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DYNAMIC RESPONSE OF FOUNDATION UNDER VIBRATING MACHINES

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Master's Thesis

Supervisor

Asst. Prof. Dr. Mohsen SEYEDI

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The thesis titled DYNAMIC RESPONSE OF FOUNDATION UNDER VIBRATING MACHINES prepared by ISMAEL AMADOU DJIBO and submitted on 22/04/2024 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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Signature

DEDICATION

I humbly dedicate this work to my dear parents, acknowledging their sacrifices, patience, and all the efforts they have made on my behalf.

I hope to have been worthy of their trust, and I dedicate this work to them, as well as to my entire family, as a testament to my deep gratitude and eternal love.

ACKNOWLEDGMENT

I want to express my thanks to GOD first and foremost, for giving me the strength, courage, and necessary time to complete this work despite some challenges I faced. I sincerely thank ALTINBAŞ UNIVERSITY for providing me with the opportunity to pursue my studies and undertake this thesis project in the best possible conditions. A heartfelt thank you to my professor and supervisor, Mr. Mohsen Seyedi, for his valuable contribution to my education and the development of this thesis project. His patience, willingness, rigor, and professional advice have been greatly appreciated. My thanks also go to all the teachers who have contributed to my academic journey. My gratitude to the faculty members of the Department of Civil Engineering

I would also like to express my gratitude to all those, near or far, who have contributed to the completion of this laborious work.

ABSTRACT

DYNAMIC RESPONSE OF FOUNDATION UNDER VIBRATING MACHINES

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In the field of civil engineering design, the dynamic response of foundations under vibrating machines is a critical aspect, as well as for structures subjected to dynamic loads. By focusing on analysis methods, influencing factors, and mitigation measures, we will conduct a study aimed at providing a comprehensive overview of the dynamic response of foundations under vibrating machines. The study begins with defining and understanding the dynamic response of foundations under vibrating machines in civil engineering and the specific challenges posed by vibrating machines. It then discusses the types of vibrating machines commonly encountered in civil engineering projects and the dynamic loads they generate. Research on case studies and examples are presented to illustrate real-world applications of the concepts. The analysis methods for studying the dynamic response of foundations are explored, including analytical and numerical techniques such as finite element analysis and dynamic soil-structure interaction analysis using PLAXIS 2D software. The purpose of this study would be to simulate the dynamic interactions between the structure and the underlying ground. It allows studying the impact of a vibrating source on the surrounding ground. The oscillations produced by the generator are transmitted into the basement through the sole. Factors influencing dynamic response, such as soil properties (we have opted for materials such as clay and sand), foundation geometry, and machine characteristics, are also discussed in detail. After designing the reference model and obtaining the results from the software, different soil materials, as well as different values for frequency and amplitude, are introduced. These new datasets added are aimed at in-depth analysis and comparison of the curves resulting from these data according to the differences in soil materials used. Thus, these new data are calculated and represented in a line chart on EXCEL software. We have two types of graphs for each point: vertical displacements Uy, horizontal accelerations Ax. For each graph, the dynamic time element is placed on the horizontal axis, and on the vertical axis, we have vertical displacements and vertical or horizontal accelerations. For each material, the amplitude and frequency values are progressively permuted to perform the calculations for a comprehensive comparative analysis. Depending on each material, a theoretical analysis will be conducted taking into account the physical properties of the materials and the results obtained from the graphs to verify the consistency of the results obtained in the calculations and modeling. The effect of applying a load to the surface of clay and sand varies depending on the mechanical properties of these materials. Clay has a higher propensity to deform under load due to its high cohesion, while sand tends to flow or compact. The choice of material will depend on the specific application and load requirements.

Keywords: Liquefaction, Dynamic Response, Machine Foundations, Pore Water Pressure, Soil.

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ABBREVIATIONS

SPT : Standard Penetration Test

CPT : Cone Penetration Test

LVDT: Linear Variable Differential Transformer

MD : Medium Dense

USCS : Unified Soil Classification System

PLC : Programmable Logic Controller

LIST OF SYMBOLS

Δu	:	The Excess Pore Water Pressure
Ru	:	Excess Pore Water Pressure Ratio
σ	:	The Vertical Stress
Uy	:	Vertical Displacements
γ_{sat}	:	Saturated Unit Weight
$E'ref$	:	Young's Modulus
ν	:	Poisson's Ratio
E_{ur}	:	Young's Modulus for Unload- Reload
$\gamma 0.7$	:	Threshold Shear Strain at Which $G_s = 0.722G_0$
Ax	:	Horizontal Accelerations
Φ	:	The Friction Angle
τ_c	:	Critical Shear Stress
μ	:	Coefficient of Viscosity
q	:	Quantity of Seepage
E_{50}	:	Secant Young's Modulus at 50% Deviatory Stress

1. INTRODUCTION

1.1 GENRAL STATEMENT

This thesis project, which focuses on the dynamic response of foundations under vibrating machines, aims initially to investigate the anticipation of the potential for liquefaction and an increase in pore pressure beneath machine foundations.

A machine exerts dynamic loads on the ground below when it vibrates on or near the ground. Cyclic stresses and rearrangement of soil particles are caused by this dynamic stress, resulting in pore pressure changes in soil voids. Thus, the generation of pore pressure in the ground under the effect of vibrating machinery is an important phenomenon that can lead to a variety of geotechnical problems.

In forecasting the likelihood of liquefaction and pore pressure beneath machinery foundations, the term "liquefaction" describes the phenomenon wherein a saturated soil weakens and loses its stiffness due to an elevation in the soil's pore pressure. water during an earthquake or other dynamic loading events. This leads to the soil behaving like a liquid, resulting in significant soil compaction, lateral spread, and potential damage to structures and infrastructure. The liquefaction process can be understood as follows: when an earthquake occurs, the ground is shaken, causing the soil particles to rearrange. In saturated soils with poor drainage, the increase in pore water pressure caused by shaking prevents soil particles from maintaining contact, resulting in a loss of effective stress and a decrease in shear strength. Liquefaction is more likely to occur in loose, cohesive soils such as sands and silts. These soils have larger void spaces which easily allow water to flow and increase the pore water pressure. In contrast, dense, well-compacted soils are less likely to liquefy. Generally, Liquefaction poses significant challenges in geotechnical engineering and requires careful thought in seismic risk assessment and structural design to ensure the safety and stability of infrastructure in earthquake-prone regions. Thus, during earthquakes, soil liquefaction has played a major cause. One can illustrate the two devastating Japanese earthquakes of 1964 and 2011, This gave rise to a contemporary approach in addressing liquefaction issues, which developed primarily as a response to these encounters. Over the past four decades, significant progress has been achieved, including enhancements in the capability to evaluate the likelihood of liquefaction initiation in clean, sandy soils.

The liquefaction in loose, water-saturated granular soils, usually induced by cyclic loading, with seismic excitation being a well-known source. Although soil density conditions are generally seen as the primary factor influencing liquefaction, this phenomenon can also occur under conditions of slow, cyclical, or even static, loading. the impact of low permeability soil layers on liquefaction potential. Current methods for evaluating liquefaction potential, such as standard penetration test (SPT) and cone penetration test (CPT), are widely used, but their theoretical evaluation of the influence of low permeability is difficult. the study of liquefaction potential by means of large-scale vibration tests offers an alternative perspective to the hypothesis of a homogeneous soil layer often formulated in practice.

The liquefaction phenomena in saturated soil due to mechanical loading, emphasizing its relevance for machine foundations subjected to dynamic loads. Various studies are cited to highlight factors influencing dynamic interactions, such as the nature of the load source, soil properties, and foundation design. The study's main goal is to investigate the impact of using a subbase layer under a machine foundation at different frequencies, considering parameters like force-time history, settlement, vertical stress, excess pore water pressure, and the role of the subbase layer in reducing liquefaction phenomena.

It is very important to take into account dynamic loads on machine foundations, which transmit both static and dynamic loads to the ground. Anchorage depth is a crucial factor influencing foundation response, with increased depth potentially reducing vibration amplitudes. The quality of contact between the foundation and the ground depends on various factors, including the nature of the soil, the method of placement, compaction and temperature. Designing an effective mechanical foundation requires information on soil profile, layer depth, soil properties and water table level, obtained through standard subsurface exploration techniques. Dynamic analysis requires knowledge of soil properties such as Poisson's ratio, dynamic shear modulus, and damping, typically acquired through field and laboratory testing or theoretical correlations. Despite low deformation conditions, soil behavior remains non-linear and Poisson's ratio plays a key role in calculating soil stiffness and damping. The typical range of Poisson's ratio varies for cohesive and cohesive soils.

Designing soles for dynamic loads, especially for high-speed machines subject to strict vibration standards, differs from those designed for static loads. Although strength is important, emphasis is often placed on rigidity when designing foundations. Dynamic loads can arise from various sources such as machine operation, construction activities, bridge movements, shocks and earthquakes. The soil experiences periodic shear stresses in these scenarios. Tests, such as those determining the permanent settlement of surface foundations under dynamic loads, have been carried out. Studies have also explored the impact of dynamic loads on foundations, including circular foundations on granular soil and strip foundations on dense sand. We can discuss the unique behavior of soil under dynamic loads, highlighting the conditions in which it can exhibit minimal shear resistance, behaving like a viscous liquid. The concept of liquefaction is explained with emphasis on increasing water pressure and decreasing effective pressure in certain soil conditions. Furthermore, the effectiveness of geogrids in improving soil compaction and bearing capacity has been evaluated in recent years. Geosynthetic materials are widely used due to their economic viability and ease of installation. These materials play a crucial role in geotechnical engineering applications including road construction, railway embankments, slope stability and soil improvement. The results of laboratory model tests examining soil liquefaction, internal displacement and settlement of rigid foundations of square machines are presented. The tests were carried out on unreinforced and reinforced multi-layer sandy soils of varying densities, subjected to dynamic loads of different amplitudes (0.25, 1 and 2 tonnes) and frequencies (0.5, 1 and 2 Hz).

