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Study the Behaviour of the Natural Clay Soil Shallow Foundation System Subjected to Impact Loads

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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. In industrial applications, these vibrations remain often caused by the impact of weights on the foundation machine. Typically, these basics transmit effective vertical stresses to the surface layers. Accordingly, the dynamic performance of natural clay soils under the influence of individual active loads was careful in this work. Energy A deflection scale system dropped different loads from several elevations. The application of this research was to study the surface soil responses only. These responses include the vertical displacements, velocities, and accelerations implied by impacts on the soil surface. Some of the results showed a decrease in the displacement value of the natural clay soil by a rate ranging from 25% to 35%, a result of an increase in the overburden pressure based on an increase in the embedment depth, which led to a rise in the stiffness of the clayey soil.

Keywords: Natural clay soil, Impact load, Shallow foundations, and Vertical displacement.

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دراسة السلوك الديناميكي لنظام الأساسات السطحية على الترب الطينية الطبيعية المعرضة لقوى الاحمال الصدمية

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الخلاصة

في الهندسة المدنية هناك العديد من المشاكل المتعلقة بانتقال موجات الضغط عبر التربة نتيجة الأحمال الديناميكية. وغالبًا ما تحدث هذه الاهتزازات في التطبيقات الصناعية بسبب تأثير الاوزان على اساسات الماكينة. عادة هذه الأسس تقوم بنقل الضغوط الرأسية الفعالة إلى طبقات السطح ، وعليه تم التحري عمليًا عن الأداء الديناميكي للتربة الطينية الطبيعية تحت تأثير الأحمال النشطة الفردية في هذا العمل، وقد بحثت هذه الدراسة في كيفية تفاعل التربة الطينية الطبيعية مع حمولة اندفاعية واحدة ,لإنشاء نبضة واحدة من الطاقة تم استخدام منظومة مقياس انحراف لإسقاط أوزان مختلفة من عدة ارتفاعات. وتم التركيز في هذا البحث على دراسة استجابات التربة السطحية فقط . تضمنت هذه الاستجابات الإزاحات العمودية والسرعات والتسارع التي تحملها التأثيرات التي تحدث على سطح التربة. وقد اظهرت بعض النتائج انخفاض قيمة الازاحة للتربة الطينية الطبيعية بنسبة تتراوح ما بين 25 الى 35 في المائة وذلك نتيجة لزيادة انضغاط الطبقة السطحية للتربة بناءا على زيادة اعماق الدفن الامر الذي بدوره يؤدي الى زيادة صلابة التربة الطينية بشكل خاص لهذا العمل.

sالكلمات المفتاحية: تربة طينية طبيعية, احمال صدمية, أسس سطحية, الازاحة العمودية.

1. INTRODUCTION

The Static and dynamic loads may remain applied to the soil, or, depending on the soil-structure contact, then differences between the various double types (stress reversals) include inertial energy (caused by an accelerated signal) and oscillation. Different loading conditions, including earthquake earth motion, wave motions, explosion, machine vibration, and transportation movement, can carry on the dynamic reaction of the soil. Impact loads on machine bases frequently bring on pulsations in the production process. These bases often transfer vertical dynamic weights to the ground and cause earth vibrations that might hurt surrounding structures or buildings. Active impacts can cause significant structural damage or make operating difficult for some delicate equipment or devices **(Svinkin, 2008).**
Consequently, the most crucial step in the planning process for a successful machine basis may remain used to evaluate dynamic reaction, and it should not exceed the limit established by the machine's designer. Before examining the permitted limits for the settlements of the machine footing, it is essential to comprehend that failures of vibrating bases occur when the motion exceeds a controlling value, frequently expressed as the ground displacements at particular frequencies **(Abdulrasool et al., 2021).** The dynamic reaction of machinery has

been the subject of several studies; among these are the authors **(Chehab et al., 2004; Pitilakis et al., 2008; Pandya et al., 2019).** Additionally, several studies looked at vertical vibration for surface footing. Dynamical soil features affect the soil's response to impact forces. They monitor the soil's reaction to impact loading to estimate its physical parameters. **(Jayawardana et al., 2018)** Consider rigidity, damping ratio, and unit weight in their dynamic studies.

Hammer foundations indicate impact-loaded foundations. In most cases, hammer foundations react to the impact initial overview by hammers as a single-degree-of-freedom program; hence, it must remain considered when studying impact machinery foundations as a source of industrial vibrations, especially vertically ground vibration. Due to vibrations caused by hammer foundations, the pressure under the footing of a column may be up to us than double static pressure. Accelerations decrease significantly as the distance from the impact machine's foundations increases. These buildings' structural integrity is not affected by horizontal vibrations to exterior structures induced by ground motions from impact machine footing. On the other hand, low-frequency foundation vibrations can produce resonant building motions at relatively long distances from hammer foundations **(Ali, 2018; Ahmed et al., 2022).** The impact of a vibration reduction technique was examined in this study using centrifuge testing. Geotechnical engineers can use centrifuge modelling, an effective research technique, to investigate complex field issues on a small scale. Gravity effects are essential in geotechnical engineering because the forces caused by self-weight are frequently the main loading. The confining forces produced by these forces control how the soil resources behave **(Itoh et al., 2005).**

Various investigators look into how machines move. For example **(Al-Azawi et al., 2016; Fattah et al., 2022)** and others observed how perpendicular vibrations move shallow footings.

(Abdulkareem et al., 2021; Abbas et al., 2022) showed that when the applied stresses from the test structure exceed the extreme weight, the damaged supporter of specific collections displays a comparatively excellent ratio of stiffness loss due to a portion of the prestressing energy, which accelerates the ratio of cracking and movements. Most studies have absorbed the active strain brought on by earthquakes and offshore waves.

The basis of the machine remains typically modelled as a block sitting on an elastic earth's surface. Usually, the fundamental foundations continue to be placed, which substantially impacts the foundation's dynamic behavior **(Mandal et al., 2012).**

(Al-Mosawi et al., 2015; Mohammed, 2022) stated that the response of soil subjected to dynamic loading depends upon several variables, including permeability, relative density, the character of the dynamic loading, and the magnitude and rate of strain.

The primary purpose of this work is to assess the soil's response to impact pressures. The emphasis will remain on the earth's function in the attenuation of waves induced by impact pressures. When conducting experiments on clay soils to determine how to study the appearance of these soils beneath the influence of impact masses with varying valuable kinetic energy, several factors will be considered, including the surface soil and diameter of the basis, as well as the significance of the bearing weight.

