P.A., Calçada, R., Cardoso, A.S. Track–ground vibrations induced by railway traffic: In-situ measurements and validation of a 2.5 D FEM-BEM model. Soil Dynamics and Earthquake Engineering. 2012. 32(1). Pp. 111–128. DOI: 10.1016/j.soildyn.2011.09.002

8. Al-Homoud, A.S., Al-Maaitah, O.N. An experimental investigation of vertical vibration of model footings on sand. Soil Dynamics and Earthquake Engineering. 1996. 15(7). Pp. 431–445. DOI: 10.1016/0267-7261(96)00023-1

9. Liu, S., Li, P., Zhang, W., Lu, Z. Experimental study and numerical simulation on dynamic soil-structure interaction under earthquake excitations. Soil Dynamics and Earthquake Engineering. 2020. 138. 106333. DOI: 10.1016/j.soildyn.2020.106333

10. Luo, C., Yang, X., Zhan, C., Jin, X., Ding, Z. Nonlinear 3D finite element analysis of soil–pile–structure interaction system subjected to horizontal earthquake excitation. Soil Dynamics and Earthquake Engineering. 2016. 84. Pp. 145–156. DOI: 10.1016/j.soildyn.2016.02.005

11. Crockett, J.H., Hammond, R.E. The dynamic principles of machine foundations and ground. Proceedings of the Institution of Mechanical Engineers. 1949. 160(1). Pp. 512–531. DOI: 10.1243/pime_proc_1949_160_048

12. Mohammed, Q.S. Dynamic Behavior of Machine Foundations on layered sandy soil under Seismic Loadings. Journal of Engineering. 2022. 28(8). Pp. 1–20. DOI: 10.31026/j.eng.2022.08.01

13. Al-Azawi, T.K., Al-Azawi, R.K., Al-Jaberi, Z.K. Stiffness and damping properties of embedded machine foundations. Journal of Engineering. 2006. 12(2). DOI: 10.31026/j.eng.2006.02.19

14. Al-Mosawi, M.J., Fattah, M.Y., Al-Ameri, A.F. Effect of saturation of sandy soil on the displacement amplitude of soil foundation system under vibration. Journal of Engineering. 2015. 21(2). Pp. 20–36. DOI: 10.31026/j.eng.2015.02.02

15. Abbas, H.Q., Al-Zuhairi, A.H. Flexural Strengthening of Prestressed Girders with Partially Damaged Strands Using Enhancement of Carbon Fiber Laminates by End Sheet Anchorages. Engineering, Technology & Applied Science Research. 2022. 12(4). Pp. 8884–8890. DOI: 10.48084/etasr.5007

16. Mandal, A., Baidya, D.K., Roy, D. Dynamic response of the foundations resting on a two-layered soil underlain by a rigid layer. Geotechnical and Geological Engineering. 2012. 30(4). Pp. 775–786. DOI: 10.1007/s10706-012-9497-2

17. Xue, X., Ren, T., Zhang, W. Analysis of fatigue damage character of soils under impact load. Journal of Vibration and Control. 2013. 19(11). Pp. 1728–1737. DOI: 10.1177/1077546312450732

18. Gupta, C.P., Visvanathan R. Dynamic behavior of saturated soil under impact loading. Transactions of the ASAE. 1993. 36(4). Pp. 1001–1007. DOI: 10.13031/2013.28427

19. Dobry, R. Dynamic properties and seismic response of soft clay deposits. Proc. of the Int. Symp. on Geotech. Engrg. of Soft Soils. 1987. 2. Pp. 51–86.

20. Chehab, A.G., El Naggar, M.H. Response of block foundations to impact loads. Journal of Sound and Vibration. 2004. 276(1-2). Pp. 293–310. DOI: 10.1016/j.jsv.2003.07.028

21. Karim, H.H., Samueel, Z.W., Hussein, M.A. Investigation of the behavior of shallow machine foundations resting on saturated layered sandy soil subjected to a dynamic load. IOP Conference Series: Materials Science and Engineering. 2020. 888(1). 012055. DOI: 10.1088/1757-899X/888/1/012055

22. Ali, A.F., Fattah, M.Y., Ahmed, B.A. The behavior of the Dry Dense Sand-Foundation System Acted upon by Impact Loads. 2016. 6(4). Pp. 86–103. DOI: 10.5923/j.jce.20160604.02

23. Ahmed, B.A., Rasheed, A.H. Experimental Analysis of the Dynamic Response of Saturated Clayey Soil Under Impact Loading. Engineering, Technology & Applied Science Research. 2022. 12(6). Pp. 9787–9794. DOI: 10.48084/etasr.5388

24. Rasheed, A.H., Ahmed, B.A. Dynamic monitoring of saturated stiff clay soil foundation structure by falling weight deflectometer system under impact loads sensors effect. Measurement: Sensors. 2023. 100673.

25. Karkush, M.O., Kareem, M.A. Behavior of pile foundation subjected to lateral cyclic loading in contaminated soils. Journal of Civil Engineering Research. 2015. 5(6). Pp. 144–150. DOI: 10.5923/j.jce.20150506.03

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