Soil liquefaction, a significant cause of earthquake-related damage, has been a focus of engineering treatment since the devastating earthquakes in Japan in 1964 and 2011. Progress in addressing liquefaction issues initially centered on assessing the likelihood of its initiation in clean, sandy soils. Advances in understanding problems associated with silty and gravelly soils, as well as post-liquefaction strength and stress deformation behavior, followed. Several studies contributed to the understanding of soil liquefaction. Amini and Duan (2002) utilized a numerical model to study liquefaction resistance under high confining pressures, finding that resistance increased with greater pressure at large depths. Ashford et al. (2004)

conducted a pilot test program using controlled blasting to induce liquefaction in deep foundations for field-testing purposes. Sitharam et al. (2004) investigated dynamic properties and liquefaction potential, emphasizing the role of material beneath the foundation. Jin et al. (2008) characterized liquefaction under bi-directional cyclic loading, while Lu et al. (2010) explored responses to horizontal vibration loading. Notably, Lu et al. (2010) found that liquefaction and deformation occur rapidly with increased loading amplitude and frequency, and decreased modulus. Liquefaction may extend a finite distance from the foundation, influencing design considerations. The overall conclusion from these studies is that while much research has focused on earthquake-induced liquefaction, there is a need to address liquefaction caused by mechanical factors, such as the vibrations from construction equipment on saturated sandy soil.

liquefaction being a phenomenon that occurs during earthquakes in sandy soils saturated with water. Liquefaction results in soil failure as the soil loses strength and behaves like a liquid under dynamic loads. Susceptibility to liquefaction is defined as the vulnerability of saturated sediments to compact during earthquakes, causing potential soil instability. We can thus highlight the methodologies for evaluating the liquefaction potential, including approaches based on cyclic stresses and cyclic deformations. Research by Fattah et al. predicts liquefaction potential and pore water pressure in a fully saturated sandy soil under dynamic loading, with emphasis on the effects of loading magnitude and frequency on machine foundations. Calbureanu et al. present dynamic investigations into a building's response to seismic ground movements, contributing to the understanding of building behavior and rehabilitation solutions. Another study by Fattah et al. experimentally investigates the responses of machine foundations on dry and saturated sand, taking into account loading frequency, footing size and soil conditions. relationships can be established between liquefaction potential and soil properties, depth and shape of foundations. Additionally, the effects of dynamic load parameters, sand density, anchoring depth and footing shape on liquefaction potential are explored.

discussion of the crucial role of machine foundations in industrial structures, with emphasis on design criteria based on limiting dynamic settlement to less than 1 mm. The complex behavior of soil and foundations subjected to anomalous harmonic and periodic vibrations caused by machines has given rise to extensive research through numerical, laboratory and field studies. Various studies, including those by Fattah et al., Al-Homoud and Al-Maaitah, Ghosh, Vivek and Ghosh, Al-Wakel et al., and others, have investigated the response of different types of foundations to dynamic loads. They explored settlement reduction, excess pore water pressure, liquefaction potential and other dynamic responses under machine vibrations. Existing literature has extensively covered the influence of soil type, foundation embedment, foundation type, interference with static foundations, and frequency and amplitude of machine vibrations on foundations of a single machine. However, there is a notable gap in the study of response and design considerations for two interfering machine foundations. This study aims to fill this gap by investigating the effect of interference on the dynamic settlement of two nearby active machine foundations resting on sand. The study takes into account factors such as sand density, vibration frequency and spacing between foundations. The research also aims to determine the critical distance beyond which interference has no effect on dynamic settlement and to provide implications for routine design of machine foundations [28].

1.2 PROBLEM STATEMENT

The problem statement of this thesis focuses on studying the behavior of the foundation when subjected to dynamic loads from operating machines. This includes analyzing the foundation's response in terms of displacement, stresses, and other relevant factors to ensure its stability and durability under such conditions. The goal is to understand how the foundation reacts to these vibrations and to develop methods to mitigate any potential issues that may arise.

1.3 AIMS AND OBJECTIVES

The aim of this thesis is twofold: firstly, to understand the dynamic response of a foundation under vibrating machines, and secondly, to analyse the dynamic behaviour of a generator situated on an elastic foundation using the PLAXIS 2D software and the PLAXIS 2D Tutorial Manual. This enables us to conduct an in-depth study of liquefaction potential beneath machine foundations, along with a technical analysis using modelling techniques of the dynamic behaviour of a generator on an elastic foundation. This is followed by a comparative analysis based on different soil materials. The model's geometry includes a vibrating source consisting of a generator placed on a 0.2 m thick, 1 m diameter concrete pedestal.

The fundamental objectives of this thesis are:

a. Firstly, to understand the mechanism of liquefaction as well as anticipate the potential for liquefaction and increased pore pressure under machine foundations.

b. A set of studies examining various aspects of liquefaction and dynamic behaviour of machine foundations under different conditions.

c. The use of PLAXIS 2D software to define dynamic calculations, specify dynamic loads, outline dynamic constraints (including viscous effects), define material damping through Rayleigh damping, and implement modelling.

d. Creating and assigning new material data sets, as well as defining and performing calculations for the purpose of a comparative analysis.

2. LITERATURE REVIEW

2.1 LIQUEFACTION

Liquefaction is a potentially dangerous geotechnical phenomenon that can occur during earthquakes or seismic tremors. It decreases the resistance of the ground and temporarily turns it into a liquid substance, which can lead to serious consequences. Damage caused by liquefaction can include settlement and collapse of foundations of buildings and structures, cracks in walls, landslides and slope instability, soil erosion, damage to underground utilities and infrastructure, surface cracks, damage to piles and deep foundations, collapse of bridges, dikes, and dams.

2.2 ANTICIPATION OF THE POTENTIAL FOR LIQUEFACTION AND INCREASED PORE PRESSURE BENEATH MACHINE FOUNDATIONS

2.2.1 Mechanisms of the Liquefaction

Two distinct processes can be used to describe the liquefaction of soils during earthquakes: flow liquefaction and cyclic softening. When static or dynamic loads upset the balance of a low-strength soil, it liquefies, reducing its ability to resist stresses. In contrast, when static shear stresses are lower than soil strength, cyclic loads cause cyclic softening. Criteria such as the "modified Chinese criterion", which is based on specific characteristics of sandy soils, are used to assess the potential for soil liquefaction at a given site. Based on this criterion, soils characterized by minimal fines, a liquid limit below 35%, and an in-situ water content equal to or exceeding 90% of the liquid limit are classified as liquefiable. To assess the risks of liquefaction when designing and building infrastructure in earthquake-prone areas, it is crucial to understand these ground behaviors. Geotechnical problems related to soil liquefaction can be prevented and mitigated by analyzing soil properties and using appropriate criteria.

In 2004, Sitharam et al. explored techniques for assessing both the dynamic properties and liquefaction potential of soils. The study emphasized the identification of parameters influencing dynamic properties and susceptibility to liquefaction.

In 2008, Jin et al. analyzed Saturated, unconsolidated sand samples were subjected to bidirectional cyclic loading to analyze and characterize liquefaction and cyclic failure. This investigation employed state-of-the-art universal static and dynamic triaxial soil equipment, along with a torsional shear apparatus.

In 2009, Worthen conducted research to characterize the potential liquefaction susceptibility of fine-grained soils, relying on the characteristics of plasticity assessment according to the Chinese criteria. This recent study indicates that these criteria lack effectiveness. Additionally, present liquefaction models do not incorporate in-situ ground pressure confinement or seismic intensity.

In 2010, Lu et al. investigated the reactions of saturated sand subjected to horizontal vibration load caused by a bucket foundation were investigated. The study revealed the development of liquefaction and deformation rapidly with increasing load magnitude and frequency and decreasing modulus.

In 2010, Fattah and Nsaif performed a coupled dynamic analysis was conducted on a zoned earth dam exposed to seismic excitation, calculating displacements and pore water pressure using the finite element method. The case study focused on the Al-Adhaim dam, an earth dam. A parametric study was undertaken to explore the impact of specific parameters on the overall response of the dam to earthquakes, with particular attention given to regions susceptible to liquefaction.

In 2012, Vivek and Ghosh. The Investigation into the dynamic interaction of two closely spaced embedded strip foundations subjected to machine vibrations. The goal was to investigate how dynamic excitation from an active foundation affects the neighboring passive base through a uniform base at the center of the ground. The numerical analysis was carried out using the PLAXIS 2D finite element software. The examination was conducted considering two loading scenarios: a sinusoidal dynamic load with a consistent amplitude and a variable amplitude.

Certain construction equipment or heavy machinery, particularly when operated on saturated sandy ground, can induce vibrations, rendering the ground susceptible to liquefaction [26].

2.2.2 Explanation of the Issue

The soil beneath a foundation with characteristics: A saturated porous medium, measuring 30 meters in width and 20 meters in depth, is represented through finite element analysis. Additionally, a footing with a width of 2 meters is positioned at the center of the upper surface. The equation of the dynamic harmonic excitation load to which the foundation will be subjected is expressed as follows:

$$F(t) = a_0 \sin(w, t) \tag{2.1}$$

a_0 is the load amplitude

w is the load frequency

t is the time

With a dynamic load of 60 sec, the plane strain problem is examined utilizing the QUAKE/W (2004) program, a finite element geotechnical software designed for the dynamic analysis of earth structures under seismic events, soil, and other abrupt loading impacts. It is Designed for addressing two-dimensional plane strain problems. Figure 1 illustrates the mesh of finite elements employed in the analysis:

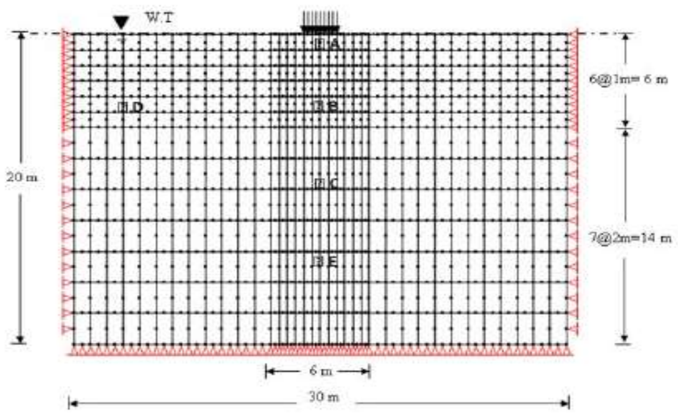

Figure 2.1: Typical Finite Element Mesh [1].

The mesh consists of 8 knotted quadrilateral isoperimetric elements. The lateral boundaries are permitted vertical movement exclusively, whereas the bottom boundary is constrained both horizontally and vertically.

For the analysis, an equivalent linear elastic model is employed. The analysis spans a time of 100 seconds with a time increment of 0.1 seconds. This process is iteratively repeated for the three soil types: permeable, intermediate, and compact sand. At points A, B, C, D and E The findings are showcased at various depths beneath the foundation, aiming to investigate the extent of the soil impacted by the dynamic load. The relationships employed for the equivalent linear elastic model are based on the shear modulus reduction function depicted in Figure 2.1.

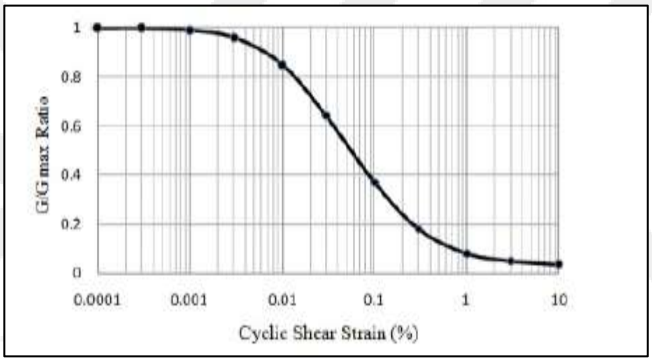

Figure 2.2: The Function Describing the Reduction in Shear Modulus [2].