2. SOIL DYNAMIC RESPONSE

The soil dynamic characteristics determine the impact response of soil exposed to dynamic loads. The reactions received for various dynamic loads must be reviewed to identify the dynamic soil parameters **(Kumar et al., 2013).**

For dynamic studies, the essential characteristics are stiffness, damping ratio, and unit weight. These are immediately included in the impact response calculations. Additionally, the position of the water table, the degree of saturation, and the grain size distribution may be significant, mainly when liquefaction is a possible issue.
Almost every structure will be subjected to one type of dynamic loading over its duration; thus, certain buildings must be built for static and dynamic loading. **(Clough and Penzien, 2003).**
The difficulties associated with the dynamic loading of soils and earth buildings that a geotechnical engineer commonly encounters include, but are not limited to, the following **(Das and Ramana, 2011):**

1. Earthquake, ground motion, and wave propagation in soils.
2. Soil dynamic tension, deformation, and strength.
3. The issue of dynamic earth strain.
4. Problems with impact-bearing capacity and the design of shallow foundations.
5. Liquefaction-related issues
6. Design of machines and vibrating equipment foundations.
7. The design of embedded foundations and piles is subjected to dynamic loads.
8. Embankment stability under impact forces.

3. IMPACT LOAD

Impact loads on machine foundations are a typical and effective cause of vibrations in industry. The vertical dynamic loads usually transferred to the soil by these foundations cause ground vibrations that might harm surrounding buildings or structures.
Dynamic effects can result in evident structural damage or extremely difficult operating conditions for some sensitive equipment or systems **(Richart, 1962).**

3.1 Waves of Soil Damping

In a perfect linear elastic material, stress waves travel without change in amplitude over an infinite distance. However, this behavior is not possible in actual materials; stress waves drop with distance. Two factors contribute to the absorption: Expansion of the wavefront (geometric damping) and energy absorption in the soil (material damping) **(Kramer, 1996; Lidén, 2012; Lin, A. N, 1984).**

3.2 Soil Damping

Damping is an essential component of soils, and its impact on the responses to vibrations is considerable only in resonant or situations similar to resonant. Many soils showed different damping characteristics according to their conditions and other defining factors. In embedding footings, the embedment level significantly affects the dampening characteristics **(Chowdhury and Dasgupta, 2009).**

4. ANALYSIS AND APPLICATION OF SOIL MODEL.

The investigations continued following the guidelines for determining soil's physical and chemical parameters, as specified in **Table 1**. In Al-Nahrawan, a subsurface model of clayey soil is collected from a distance of 1.0 m at a brick manufacturing site (54 km east of

Baghdad).To control the physical characteristics of the natural soil clay state by using the cylinder tube were found the bulk density for the realistic clay model of 16.5 kN/m2 and the initial moisture content of 6 % as shown in **Fig. 1** and using the unified system for classifying soil, the soil is classified as (CL) as shown the granular distribution of the soil in **Fig. 2.** The natural models be situated set in four level with 10 cm continuous depth for each one toward get the latest height of 40 cm from the lowest of a container and then compressing is prepared by a hammer of 15 kg mass five periods on the surface of individually level and installing the sensors for specific heights, as shown in **Fig. 3.** From the direct shear test the cohesion of the natural soil (c) is 42 kN/m2 and the angle of internal friction (ϕ) is 16∘.
The analysis program for natural clay conditions is there shown in **Table 2.** The program consists of 18 experiments conducted on natural clay soil by impacting masses from different bases and measuring the energy at the soil's surface using three distinct footing sizes (where B is the diameter of the basics). This investigation conducts regular analysis to determine how dynamically reactive a foundation will be to energy impacts on the surrounding soil.

Table 1. Standard chemical and physical properties.

Property	Value	Standard of the test
Specific Gravity, Gs	2.71	(ASTM D854, 2006)
Gravel (> 4.75 mm) %	0	
Sand (4.75 - 0.075 mm) %	3	(ASTM D422-63, 2002)
Silt (0.075- 0.005 mm) %	40	
Clay (< 0.005 mm) %	57	
Liquid limit (L.L.)	39	
Plastic limit (P.L.)	22	(ASTM *D4318-10, 2010)*
Plasticity index	17	
Gypsum content (CaSO4 2H2O) %	0.23	BS 1377-3, 2018
Total dissolved salts (TDS) %	0.39	ASTM D5907
SO_3 content %	0.19	BS 1377-3, 2018
Organic matter (O.M) %	0.2	ASTM D2974-20e1, 2020
Ph value	9.18	(ASTM D4972-19, 2019)
Classification according to (USCS)	CL	(ASTM D2487-06, 2006)

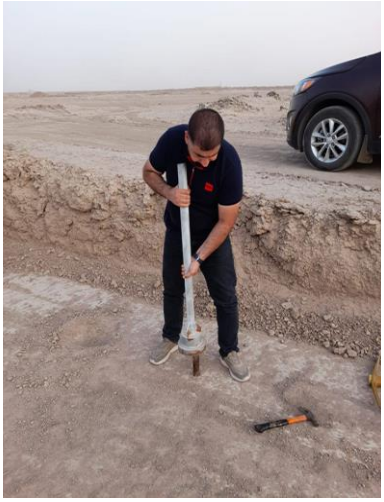


Figure 1. Soil sampling for natural clay model.

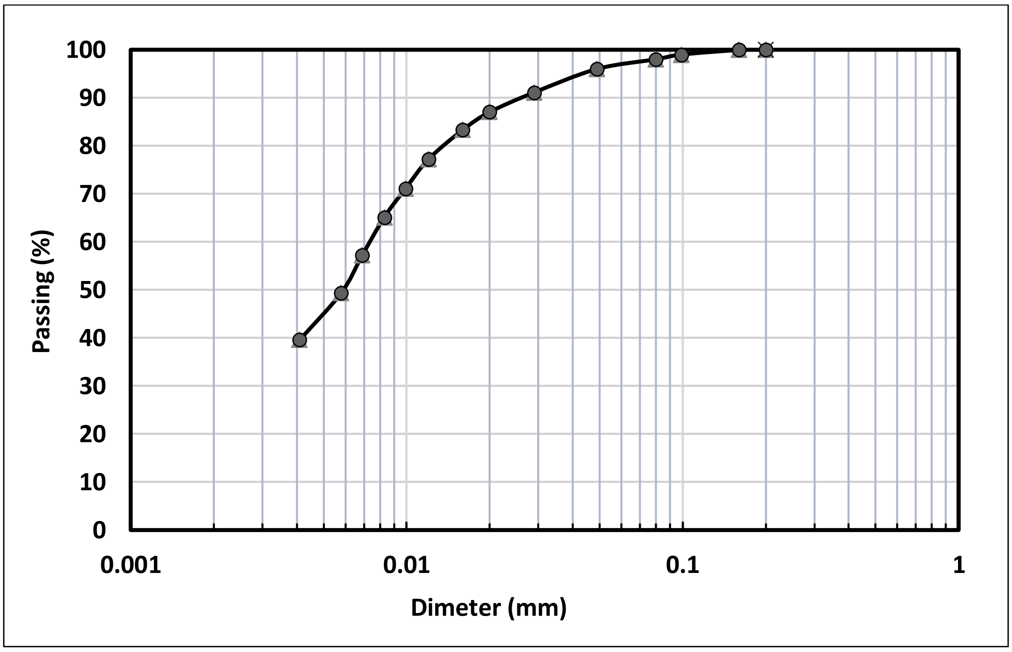


Figure 2. Grain size distribution of the clay soil.

Table 2. Description of the analysis program and description of the test.

No.	Testing description	Bearing plate sizes (mm)	The dropping mass (kg)	The height of drop (mm)
1	NsP10M5H25	100	5	250
2	NsP10M5H50	100	5	500
3	NsP15M5H25	150	5	250
4	NsP15M5H50	150	5	500
5	NsP20M10H25	200	5	250
6	NsP20M10H50	200	5	500
7	NsP10M10H25	100	10	250
8	NsP10M10H50	100	10	500

9	NsP15M10H25	150	10	250
10	NsP15M10H50	150	10	500
11	NsP20M10H25	200	10	250
12	NsP20M10H50	200	10	500
13	NsP10M15H25	100	15	250
14	NsP10M15H50	100	15	500
15	NsP15M15H25	150	15	250
16	NsP15M15H50	150	15	500
17	NsP20M15H25	200	15	250
18	NsP20M15H50	200	15	500

Figure 3. Laboratory soil model construction.

5. EXPERIMENTAL WORK

An impact-loaded foundation resting on a natural soil medium there simulated using a small-scale model. Waves that originate from impact load sources go outward through the soil medium, which is the dynamic system. The system's output signal is the active response of an area of importance located on a basis delivery impulse or inside the soil level. The response signal for the system is the ground's impulse reaction at the site of the foundation installation. Under impact load and various energy forces, the tests led to the natural soil state. In evaluating the models, they are then using three different footing sizes.
The model tests a steel container with two pieces with measurements of 1.20 m in length, 1.20 m in width, and 0.8 m in height.
The (Falling Weight Deflectometer) applies impact force to the soil sample using base-bearing plates of three dimensions, referred to as shallow circular foundations. Each part of the container has a height of 400 mm.

6. INSTRUMENTATIONS

The dropping weights used to convert the soil type to the vertical influence dynamic filling remained of variable masses (5 kg, 10 kg, or 15 kg) and altitudes to represent different values since the supporting plates were set indirectly on the surface of the bases (500 mm or 250 mm). The reactions of the soil outward to an effective force are restrained using foundation contacting plates in three sizes (100 mm, 150 mm, and 200 mm), as illustrated in **Fig. 4.** The data collecting technique remained created to allow for continuous evaluation and gathering of all data. This technique calculates the soil surface depths, the displacement-time history, and the transferred impulse reaction—each test's acceleration-time history using an accelerometer transducer and surface points. The FWD apparatus's base structure includes an integrated accelerometer and an indication unit. Many computations may be detailed and stored by the card reader. The indicator shows the displacement value as well as the peak load value. Data from its storage card is transferred either directly to a laptop. The platform contains a load cell and an accelerometer to calculate the mass of the small FWD central body once it has fallen freely. The displacement calculation remains done by double values of integrating. The measurement/processing software is crucial for a laptop-based scheme of units. In this method, the indicators' recorded information is sent right from the gauges to the laptop. To determine the clay's rate of acceleration. In this method, the indicators' recorded data is transmitted from the hands to the PC. to determine the clay's rate of acceleration.

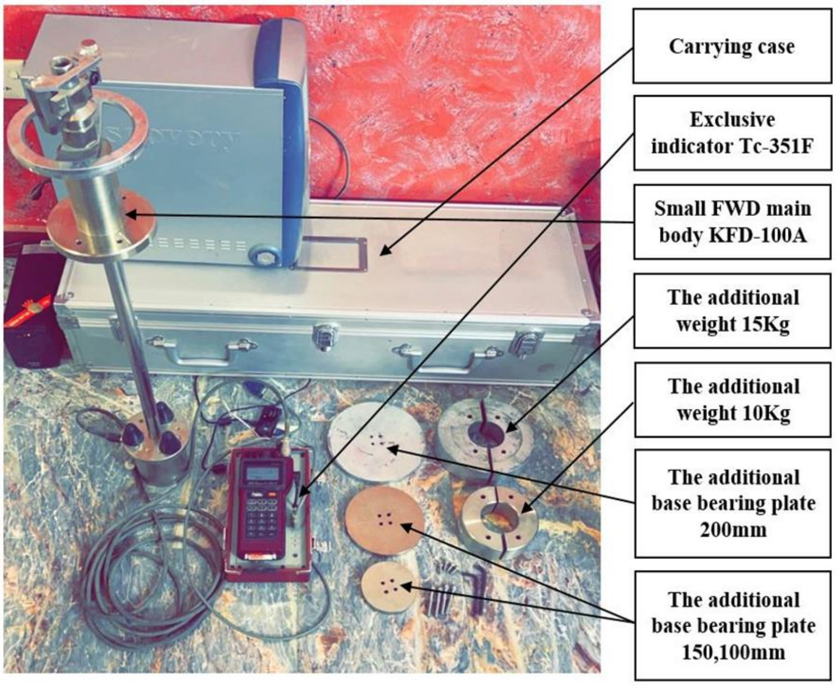


Figure 4. Tested compact FWD system with usual accessories.

7. ANALYSIS METHOD

The phases refer to this experiment plan steps such that:

1. The layers of natural clay are organized to a total distance of 80 cm (10 cm per level).
2. The accelerometer device is installed at a level of B, according to the dimensions of the bearing surfaces, beneath the midpoint of the bearing faces plate in the middle of the clay soil.
3. The sensors are laid down horizontally at a 10 mm depth.

4. It is flattening the outward, connecting the FWD on the middle of the typical surface, and testing if it is vertical to the outward of the sample.
5. After the impacting mass is delivered, the data file collection records the reaction to display the data for post-processing **(Fig. 5).**

The dynamic system propagates waves from impact load sources. The system's input signal is the ground's impulse response at the location of an apparatus basis, and its output signal is a point of interest's dynamic reaction on a receiving foundation or inside the soil stratum **(Ali et al., 2016).**

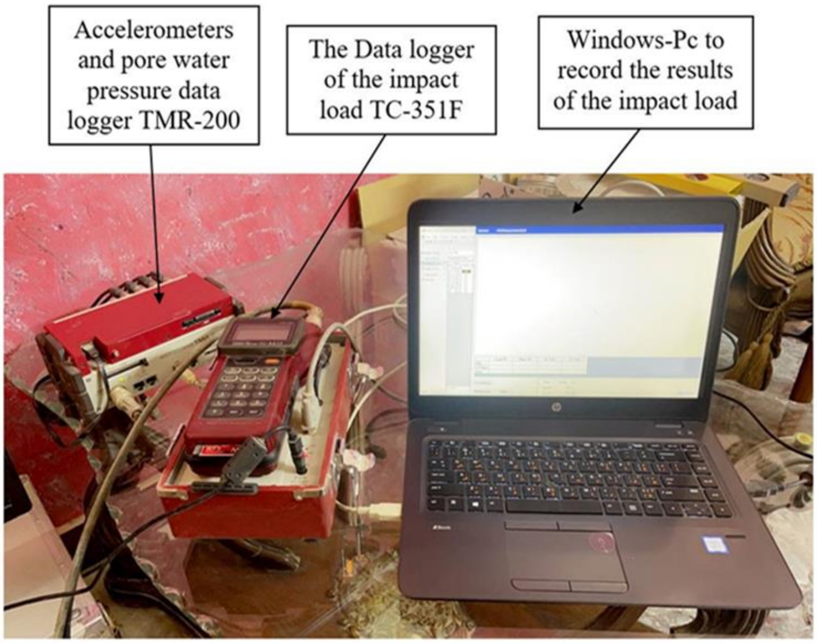


Figure 5. Data acquisition system.