2.3 LIQUEFACTION TRIGGERED BY INTENSE VERTICAL VIBRATORY COMPACTION

Through Liquefaction caused by extensive vertical vibratory compaction, we can explain the phenomenon of liquefaction of loose granular soils saturated with water and its causes, in particular seismic excitation. He also points out that the density of the soil emerges as the predominant factor influencing liquefaction, yet it is noteworthy that liquefaction may occur under gradual cyclic loading or even in the absence of motion. He points to the often-overlooked impact of low permeability soil layers on liquefaction, it’s important to acknowledge that their impact is challenging to assess through theoretical means. Standardly employed approaches to evaluate liquefaction potential rely on penetration tests like SPT and CPT. However, factoring in the influence of soil layers on the rise in pore pressure poses a challenge. Thus, the use of large-scale vibration tests to study the liquefaction potential more precisely, considering the influence of low permeability soil layers. These advances could lead to a better assessment of liquefaction under various loading conditions.

2.3.1 Vibratory Compaction

The use of vibratory compaction strengthens granular soils, reduces their potential for liquefaction and improves their strength. A specifically crafted vibrating compaction probe, equipped with a vibrator of variable frequency, is employed. This probe is inserted into the ground for compaction purposes. The first developments of this method, called TriStar compaction, are presented, and it is mentioned that the TriStar probe consists of three steel blades welded together at a 120-degree angle, thus increasing the contact surface with the ground. A study carried out in Borechem near Antwerp, Belgium, In the area where compaction activities were conducted on a hydraulic fill composed of fine to medium sand. The compaction process utilized a hydraulic vibrator featuring an eccentric moment of 40 kgm and operated at a frequency of 26 Hz. The compacted backfill had a thickness of approximately 10 meters, leading to a lasting elevation in the effective horizontal stress following the vibration treatment. This observation has been reported in many compaction projects.

2.3.2 Compaction Effect

This section summarizes the results of a resonance compaction project carried out in the Annacis Channel. Investigations were conducted before and after the compaction process to evaluate the rise in cone stress and sleeve strength within the soil. The results show an increase in these parameters throughout the soil deposit, except for one specific layer. This increase persists even after 82 days, suggesting a time effect related to soil reconsolidation. It is emphasized that the increase in sleeve friction is just as important as the increase in cone stress, as it indicates the alteration in effective lateral stress compaction induced by vibration. The recorded high vibration velocities play an important role.

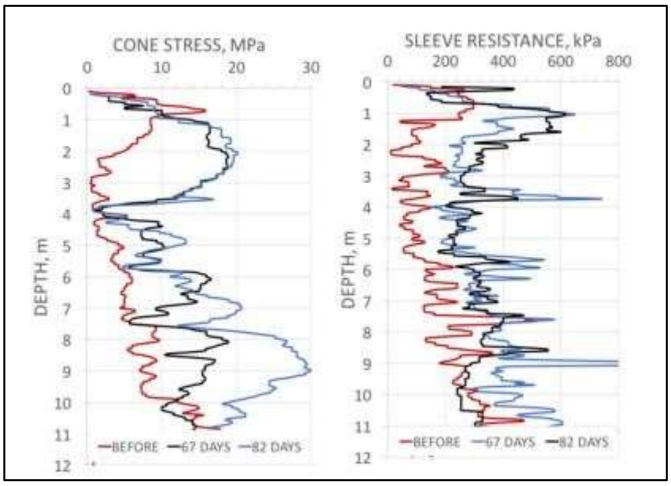

Figure 2.3: Cone Stress and Sleeve Resistance were Measured before Compaction, as Well as 67 and 82 days after Compaction, at Various Points Between the Compaction Locations [3].

2.4 POTENTIALFOR LAYERED SOIL LIQUEFACTION UNDER VERTICAL VIBRATION LOADS

Soil liquefaction and its effects on machinery foundations require a thorough evaluation of dynamic loads, pore pressure, pressure distribution and soil response. The risks associated with soil liquefaction and ensuring the stability of structures can be mitigated by the proper engineering the foundations for machinery. During this research the emphasis is placed on investigating the impact of incorporating a sand sub-layer as a cushion beneath a machine foundation, embedded at various frequencies. Thus, the research will analyze several parameters, such as the history of force over time, the ultimate settlement of the foundation, as well as the vertical stress exerted on the ground.

2.4.1 Research Signification

This research is focused on the liquefaction of sandy soils. Research has shown that the risk of liquefaction increases when there is a dynamic load on the ground. The research used a scale model to simulate an inducing liquefaction scenario through the application of a cyclic vertical load. This discovery is crucial for comprehending the mechanisms of liquefaction, particularly in sandy soil profiles.

2.4.2 Experimental Work

i. Footing model and ground properties

In table 2.1, The specifications for the steel flange, having dimensions of (300 × 200 × 50) mm, are provided.

Table 2.1: Properties of the Used Sand [4].

Soil Properties			Value	Standard
Specific Gravity, G_s			2.65	ASTM D854
Gravel (> 4.75 mm) %			0	
Sand (0.075-4.75 mm)%			97	
Silt and clay (< 0.075 mm)%			3	
Coefficient of curvature, C_c			1.55	
Coefficient of uniformity, C_u			1.73	
D_{10}, D_{30}, D_{60} (mm)			0.11, 0.18, 0.19	
Soil classification according to USCS			SP	ASTM D2487
Loose state relative density, RD %			24	
Medium state relative density, R_D %			50	
Dense state relative density, R_D %			75	
friction angle, ϕ	Loose state	Soaked	18.0	ASTM D3080
	Medium state	Soaked	32.0	
	Dense state	Soaked	39.0	
Permeability coefficient, k, (m/s)	Loose state		0.04	ASTM D2434-68
	Medium state		0.009	
	Dense state		0.005	

The physical and mechanical characteristics of the sand utilized in all footing designs are detailed in Table 2.2.

Table 2.2: Properties of Steel Footing [4].

Item.	Property	Value
1	Secant modulus, GPa	37.4
2	Tangent modulus, GPa	140
3	Unit weight, kN/m^3	77

ii. Configuration of the machine foundation model

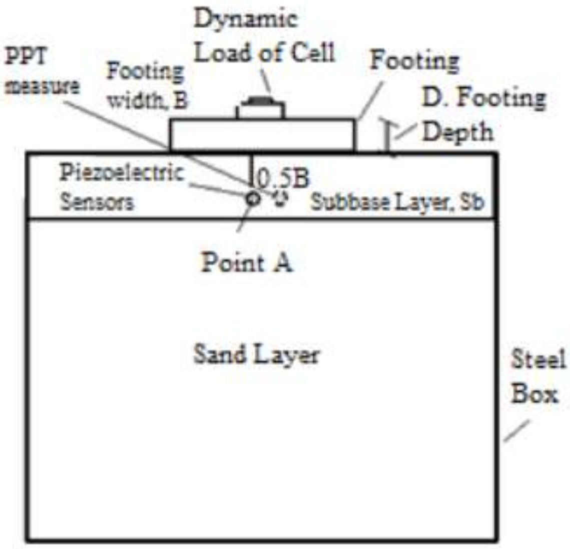

Figure 2.4: Diagram Illustrating the Model and Instrumentation [4].

Figure 2.5: Depicting the Arrangement of the Sand Model Setup [4].

At Figures 2.4 and 2.5, the test equipment and instruments are illustrated. They consist of the following elements:

a. Vertical vibrations induced by the machine.

b. Measurements of dynamic response.

c. Metallic container measuring (1000×800×600) mm in dimensions.

d. Recording the dynamic force-time history, utilizing a dynamic load cell.

e. Tools or devices employed to measure footing settlement through LVDT (Linear Variable Differential Transformer).

f. Instruments for determining ground stresses through the utilization of piezoelectric sensors.

g. Instruments for Recording pore water pressure (PWP) through the use of pore pressure transducers (PPT).

iii. Preparing and placing models

To prepare the model in the study the following procedures were used:

a. To absorb the reflected waves, Sheets of cork were applied to the internal surfaces of the steel box.
b. The sand was poured into the box using the rain pour method, with different drop heights corresponding to different relative densities. Procedures obtained by Al-Jebouri [21].
c. To measure stresses and pore pressure, Piezoelectric sensors and pore pressure transducers were installed at a designated depth (0.5 times the foundation width below the footing).
d. The sand was poured continuously until it reached a specified level.
e. To allow even water distribution, a perforated plate was placed on the top surface of the sand.
f. A steel foundation was positioned at the center of the sand bed, and a dynamic load cell was employed to capture the dynamic load-time history.
g. To record the vertical settlement a Linear Variable Differential Transformer (LVDT) was used.
h. To determine the relative density these steps were repeated for each model test.

2.4.3 The Various Studies Carried Out:

Tileylioglu et al. [5] conducted an investigation in Garner Valley, California, utilizing a large-scale model. Results indicate that damping will invariably rise with frequency. Furthermore, the strength is greater in translation than in tilting, attributing contributions from each radiation source and hysteresis.

Alzabeebee [6] examined the efficacy of employing skirts as a strategy to mitigate settlement of a strip footing under machine-induced vibration. The study revealed that the effectiveness of the skirt in diminishing dynamic settlement diminished with an increase in soil stiffness. The percentage reductions in settlement varied, ranging from 2% to 70% for loose sand, 1% to 68% for medium sand, and 0.5% to 67% for dense sand.

Fatah et al. [7] conducted an analysis of a machine foundation situated on saturated sandy soil using the computer program QUAKE/W. Their findings indicated that augmenting the magnitude and frequency of loading accelerates liquefaction and deformation, particularly when the foundation is constructed on loose saturated sand. Furthermore, the liquefaction extends to reach a depth of five times the width of the foundation.

Javdanian [8] explored the dynamic bearing capacity of neighboring shallow strip footings situated on sandy soil. The findings emphasize the significance of accounting for interferences when assessing the bearing capacity of shallow foundations subjected to cyclic loads, such as those of vibrating machines.

Choudhury & Rao [9] examined three distinct types of failure surfaces, considering the depth of embedment and ground inclinations. The obtained results, illustrating the impact of parametric variations on seismic bearing capacity factors, were analyzed.

Bhatia [10] presented the permissible amplitude limits for various machines across different frequencies, categorizing frequencies into low-speed machines (100-1500 rpm), medium-speed machines (1500-3000 rpm), and high-speed machines (3000-10000 rpm and beyond).

Fatah et al. [11] demonstrated that the settlement of a square foundation in medium sand was influenced by embedment. The percentage reductions in settlement varied from 15.2 to 17.3% at a load amplitude of 0.5 tons, from 6.7 to 10.5% at a load amplitude of 1 ton, and from 9.3 to 10.9% with an increasing applied load of 2 tons. In the dense sand state, the percentage reductions in settlement values ranged from 25.2 to 42.5% at a load amplitude of 0.5 ton, from 9.7 to 29.1% at a load amplitude of 1 ton, and from 12.6 to 23.18% at a load amplitude of 2 tons.

Fatah et al. [12] uncovered that elevating the loading amplitude and frequency results in the swift emergence of liquefaction and settlement phenomena, leading to an expanded liquefaction region.

Fatah et al. [13] demonstrated that the maximum settlement response of a footing placed on dry sand samples is higher than that on fully saturated sand soil by approximately 5.0–10%.