8. RESULTS AND DISCUSSION

The understanding of how natural clay soil behaves. It is essential to know that various loading situations were used in impact analysis on plates with diameters ranging from 10 cm to 15 cm. Depending on where the assistant containers were placed on the soil surface, a mass of 5 kg, 10 kg, or 15 kg fell from an elevation of 50 cm or 25 cm to generate the power force. **Fig.s 6 and 11** display the findings of the dynamic analysis. The load history, displacement, accelerations, and speed jobs of time are included in divisions (a), (b), (c), and (d) of individual figures for each response. Just under the surfaces, we can see all reactions. Section (c) of each figure illustrates differences in vertical displacements (below the plates). The reactions stay based on movements of the soil outward stratum caused by vertical energy influences (measured beneath the center of the impact plate's surface depth alone); these responses remained depicted in the lowest portion of factor (c) of **Fig.s 6 to 11.** Examples of typical impact characteristics include the following:

- For the natural clay ($N_SP_{(10,15,20)}M_{15}H_{50}$) model, the most significant impacting loads of almost (13000 N) and the most significant displacement value of nearly (2 mm) only occurred when the impact plate remained positioned at the foundations' area's soil surface (20 cm). The impactor plate (15 kg) was raised to a height of 50 cm, as shown in **Fig. 11.**

- The scheme's operations may be described as the following. Suppose the plate remains positioned at the top of the soil surface. In that case, the resultant pulse has a considerably reduced amplitude (less maximal impact force) than in all other circumstances of plate depth. It is accurate when the plate diameter is modest (10 cm) and the falling mass is low (lower fall height). Both the amplitude and length of the pulses are essentially equal. **(Karkush et al., 2022)** This principle indicates that no confinement and less active soil mass will contribute to the response. Thus, the absorbed energy is predicted to be more significant, leading to lower values of the highest impact energy amplitude**.**

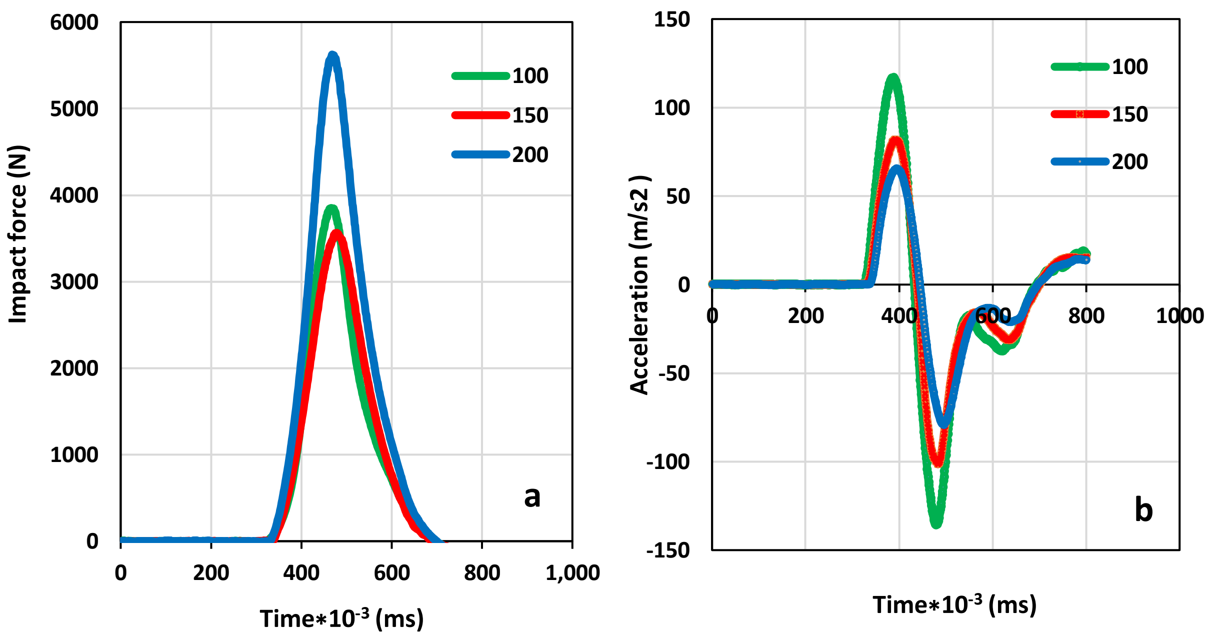
A soil-foundation system shows the following factors:

- When the dynamic energy of the falling hammer increased, it remained consistently discovered that the maximum displacements reacted in the situation of the soil sample, as displayed in Fig (weight and level of drop). When each, the importance of the pounding or the elevation of the fall is pleated (from 5 kg to 15 kg or 25 cm to 50 cm, respectively) **(Rasheed et al., 2023)**.
- We researched several forced and natural vertical vibration models for modelling footings on dry and wet, poorly graded sand. Similar results were reported by **(Ahmed and Rasheed, 2023)**, showing that the natural frequency and amplitude decrease as the footing base area rises, as seen in **Table 3.**
- Using the energy damage model presented in this study, the vertical movements of the footing mass generated by the original hammer blows remained calculated and compared to the analytical results **(Xue et al., 2013).** It can remain demonstrated that the simulation results for vertical movement correspond well with the analytical outcomes.
- One consistent pattern that can be practical is that the amplitude of the impact pulse force tends to get more significant as the amount of energy that the hammer possesses (its mass and the height from which it falls) is more effective.
- The variation in soil density results in a (20-80%) increase in the reduction ratio when the soil density changes from weak to dense **(Fattah et al., 2018).**

No	Author	Research area	Type of soil	Depth of the soil	Displacements under maximum impact loads
1	**(Adnan et al., 2016)**	Karbala city	Saturated Sand	At Surface depth	(30-60) %
2	**(Ahmed et al., 2022)**	Al Nahrawan city	Saturated soft clay	At Surface depth	(50-80) %
3	**(Ahmed et al., 2022)**	Al Nahrawan city	Saturated stiff clay	At Surface depth	80%

4	**(Rasheed et al., 2023)**	Al Nahrawan city	Saturated soft clay	At Surface depth	(50-80) %
5	**(Rasheed et al., 2023)**	Al Nahrawan city	Saturated stiff clay	At Surface depth	80%

Table 3. Comparison of the maximum impact loads and displacement values for a studied area in Iraq.