As already mentioned, the study examined the impact of employing an underlayment (sand cushion layer) beneath a machine foundation embedded at three frequencies, ranging from low to high (wr = 1000, 2500, and 3500 rpm), on liquefaction phenomena. Various parameters were considered in this investigation, including the time history of the force applied to the machine foundation, the ultimate settlement of the foundation, the vertical stress within the ground beneath the machine foundation, the excessive pore pressure (EPWP) generated under the vibratory load, the assessment of liquefaction, and the influence of the sub-base layer in mitigating liquefaction phenomena [24].

2.5 DYNAMIC REPONSE OF A MACHINE FOUNDATION ON A TWO-LAYER SYSTEM

Machinery foundations are necessary to transfer static and dynamic loads to the foundation and in general, static loads are greater than dynamic loads. The embedding of the foundation can reduce vibration and it has a significant factor in its overall behavior. The effectiveness of the interface between the foundation and the soil is contingent on the soil type, the installation process, and the temperature conditions. To design the foundation of a machine, information about the soil profile, physical soil properties and water table are needed. For dynamic foundation analysis, the determination of soil properties, including Poisson's ratio, dynamic shear modulus, and damping, can be achieved through field or laboratory testing. Even with small deformations, the behavior of the ground remains nonlinear. Poisson's Ratio varies with soil type and is employed to compute soil stiffness and damping.

2.5.1 Dynamic Shear Modulus

The dynamic shear modulus (G) is the most influential factor in the dynamic behavior of the soil-foundation system. Poisson's ratio is used to determine the ground impedance. The gradient of the curve depicting shear stress against shear strain is represented by the dynamic shear modulus. Most soils react plastically and elastically to shear stresses. Therefore, the shear stress-strain curve is a curve rather than a linear relationship. The value of G varies based on the considered deformation. Generally, the dynamic shear modulus increases with decreasing strain. Research has been carried out to investigate the influence of subgrade flexibility, mass, and foundation embedment on the dynamic behavior. It has been found that the dynamic response of foundations, especially under vertical loads, is significantly influenced by the flexibility of the foundations. Research has also been carried out to investigate the dynamic interaction of embedded strip foundations and investigating the influence of dynamic excitation from an active footing on a neighboring passive footing through a uniform soil medium. Different numerical modeling software, such as FLAC and PLAXIS 2D, were used to perform simulations and analyze the dynamic responses of the foundations. It has been found that the flexibility of foundations is a key determinant in dynamic response, particularly for foundations experiencing vertical loads. Research has also been carried out to investigate the dynamic interaction of embedded strip foundations and examining how dynamic excitation from an active footing affects a neighboring passive footing through a homogeneous soil layer. Different numerical modeling software, such as FLAC and PLAXIS 2D, were used to perform simulations and analyze the dynamic responses of the foundations. It has been found that dynamic response, especially in foundations exposed to vertical loads, is notably impacted by the flexibility of the foundations. Research has also been carried out to investigate the dynamic interaction of embedded strip foundations and investigating the influence of dynamic excitation from an active footing on an adjacent passive footing through a uniform soil medium. Different numerical modeling software, such as FLAC and PLAXIS 2D, were used to perform simulations and analyze the dynamic responses of the foundations. Research has also been carried out to investigate the dynamic interaction of embedded strip foundations and the effect of dynamic excitation of an active footing on a neighboring passive footing through homogeneous soil. Different numerical modeling software, such as FLAC and PLAXIS 2D, were used to perform simulations and analyze the dynamic responses of the foundations. Research has also been carried out to investigate the dynamic interaction of embedded strip foundations and the effect of dynamic excitation of an active footing on a neighboring passive footing through a homogeneous soil layer. Different numerical modeling software, such as FLAC and PLAXIS 2D, were used to perform simulations and analyze the dynamic responses of the foundations.

2.5.2 Defining the Core Problem

The behavior of strip foundations subjected to vertical harmonic excitation is examined in this research using dynamic finite element analysis. The model includes two soil layers, a three-meter-wide multi-thickness strip foundation and specific boundary conditions to reduce edge effects. PLAXIS 2D software version 8.2 is used to discretize the ground in plane strain condition with triangular elements at 15 nodes. The ground surface is assumed to be saturated, and the water table is aligned. At the top center point of the foundation, measurements are taken to assess vertical displacements and pore pressure. The analysis is performed for 60 seconds and a time step of 0.0256 seconds. The main objective is to study the excessive build-up of pore pressure due to harmonic excitation. Complete fixities are imposed at the model's base, absorbing boundaries are employed to prevent the reflection of stress waves. In conclusion, this analysis furnishes crucial insights into the response of both the soil and foundations under vertical harmonic excitations.

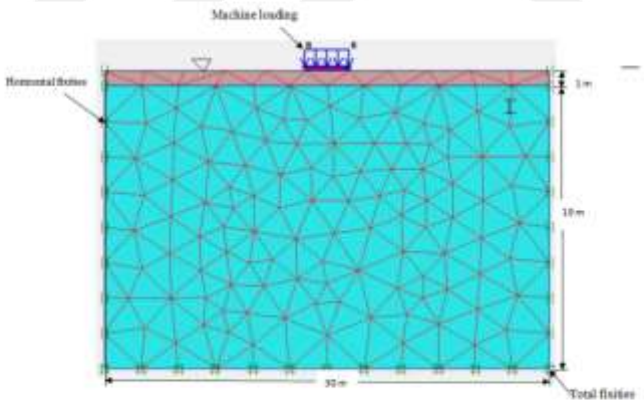

Figure 2.6: Mesh Details and Boundary Conditions for the Machine Foundation Problem in the Finite Element Analysis [14].

2.5.3 Characteristics of the Materials

Characteristics are divided into three main groups: soil properties, foundation properties, and machine weight [27].

a. Soil properties

Considering the impact of expansion, this study simulates soil behavior using the advanced Mohr-Coulomb yield criterion. The topsoil is medium sand, and its characteristics are used from references. To simplify the analysis, the cohesion is fixed at 1 kPa, while the expansion angle ψ is defined as ψ = Ø - 30 for soils with a friction angle (Ø) exceeding 30 and ψ = 0 for soils having a friction angle Ø of less than 30. Table 1 lists soil properties including dilatancy.

b. Properties related to the foundation

The concrete foundation is modeled as a material exhibiting linear elasticity, with its corresponding parameters are detailed in Table 1.2.

Table 2.3: Material Properties [15].

Material	Material properties	Unit	Sand
Soil	Unit weight, γ	(kN/m^3)	18.5 **
	Young's modulus, E	(kN/m^2)	35000 **
	Poisson's ratio, v	-	0.32 **
	Friction angle, ϕ	(°)	35 **
	Cohesion, c	(kN/m^2)	1
	Dilatancy angle, ψ	(°)	5
	Horizontal permeability, k_x	(m /sec)	10^{-4} **
	Vertical permeability, k_y	(m /sec)	10^{-4} **
Foundation	Young's modulus of concrete, $E_{concrete}$	(kN/m^2)	2×10^7 *
	Unit weight of concrete, $\gamma_{concrete}$	(kN/m^3)	24 *
	Poisson's ratio of concrete, $v_{concrete}$	-	0.15 **
Machine	Weight of machine, $W_{mach.}$	(kN/m^2)	10 *

c. Machin weight

The machine's weight is contingent on its type, as indicated by Leonards in (1962). The correlation between the foundation weight and the machine weight is provided in Table 2. As per the data in this table, the ratio between the foundation weight and the machine weight is approximately 2.16, indicating that the machine's weight is 10 kN.

Table 2.4: Criteria to Consider when Determining the Weight of the Foundation Block [16].

Type of engine	Weight of foundation/weight of engine
Gas engines one cylinder	3.00
Gas engines two cylinders	3.00
Gas engines four cylinders	2.75
Gas engines six cylinders	2.25
Gas engines eight cylinders	2.00
Diesel engines two cylinders	2.75
Diesel engines four cylinders	2.10
Diesel engines six cylinders	2.10
Diesel engines eight cylinders	1.90
Rotary converter	0.50-0.75
Vertical compound steam engine coupled to generator	3.80
Vertical triple-expansion steam engine coupled to generator	3.50
Horizontal cross-compound engine coupled to generator	3.25
Horizontal steam turbine coupled to generator	3.00-4.00
Horizontal steam turbine coupled to generator	3.50
Vertical diesel engine coupled to generator	2.60
Vertical gas engine coupled to generator	3.50

2.6 EXPLORATION OF THE RESPONSE OF A SURFACE-LEVEL MACHINE FORMATION SITUATED ON SATURATED SANDY STRATIFIED SOIL SUBJECTED TO DYNAMIC LOADING.

Examining the performance of a shallow machine foundation on saturated sandy stratified soil under dynamic loading provided insights into its impact on the drainage soil conditions and the effect of geo-synthetic reinforcement on settlement and bearing capacity. It states that when the water pressure in the soil pores reaches the total pressure, the soil can liquefy, thereby losing its shear strength. The use of geogrids, economical and easy to install geo-synthetic materials, are studied to reinforce soils in various geotechnical applications.

Laboratory experiments were conducted to investigate the impacts of dynamic loads on settlement and internal displacement of the foundations of rigid square machines. These tests were carried out on unreinforced and reinforced multilayer sand soils with different densities. The results of these tests provide insight into how geosynthetic reinforcement can improve soil performance under different load and frequency conditions.

2.6.1 Geometry of the Problem

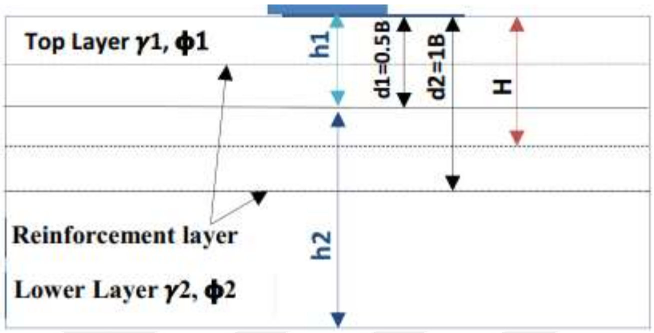

Figure 2.7: Description of the Geometry, where h1 Represents the Depth of the Top Layer, and h2 Denotes the Depth of the Lower Layer (ICCEET 2020) [17].

In engineering, it is common to place shallow foundations on stratified deposits. The deposit located under the foundation, and which influences its bearing capacity is called the basement. A stratified structure is referred to when the thickness of the surface layer of the deposit is less than a certain value H. The simplified analysis makes it possible to estimate the thickness of the subsoil using equation:

$$H = \frac{b}{2}\left(\tan 45 + \frac{\emptyset}{2}\right) \tag{2.2}$$

In this context,

b: denotes the breadth of the surface-level foundation.

while, Φ: represents the angle of internal soil friction.

In typical scenarios, the basement consists of two layers, as shown in the figure.

2.6.2 Test Procedure

This text procedure discusses a series of tests conducted on twenty models to examine how saturated sand reacts to dynamic loads. The sand models consisted of two layers: a preliminary layer of medium dense (MD) sand measuring 15 cm in height, followed by a second layer with a height of 55 cm. The tests were conducted both with and without reinforcement using three series of model surface reinforcement depths 0.5B, 1B and 0.5B, where B represents the width of the foundation (200×200×20 mm). The surface of the foundation has undergone testing. The tests used Karbala sand. The physical properties of this sand were evaluated using conventional tests.

Table 2.5: Physical Characteristics of the Sandy Soil in Use [17].

Index Properties	Value	Specification
Specific gravity	2.6	ASTM D 854 (2006)
D_{10} (mm), D_{30} (mm), D_{60} (mm)	0.15, 0.2, 0.5	
Coefficient of Uniformity (Cu)	3.3	ASTM D 422 and 2487 (2006)
Coefficient of Curvature (Cc)	1.2	
Soil classification (USCS)	SP	
Maximum Void ratio	0.49	ASTM D4254 (2014)
Minimum Void ratio	0.33	ASTM D4254 (2014)
Maximum dry unit weight (kN/ m^3)	19.5	ASTM D 4253 (2006)
Minimum dry unit weight (kN/ m^3)	17.4	ASTM D 4254 (2006)
Angle of internal friction (RD =50%)	40°	ASTM D 3080 (2006)
Angle of internal friction (RD =85%)	44°	ASTM D 3080 (2006)

2.7 THE RESONANT FREQUENCY AT WHICH MACHINE FOUNDATIONS OSCILLATE POSITIONED ON SATURATED SANDS

The resonant frequency of machine foundations situated on saturated sands has taught us that, soil liquefaction is a major problem during earthquakes, and that progress in addressing this phenomenon has evolved over decades. Early efforts focused on assessing the probability of liquefaction occurring in clean, sandy soils. However, other issues related to silty and gravelly soils as well as post-liquefaction strength and stress deformation behavior began to be considered. Various studies have been conducted to better understand soil liquefaction.

2.7.1 Description of the Problem

The research centers on scrutinizing variations in pore pressure within a saturated soil exposed to dynamic loading for a duration of 60 seconds, utilizing a time step of 0.1 second. The QUAKE/W software, integrated with GeoStudio, is used for this geotechnical analysis.

A foundation soil, saturated and porous, with dimensions of 30 m in width and 20 m in depth, is simulated through finite element analysis. A footing, 2 m wide, is positioned at the center of the upper surface.

The outcomes are displayed at specific points (A, B, C, D, E) situated at various depths beneath the foundation to examine the influence of the dynamic load at different soil depths.

Relations used in the model of equivalent linear elasticity encompasses:

a. Function for reducing shear modulus.

b. The connection between the ratio of cyclic numbers and the ratio of pore pressure.

c. The restriction on the cyclic deviator as per the cycle count.

The analysis makes it possible to understand how the pore pressure evolves in the soil in response to analyze the dynamic load and investigate how the depth influences the soil's response under such loads.

The investigation encompasses three soil types: loose, medium, and dense sand. Sand properties are summarized in table 2.6.

Table 2.6: Characteristics of the Sandy Soil Employed in the Parametric Investigation [18].

Material Properties	Loose sand	Medium sand	Dense sand
Modulus of elasticity, E (kN/m^2)	20000	40000	60000
Poisson s ratio, υ	0.2	0.3	0.4
Unit weight γ_t, (kN/m^3)	14.0	17.0	22.0

2.7.2 The Various Studies Carried Out

A numerical model to examine the resistance of soils to liquefaction under high confining pressures was defined by Duan (2002). They found that liquefaction resistance increased with confining pressure at great depths.

Ashford et al. (2004) conducted pilot trials to induce liquefaction in field trials. They confirmed the effectiveness of controlled blasting techniques in inducing liquefaction in specific areas. They also observed that liquefaction could be induced repeatedly at the same site with similar results.

Sitharam et al. (2004) explored techniques for assessing the dynamic properties and liquefaction potential of soils. They emphasized the significance of the material directly beneath the foundation in influencing the dynamic response. They also observed a decrease in shear modulus coupled with an augmentation in sand damping in the range of large shear strains.

Jin et al. (2008) conducted experiments on loose sand samples that were saturated to characterize liquefaction and cyclic rupture. They used a triaxial, torsion shear apparatus to simulate seismic loading conditions. Their findings indicated that liquefaction was affected by both horizontal and vertical shearing forces.

Lu et al. (2010) examined the reactions of saturated sand exposed to a horizontal vibratory load caused by a bucket foundation. They observed that liquefaction and deformation developed rapidly with increasing load amplitude and frequency, as well as decreasing modulus.

These studies highlight the importance of considering liquefaction caused by mechanical factors, such as vibrations induced by heavy construction equipment. It is essential to understand and predict the behavior of soils under seismic or dynamic loading conditions to design foundations and structures resistant to potential liquefaction.

2.8 POTENTIAL FOR LIQUEFACTION IN SANDY SOIL WITHIN A LABORATORY MODEL OF A SMALL MACHINE FOUNDATION

The assessment of liquefaction potential in sandy soil through a small laboratory model of a machine foundation serves as the foundation for studying soil liquefaction in the context of machine foundations. The phenomenon of liquefaction, which occurs during earthquakes, fractures the ground. When water-saturated fine sandy and loamy soils liquefy, they behave like viscous fluids. The primary conclusions drawn from the investigation are as follows: At shallow depths, liquefaction occurs faster, mainly in the first 10 meters, but can spread up to about 20 meters deep. The magnitude and frequency of loading greatly affect soil liquefaction and deformation. Liquefaction times are shorter with higher amplitudes and frequencies. The resistance to liquefaction is affected by the overload pressure of the soil. Depth increases liquefaction resistance and liquefaction time. A conventional trend is observed in the relationship between frequency ratio and peak displacement: larger amplitudes have a higher peak displacement. When the foundation is built on saturated loose sand, liquefaction can occur in some cases at a frequency ratio of 1.0. Other experimental and numerical studies were also carried out in order to evaluate the liquefaction potential and to understand the behavior of machine foundations under dynamic loading conditions. The objectives of this study are to determine how the potential for liquefaction and soil characteristics such as relative density and shear strength, as well as the depth and shape of the foundation, are related. Also study how dynamic load parameters (frequency, amplitude), sand density, burial depth, and footing shape influence the potential for liquefaction [29].

2.8.1 Test Program

Two sets of model tests are used in the study, with sand at two relative densities: 36 saturated medium sand models and 18 saturated dense sand models. Three loading levels (0.5ton, 1 ton, and 2 tons) along with three excitation frequencies (0.5 Hz, 1 Hz, and 2 Hz) were used in each group. The experiments were conducted at a depth B, using either square or circular foundations, positioned either on the surface or embedded. The objective is to understand the bearing capacity and the dynamic response of sand foundations by examining their behavior under different conditions.

a. Soil properties

The study utilized sand sourced from the city of Karbala, exhibiting two distinct densities: medium and dense. Standard tests were conducted to determine the physical properties of the soil, summarized in Table 2.7. According to the Unified Soil Classification System (USCS), the soil is classified as poorly-graded sand, denoted by the symbol (SP).

Table 2.7: The Physical Attributes of the Soil Employed in the Investigation [19].

physical properties		Value	Specification
Specific gravity (Gs)		2.66	ASTM D 854[11]
D_{10} (mm)		0.23	ASTM D 422[12] and ASTM D 2487[13]
D_{30} (mm)		0.42	
D_{60} (mm)		1.15	
Coefficient of uniformity (Cu)		5	
Coefficient of curvature (Cc)		0.66	
Soil classification		SP	
Maximum void ratio		0.66	--------
Minimum void ratio		0.4	--------
Maximum dry unit weight $(\gamma_{dry})max$ (kN/m^3)		19	ASTM D 4253[14]
Minimum dry unit weight $(\gamma_{dry})min$ (kN/m^3)		16	ASTM D 4254[15]
Angle of internal friction at (R.D = 60%)	Dry	41°	ASTM D 3080[16]
	Saturated	35.6°	
Angle of internal friction at (R.D = 80%)	Dry	43.5°	
	Saturated	37.4 °	

b. Dynamic load machine design

Emulating test conditions as close to field conditions as possible is essential to explore the likelihood of liquefaction in saturated sand. A specific test device is used to achieve this goal. The apparatus possesses the capability to administer dynamic loads featuring various magnitudes and frequencies.

i. Steel framework for loading

A steel frame was constructed to support a hydraulic cylinder and provide stability when applying a central concentrated load. It is composed of 4 columns and 4 steel beams, reinforced by the addition of additional beams. A steel plate has been welded to the center of the frame was designed to support the hydraulic cylinder and the encoder. Four base plates are used to secure the frame to the floor using bolts. In summary, the steel frame is designed to support the hydraulic cylinder and ensure verticality when applying the load, while being reinforced and firmly fixed to the ground.

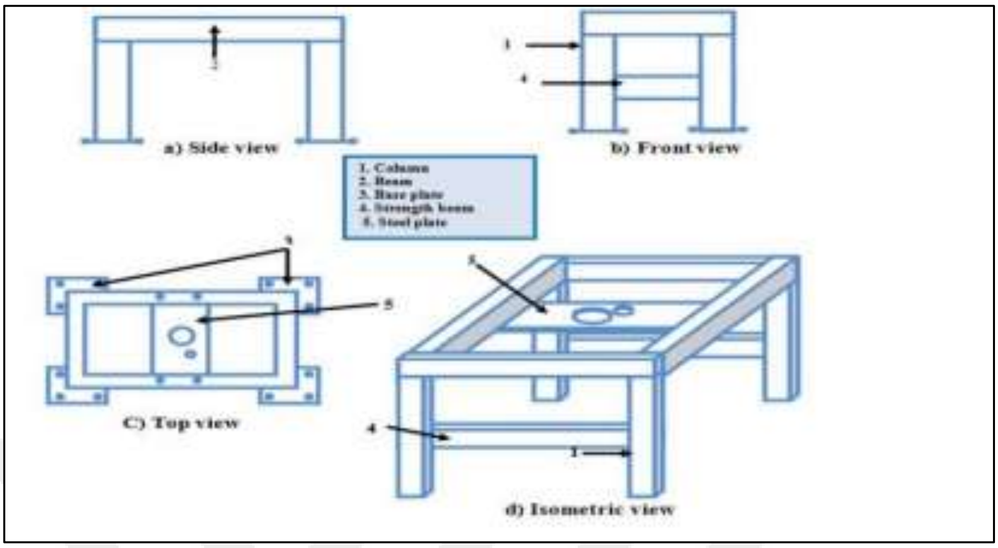

Figure 2.8: Steel Loading Frame [20].

ii. Axial loading system

The hydraulic axial loading system is composed of two main parts: the cylinder system and the control system. The hydraulic ram system is equipped with a 70-liter steel tank. There are two holes in the tank: one for filling oil and the other for draining. It is also equipped with a hydraulic pump capable of delivering a flow rate of 12 liters per minute and achieving a maximum pressure of 150 bars. The dynamic load is applied through the movement of the cylinder piston, controlled by the hydraulic system through a valve. The hydraulic cylinder's movement is regulated by a programmable logic controller (PLC), which can be manipulated by selecting parameters through data acquisition.

iii. Sole model

A 100×100 mm square steel footing with a 20 mm thickness was utilized to simulate a machine foundation. Additionally, a circular footing with a 100 mm diameter was employed.

iv. Collecting data

The data acquisition system is utilized for measuring and recording displacements during machine foundation testing. This system allows the operator to quickly obtain many readings and choose a specific test frequency. The collected data is subsequently analyzed digitally using a Programmable Logic Controller (PLC), a digital computer employed in electromechanical automation processes. The PLC is equipped with an LCD panel that displays input and output data, allowing the operator to program input parameters and save The outcomes are then transmitted to the computer for subsequent computations. During machine foundation testing, this enables displacements to be measured, analyzed, and controlled effectively.

v. shaft encoder

A shaft encoder, especially an incremental encoder, translates the rotational positions of a shaft into either analog or digital signals, and provides important information about its motion, such as its speed, displacement, RPMs, and position.

vi. Metal container

The experiments were conducted within a cubic steel tank measuring 800 x 800 x 800 mm, featuring a 6 mm thickness and reinforcement from welded steel sections. By using a 30 mm thick cork covering and a 2.5 mm thick rubber sheet, Precautions have been implemented to minimize the propagation of waves. The load was applied to a steel frame with a hydraulic cylinder.