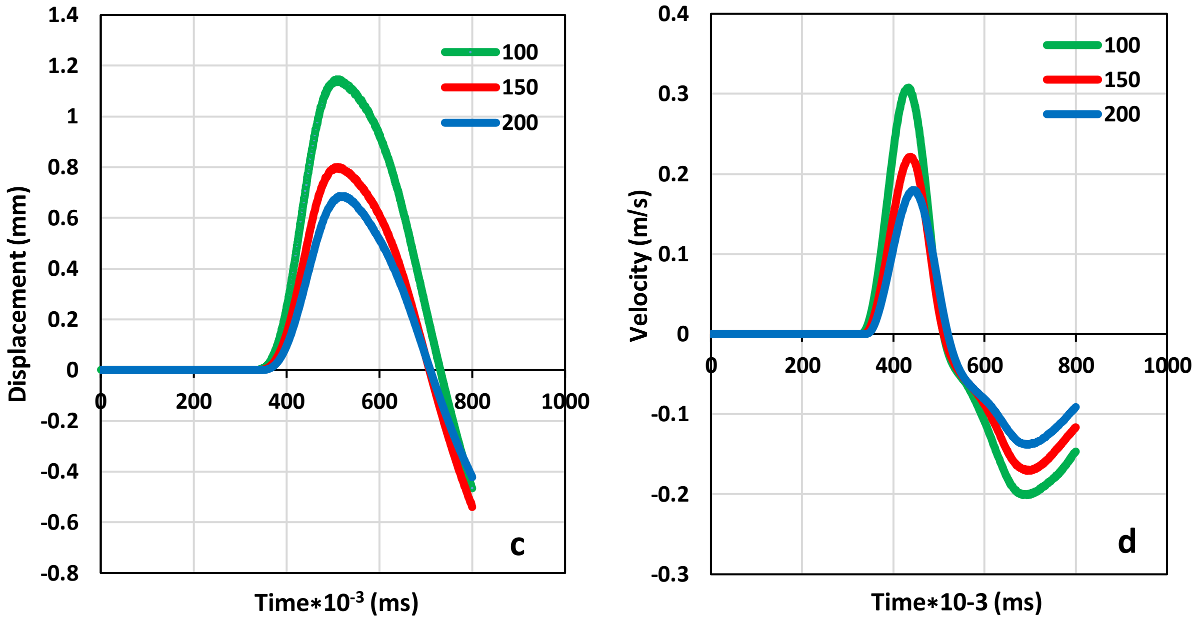
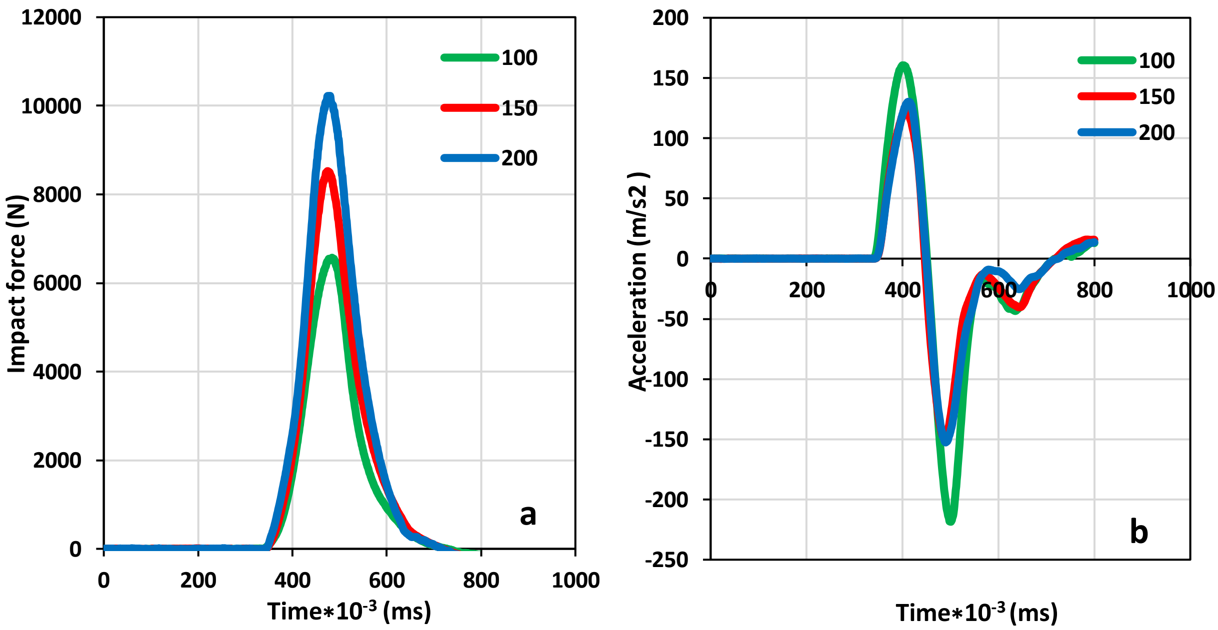


Figure 6. Dynamic results for $N_5P_{(10,15,20)}M_5H_{25}$ model, a) and c) influence the force-time history through displacements, b) a history of acceleration, d) time history of velocity.