C. The sand bed prepared for testing.

Organization of the sand deposit involved the use of a steel tamping hammer and the creation of layers of sand of predetermined relative densities. The soil was compressed in 100 mm thick layers within a cubic container. A vibrometer probe was installed at specific depths and the last layer of soil was completed. The upper surface of the floor was smoothed using the sharp-edged ruler. After leveling the top surface of the floor, the footing was brought into contact with the model. The saturation process involved adding water from the model's bottom to its top surface while ensuring a consistent water level to prevent channeling. Each layer of soil was submerged for about an hour.

2.9 INVESTIGATION INTO THE INTERFERENCE BETWEEN TWO FOUNDATIONS OF ACTIVE MACHINES

Based on the numerical analysis, investigating the interference between two active machine foundations, many studies have been carried out to understand how the dynamic loads induced by the vibrations of the machines affect the behavior of the foundations. The magnitude of the load, the relative density of the soil, the shape of the footing, the embedment of the foundation and the interference between the static and dynamic foundations are all elements that have been examined in these studies. The results of these studies showed that the magnitude of the load increases the settlement of the surface and that the medium sand has a higher rate of settlement than the dense sand. The embedding of the square footing has made it possible to significantly reduce surface settlement, while the interference between static and dynamic foundations showed varying effects on the response of the static foundation. It should be noted that most of these studies have focused on structural foundation strength and have less examined the impact on dynamic settlement. However, the engineering of machine foundations is centered around minimizing dynamic settlement to ensure stability, which requires additional studies.

In order to gain a deeper insight into the influence of dynamic loads with the performance of machinery footings and to formulate relevant design guidelines, it is crucial to continue research in this area. Experimental laboratory studies, field studies and numerical analyzes can help us deepen our knowledge and improve our design practices for machine foundations. Thus, it is necessary to consider the results of this research during the design and construction of machine foundations in order to ensure their stability and satisfactory operation under complex vibration conditions.

2.9.1 The Objectives of this Research and the Definition of the Problem

The objectives of this research are:

a. Investigation of how interference influences the dynamic settlement of two neighboring active machine foundations positioned on sand. The study takes into account varying sand density, vibration frequency, and the spacing between foundations to fulfill this aim.

b. Determine the crucial distance at which the influence of Impact on the dynamic subsidence caused by interference, caused by machine vibrations, becomes negligible.

c. Incorporate The impact of interference on the standard design of machine foundations.

Problem Statement:

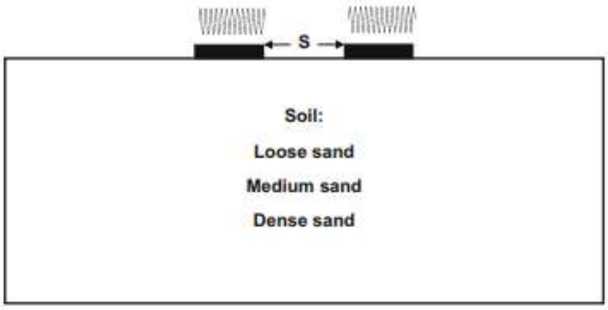

Figure 2.9: Outline or Depiction of the Problem under Investigation in this Study [21].

This study investigated the challenges associated with equipment bases featuring two belts, exposed to machine oscillations, and situated on a bed of sand. The foundations were considered to have a width of 1.0 m and were positioned at a separation distance denoted as S. The study depicted a simplified illustration of the addressed problem, as presented in the figure. Employing a harmonic load on each foundation, consistent with earlier research (Vivek and Ghosh 2012; Fatah et al. 2014, 2015a, 2016), the investigation focused on machine vibration. The equation governing the harmonic load (1) was presumed to align with the parameters specified in the aforementioned prior studies.

The maximum amplitude of vibration was assumed to be 10 kPa, as established by Fattah et al. in 2012. Additionally, the analyzed frequencies included 0.5 Hz, 1.0 Hz, 2.0 Hz, 5.0 Hz, 10.0 Hz, and 20.0 Hz; These frequencies replicate situations similar to those observed in a series of large centrifugal pumps, as described by Gazetas (1981). The equation presented is an illustrative example of the considered harmonic load, characterized by a maximum vibration amplitude of 10 kPa and a vibration frequency of 10.0 Hz.

$$DS(t) = A \sin(2\pi f t) \quad (2.3)$$

$DS(t)$: is the dynamic stress at the time t.

A: is the maximum amplitude of vibration in kPa.

f: is the frequency of vibration in Hz.

2.9.2 Models and Analytical Parameters for Constitutive Analysis

In this study, the choice was made to adopt the linear viscoelastic model to characterize the soil's response. This decision stems from the low load generated by machine vibrations and the specified settlement limit of less than 1 mm, as outlined in the Introduction. The suitability of the linear elastic model for these conditions has been affirmed in previous studies (Ali and al. 2017; Bose and al. 2018; Kumar and Ghosh 2018). To strengthen the rationale for using the linear elastic model, the dynamic settlement results produced using this model were compared to the results produced by the perfectly plastic elastic Mohr-Coulomb model. The comparisons were made for a machine foundation subjected to Vibrations exhibiting a 10 kPa amplitude and operating at a frequency of 2.0 Hz.

And the same time Models and analytical parameters for constitutive analysis form the basis of understanding the behavior of materials under various conditions. These models and parameters are essential for predicting how materials will deform and respond to external forces, which is crucial for designing structures that can withstand different loads and environments. In constitutive analysis, the goal is to develop mathematical models that accurately describe the relationship between stress and strain in a material. This involves identifying the key parameters that influence the material's behavior, such as its elasticity, plasticity, and strength properties. By using these models and parameters, engineers can simulate the behavior of materials in complex situations, allowing them to design safer and more efficient structures [25].

The problem of the foundations of machines with two bands, which rest on sand and are subjected to the vibrations of the machine, has been examined. Due to the low vibration-induced load, the linear elastic model was used for foundation modeling. The analysis took into account loose sand, medium sand, and dense sandy soils. The analyzes considered the parameters of linear elasticity and viscous damping of the soil. In addition, ground motion measurements were calculated. Additionally, a linear elastic model with specified parameters was used to model the concrete foundation. These numerical analyzes will make it possible to study the impact of the impact on the dynamic settlement caused by interference induced by the vibrations of the machine and to identify a critical distance after which the interference no longer has a significant impact. These results could have an impact on how machine foundations are designed to work in practice.

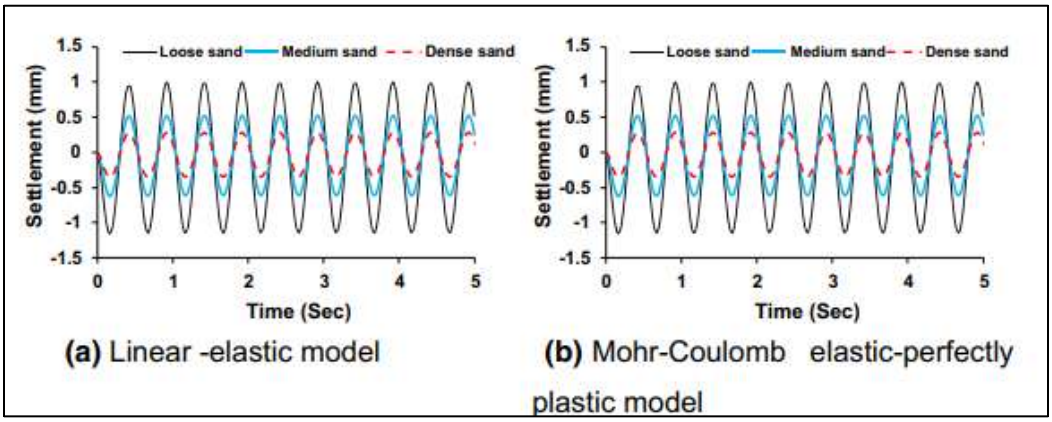

Figure 2.10: Settlement of the Machine Foundation in Loose Sand, Medium Sand, and Dense Sandy Soils due to Machine Vibration (vibration frequency: 2 Hz, vibration amplitude: 10 kPa) [22].

3. METHODOLOGY

This chapter focuses on methodology for theoretical analysis and numerical simulation of the dynamic behavior of elastic foundation under vibratory machine by using the PLAXIS 2D software.

3.1 PRESENTATION OF PLAXIS 2D SOFTWARE

In the field of geotechnical engineering PLAXIS 2D is a widely used geotechnical simulation software. It is software developed by the company PLAXIS bv, which is part of Bentley Systems. Its function is to model and analyze the behavior of soils, foundations, embankments, and geotechnical structures in a two-dimensional environment. And also, it’s reasonable to know that PLAXIS 2D is a finite element software package specifically designed for the analysis of deformation and stability in geotechnical engineering projects. It is widely used by geotechnical engineers, researchers, and students for analysing soil-structure interaction problems. Here is some detailed information about PLAXIS 2D.

Thus, we can present the main characteristics and functionalities of PLAXIS 2D, as follows:

i. Geometric modeling: PLAXIS 2D allows you to create two-dimensional geometric models to represent complex geotechnical structures such as excavations, tunnels, embankments, dikes, etc.
ii. Geotechnical Materials: This software supports a variety of geotechnical materials, such as soil, rocks and artificial materials. Geotechnical properties such as shear strength, density, cohesion, friction angle, etc. can be defined.
iii. Boundary conditions: it allows you to simulate various scenarios by defining boundary conditions. You can apply loads, deformations, constraints, or displacements to the edges or certain locations of the model.
iv. Stability Analysis: The software is frequently used to evaluate the stability of embankments, excavations, and slopes. It allows the prediction of deformations, stresses and effective stresses caused by static and dynamic loads.
v. Settlement Analysis: This software can be used to examine foundation settlements and deformations under different loads and to assess the risk of failure or excessive deformation.

vi. Stress calculation: implementing effective stress analyzes to assess the stability and safety of geotechnical structures.

vii. Modeling of interactions between structures and the ground: PLAXIS 2D also takes into account the interactions between geotechnical structures and the surrounding ground, which allows more realistic and precise analyses.

viii. Consolidation analysis: this is software that also has the capacity to evaluate the behavior of clay soils under static loads.

ix. Dynamic Construction Modeling: It also supports the analysis of dynamic problems such as shock waves, earthquakes, and construction-induced vibrations.

x. PLAXIS 2D's user-friendly user interface facilitates the modeling, simulation and analysis of complex geotechnical problems.