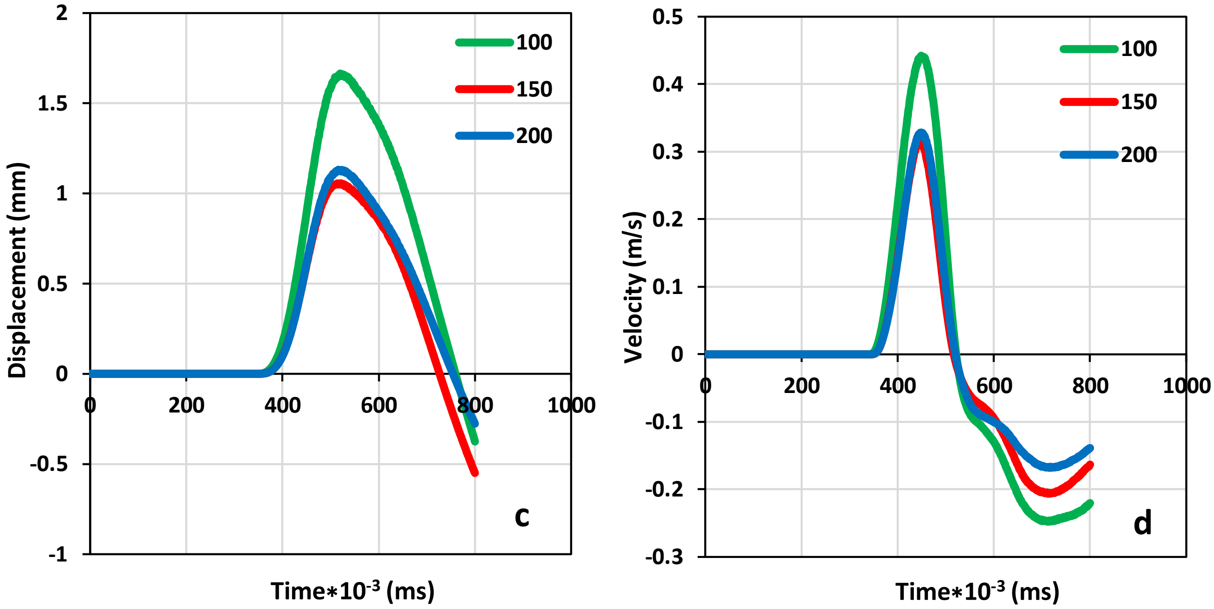
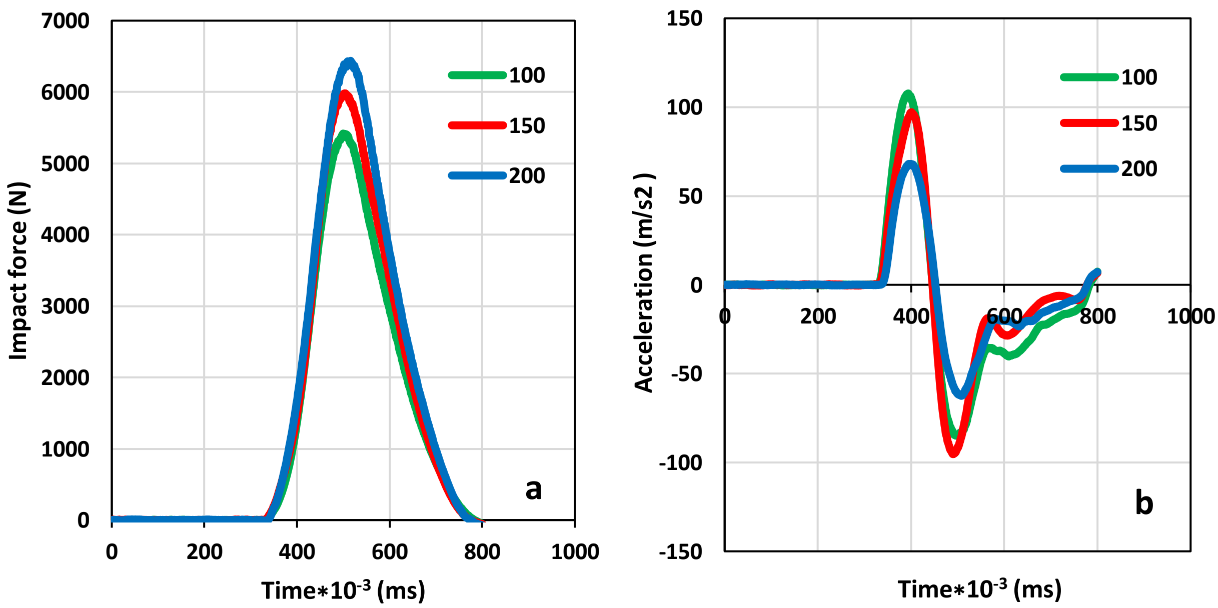


Figure 7. Dynamic results for $N_sP_{(10,15,20)}$ M_5H_{50} model, a) and c) influence the force-time history through displacements, b) a history of acceleration, d) time-history of velocity.



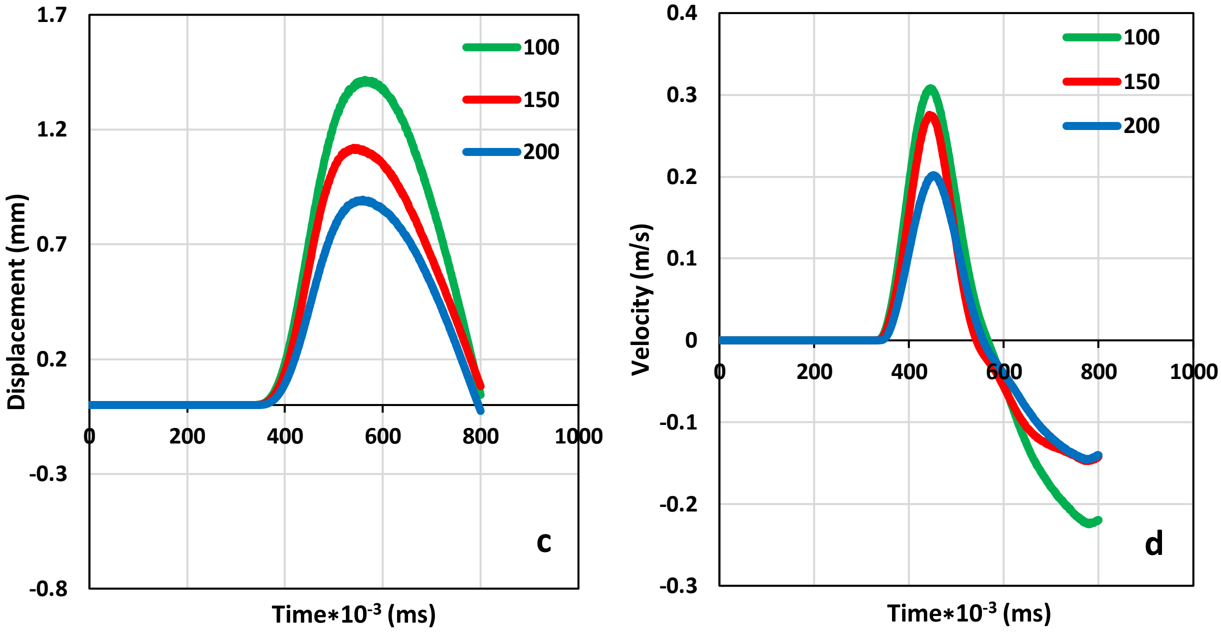
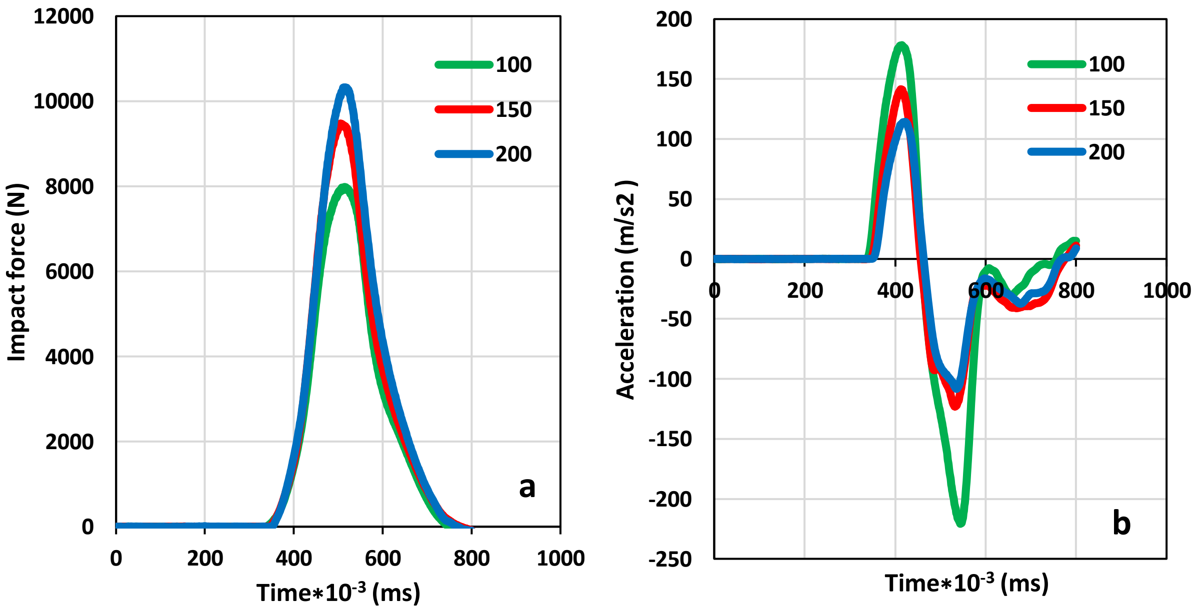


Figure 8. Dynamic results for $N_SP_{(10,15,20)}$ $M_{10}H_{25}$ model. a) and c) influence the force-time history through displacements. b) a history of acceleration. d) time history of velocity.



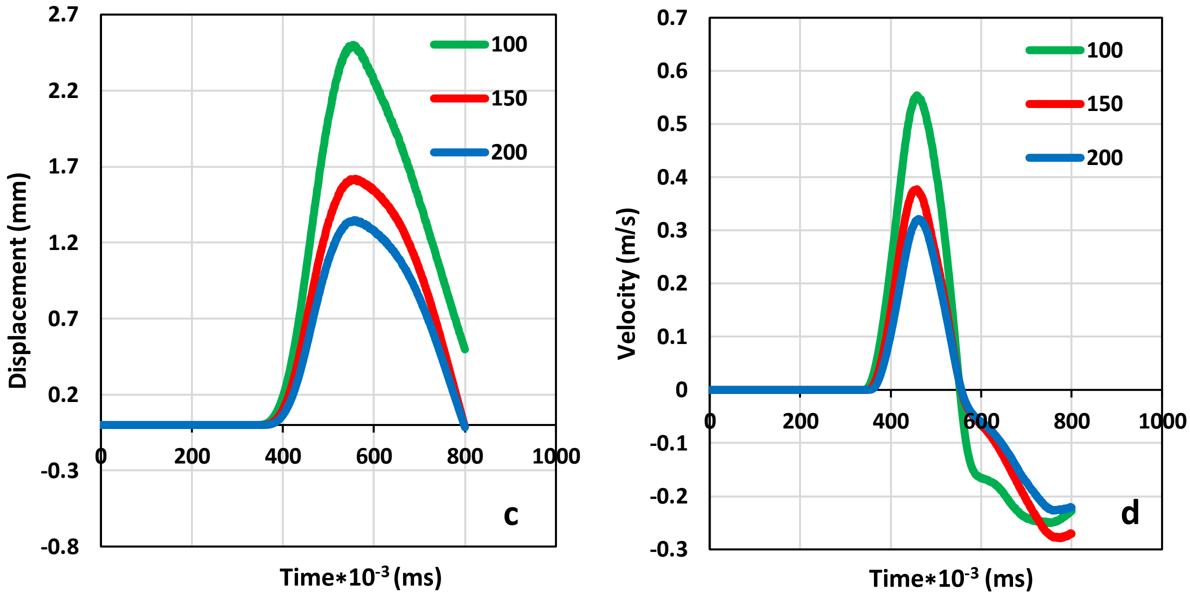


Figure 9. Dynamic results for $N_SP_{(10,15,20)}M_{10}H_{50}$ model, a) and c) influence the force-time history through displacements, b) a history of acceleration, d) time history of velocity.