In short, PLAXIS 2D is a powerful tool for geotechnical engineers and civil engineering professionals who seek to understand the behavior of soil and structures in a 2D environment. It allows you to make informed decisions when designing and analyzing various geotechnical projects.

3.2 ANALYSIS OF THE DYNAMIC BEHAVIOR OF ELASTIC FOUNDATION UNDER VIBRATORY MACHINE

3.2.1 Problem Statement

PLAXIS 2D software enables the simulation of dynamical interplays between the structure and the underlying ground. On the surrounding ground It has the capacity to study the impact of a vibrating source. The oscillations produced by the generator are transmitted into the basement through the sole.

Rayleigh damping is used to account for physical damping caused by viscous effects. Additionally, "geometric damping" can be important in reducing vibration due to axisymmetric symmetry. An important point is the modeling of boundaries. Specific conditions must be applied to absorb waves reaching the boundaries of the model in order to avoid spurious wave reflections, which do not exist in reality.

3.2.2 Objectives and Geometry

To carry out a dynamic generator analysis on an elastic foundation, the objectives will be to: Provide a dynamical computation definition, specify dynamic loads, outline dynamical constraints (including viscous effects), and define material damping through Rayleigh damping.

Geometry:

We apply a load at the center on a soil layer with a length of 1 m, which has a thickness of 0.16 m.

3.2.3 Creation of New Project

These different steps must be carried out in order for the creation of a new project:

1. Begin the input program and opt for "Initiate New Project" within the Quick Select dialog box.
2. Input a suitable title in the Project tab within the Project Properties window.
3. In the Model tab, opt for the Axisymmetric model option and retain the default selection for Elements (15 nodes), acknowledging the three-dimensional aspect of the problem.
4. Maintain the default settings for units and constants, and configure the model contour as follows: xmin = -50 m, xmax = 50 m, ymin = -15 m, and ymax = 0 m.

3.2.4 Elaborate on Soil Stratigraphy.

The lowermost layer extends to a depth of 10 meters, with the ground level denoted as y=0. It's essential to highlight that this example does not account for water conditions. The soil stratigraphy can be outlined as follows, maintaining the sequence of layers:

a. Initiate the borehole creation process by right-clicking on the designated "Create Drilling" button, placing the borehole at a specified location, such as x = 0.

b. Generate a soil layer that stretches from ground level at y = 0 to a depth of 10 meters (y = -15).

c. Ensure that the borehole reference remains at 0 meters, indicating complete subsoil saturation.

3.2.5 Generate and Allocate Material Data Sets.

Establish a dataset within the Ground and Interfaces set category using the details outlined in Table 3.1.

Table 3.1: Material Properties of the Clay Soil.

Parameter	Name	Value	Unit
General			
Material Model	Clay	Mohr-columb	-
Type of material behavior	Type	Drained	-
Soil unit weight above phreatic	γ unsat	16	KN/ m3
Soil unit weight below phreatic	γ sat	18	KN/ m3
Parameters			
Stiffness	E'	50.E3	KN/m2
Poisson's ratio	ν	0.3	
Initial			
Ko determination	-	Automatic	-
Lateral earth pressure coefficient	Ko, x	0.4554	-

Table 3.2: Material Properties of the Sand Soil.

Parameter	Name	Value	Unit
General			
Material Model	Sand	Hardening soil	-
Type of material behavior	Type	Drained	-
Soil unit weight above phreatic	γ unsat	17	KN/ m3
Soil unit weight below phreatic	γ sat	20	KN/ m3
Parameters			
Stiffness	$E_{50}{}^{ref}$	35.00E3	KN/m2
Poisson's ratio	v_{ur}	0.2	
Initial			
Ko determination	-	Automatic	-
Lateral earth pressure coefficient	Ko, x	0.4554	-

3.2.6 Define Structural Components

The definition of the generator is established in Structures mode, while the material characteristics of the sole are detailed in the provided table.

Table 3.3: Material Properties of the Plate.

Parameter	Name	Value	Unit
Material type	footing	Elastic	.
isotropic		No	.
Axial stiffness	EA	$7.6\ .10^6$	KN/m
Flexural rigidity	EI	24.10^3	KNm^2/m
Weight	W	5	KN/m/m
Poisson ration	V	0	.

Generate a plate that spans from (0, 0) to (-1, 1) to symbolize the footing and then press enter.

Define a given set for the material for the sole based on the information provided in the provided table. Impose a uniformly uniform load on the foundation to emulate both the mass of the generator and the induced vibrations. The exact magnitude of the load will be determined subsequently. The model schematic is illustrated below:

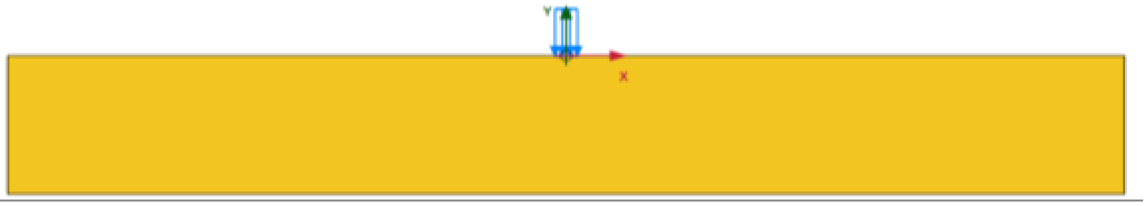

Figure 3.1: Layout of the Model.

3.2.7 Creation of the Mesh

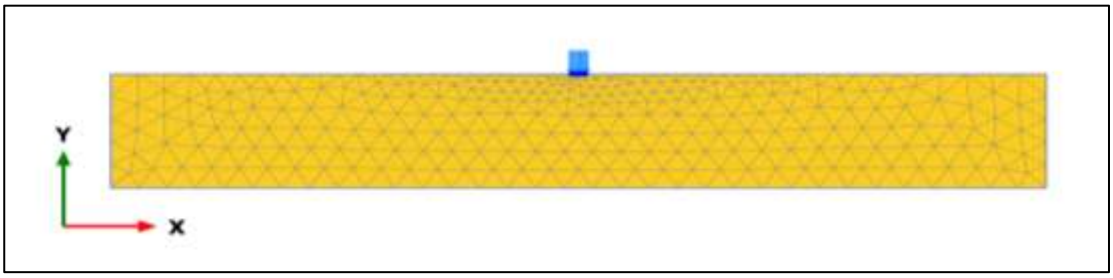

Figure 3.2: The created mesh.

After the mesh generate it's going to the flow condition and then its forward to the stage construction and in the numerical modeling we have 4 phases. Initial Phase: Static analysis in the absence of foundation and machine, phase 1: Plastic analysis with only foundation and weight of machine, phase 2: Dynamic analysis when machine operates and phase 3: Dynamic analysis when machine stops.

3.2.8 An Outlook after Running the Project for Every Phase in Clay Soil

i. Total displacement in y direction for clay in initial phase, phase 1, phase 2, phase 3:

Figure 3.3: Total Displacement for Clay in y Direction in Initial Phase.

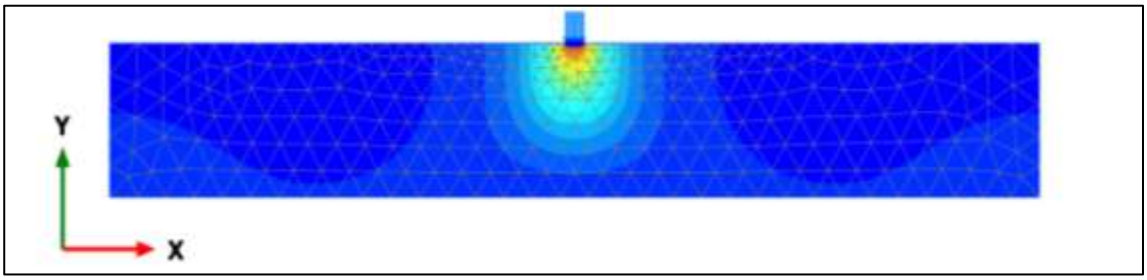

Figure 3.4: the Total Displacement in y Direction Phase 1 (just machine weight, no vibration).

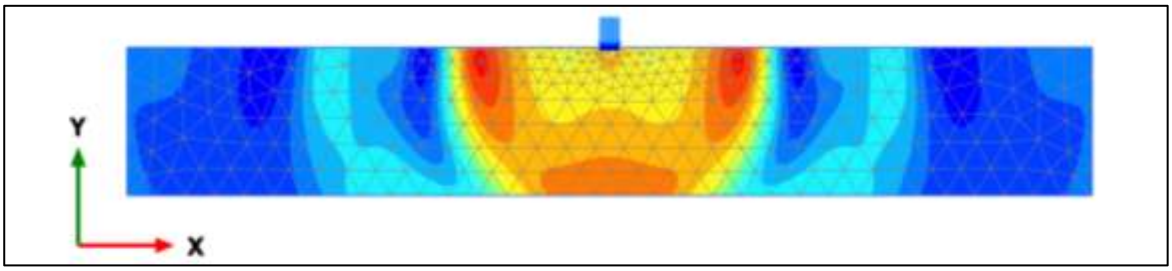

Figure 3.5: The Total Displacement in y Direction Phase 2 (machine weight with vibration).