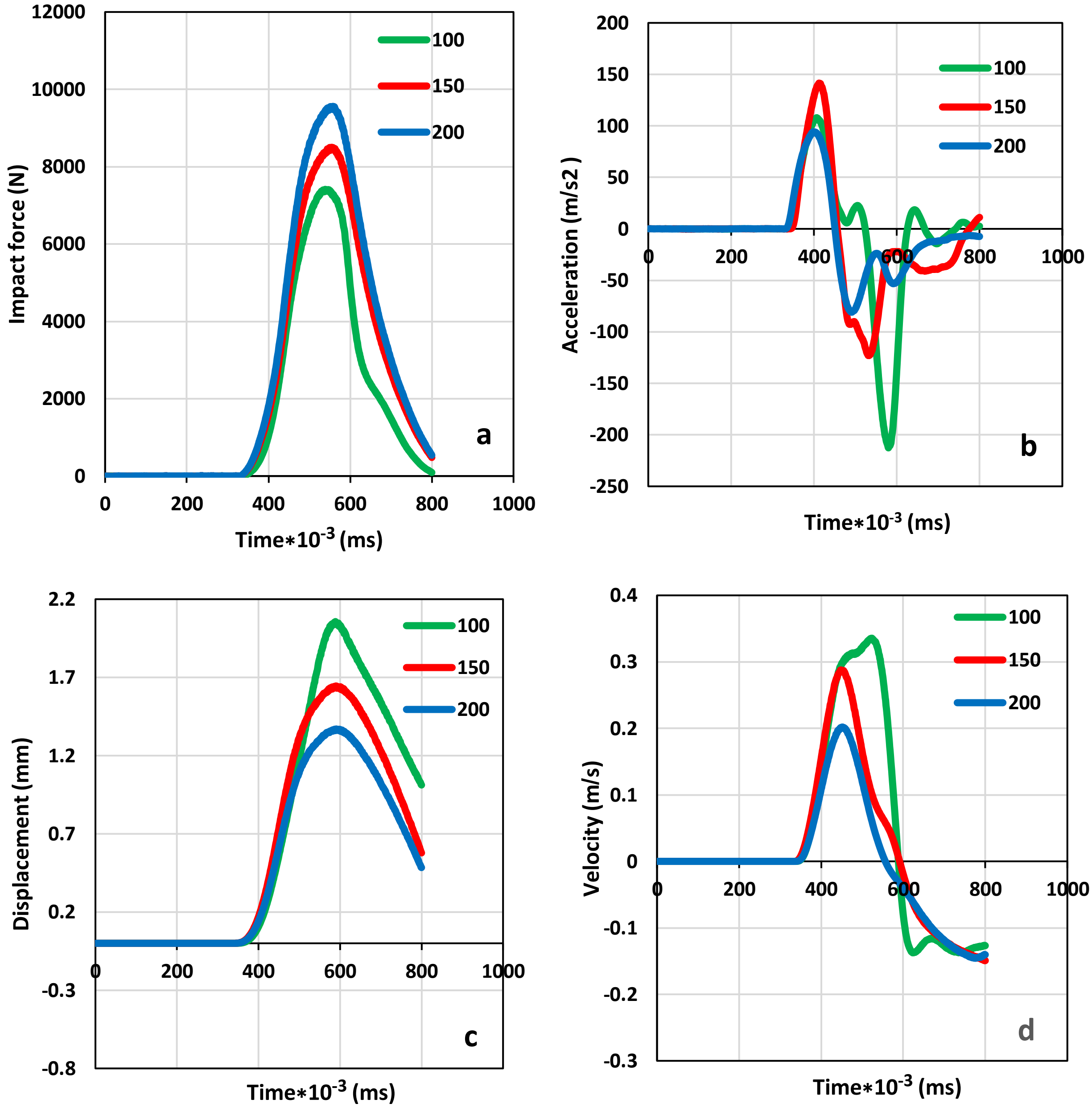


Figure 10. Dynamic results for $N_SP_{(10,15,20)}$ $M_{15}H_{25}$ model. a) and c) influence the force-time history through displacements. b) a history of acceleration. d) time history of velocity.

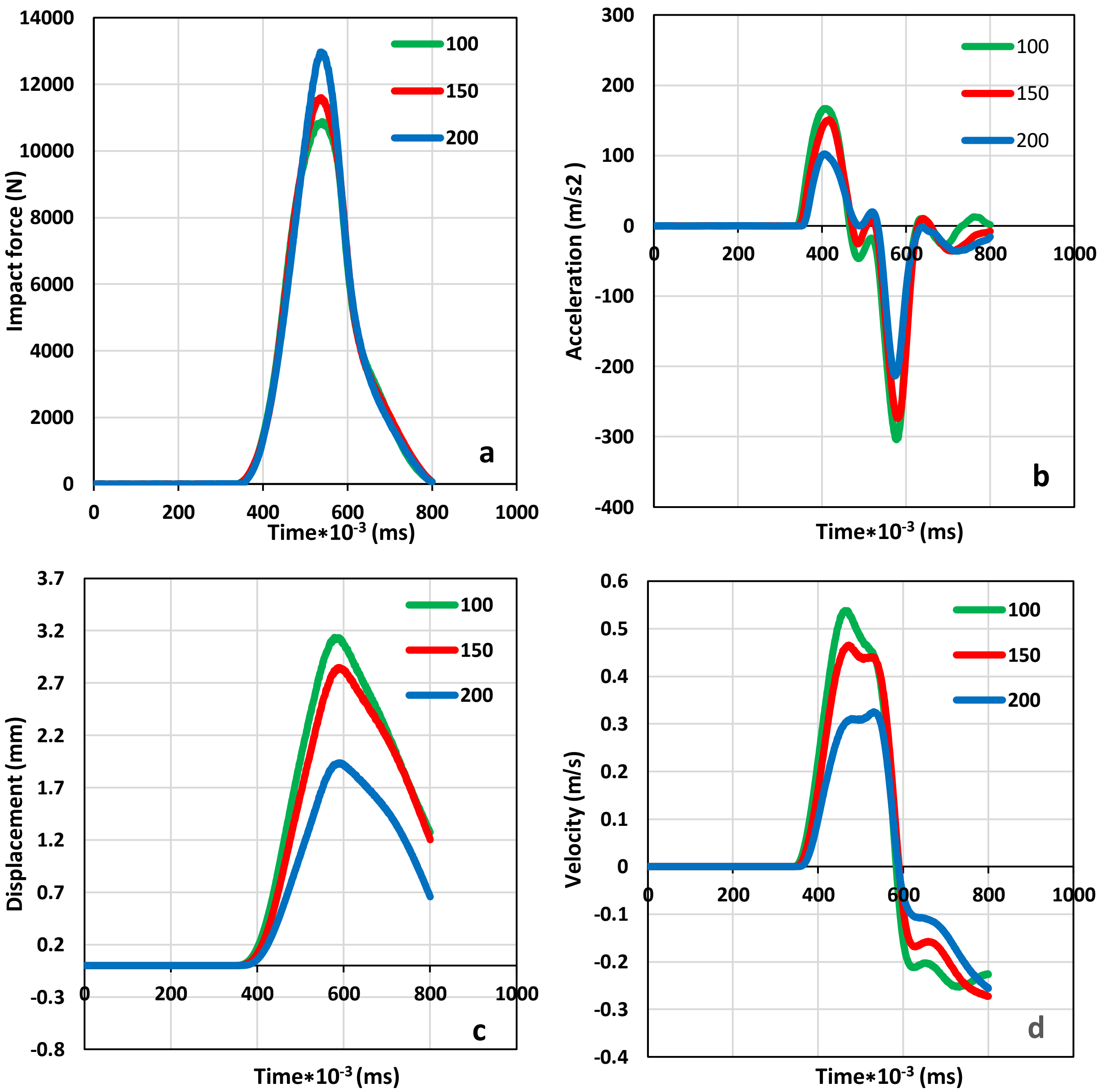


Figure 11. Dynamic test results for $N_SP_{(10,15,20)}$ $M_{15}H_{50}$ model. (a) and (c) influence the force-time history through displacements. (b) a history of acceleration. (d) time-history of velocity.

9. CONCLUSIONS

The dynamic performance of natural clay soils under the influence of individual active loads is considered in this work. Based on the experimental effort carried out for the tested conditions, the response of soil and foundation under impact loads with variable weight of impact bearing plates and different soil types are reported. The following conclusions can be extracted according to the discussed results:

1. For natural clay, the displacement reaction of the soil will decrease by around (25–35%) due to a rise in embedment depth-related increases in overburden pressure and stiffness of clayey soil.
2. A 20–30% increase in the total dynamic weight of natural soil results in a more excellent force-time history due to the high rigidity of the earth at the surface level.
3. The natural frequency of the soil-foundation structure will increase by (35–65%) at the foundation surface structure.
4. The maximum displacements are more significant with growing operational frequency and dynamic loads.
5. The energetic reaction rises considerably with the grade of damage, which impacts damage transmission in both the foundations and the soil due to increased stresses concentrated close to the footing areas. The computational examination of soil damage's dynamic properties shows that hammer strikes on the ground near the foundation's surface as damage increases and depth becomes more relevant. It allows the creation of a way to manage the damage, its evolution in a defective material, and the dynamic reaction of an impaired construction.
   Resulting in the achievement of these decisions, studying the behavior of the plane runways-bearing soil, which is constantly exposed to impact loads when the plane touches the ground.

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