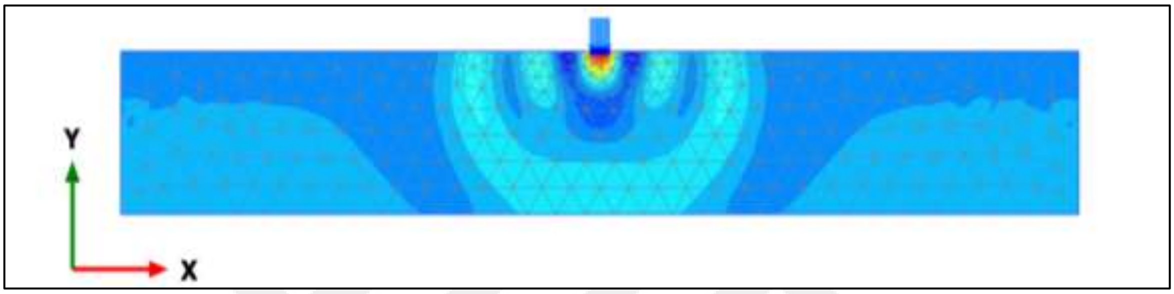

Figure 3.6: The Total Displacement in y Direction Phase 3 (just machine weight, no vibration).

ii. Accelerations for clay in initial phase, phase 1, phase 2 and phase 3:

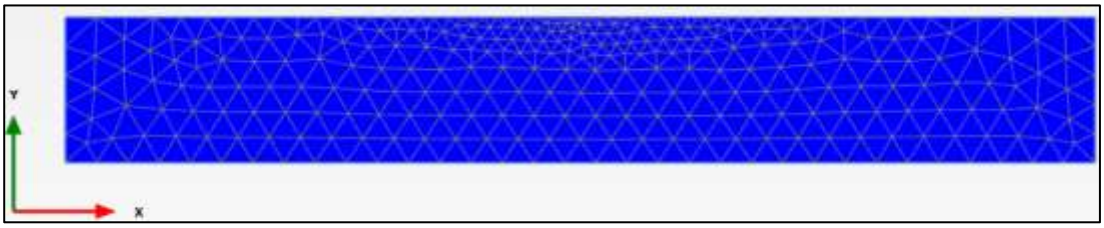

Figure 3.7: Acceleration in Initial Phase.

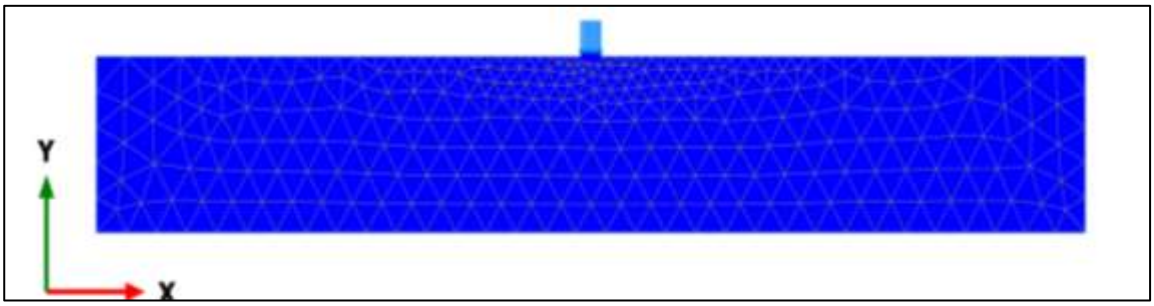

Figure 3.8: Acceleration in Phase 1 (just machine weight, no vibration).

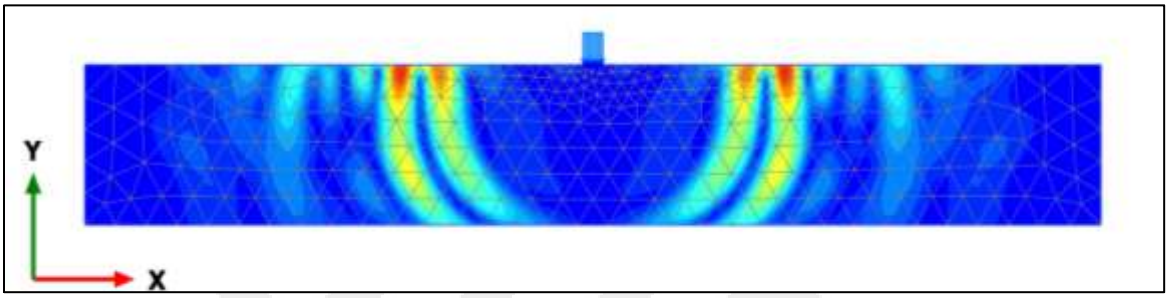

Figure 3.9: Acceleration in Phase 2 (machine weight with vibration).

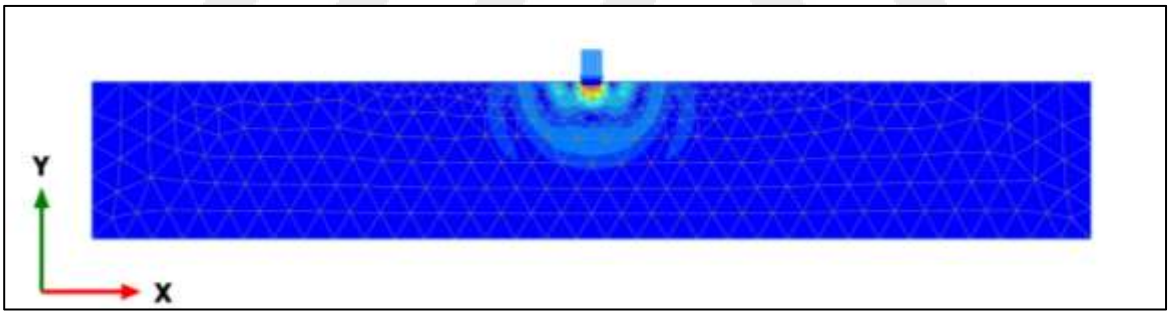

Figure 3.10: Acceleration in Phase 3 (just machine weight, no vibration).

In the rest of this project, we will continue with the geometry already created. Then introduce different ground material (sand), as well as different values for frequency and amplitude. These new data sets will be added for the purpose of in-depth analysis and comparison of the curves resulting from these data according to the differences in soil materials used.

For sandy material, we will also proceed in the same way for the choice of amplitudes and frequencies to carry out the calculations.

3.2.9 An Outlook after Running the Project for Every Phase in Sand Soil

i. Total displacement in y direction for sand in initial phase, phase 1, phase 2, phase 3:

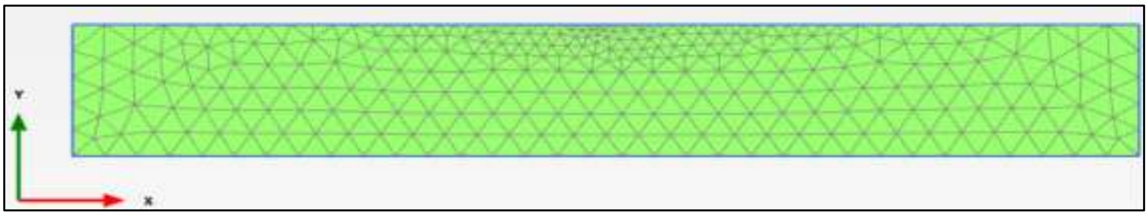

Figure 3.11: Total Displacement for Sand in y Direction in Initial Phase.

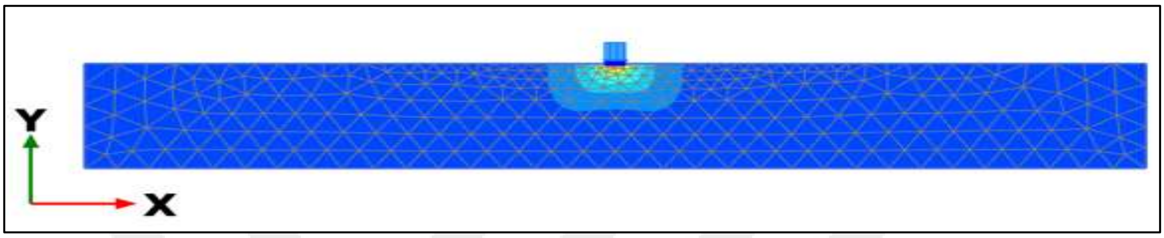

Figure 3.12: Total Displacement in y Direction for Sand in Phase 1 (just machine weight, no vibration).

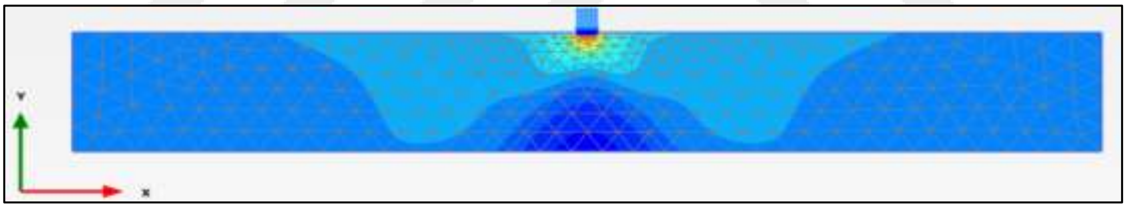

Figure 3.13: Displacement in y Direction for Sand in Phase 2 (machine weight with vibration).

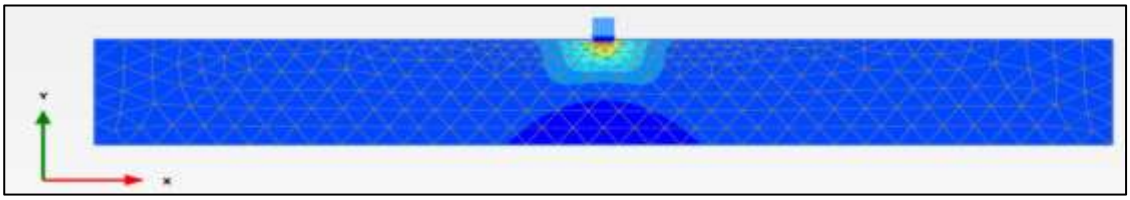

Figure 3.14: Total Displacement in y Direction for Sand in Phase 3 (just machine weight, no vibration).

ii. Accelerations for Clay in Initial Phase, Phase 1, Phase 2 and Phase 3:

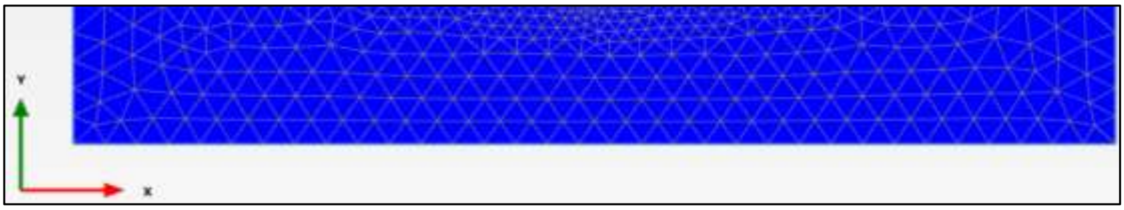

Figure 3.15: Acceleration for Sand in Initial Phase.

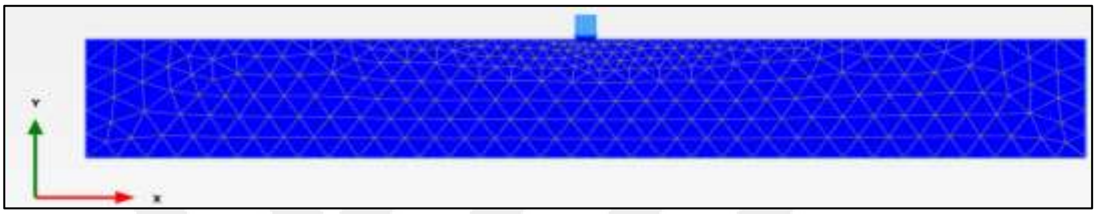

Figure 3.16: Acceleration for Sand in Phase 1 (just machine weight, no vibration).

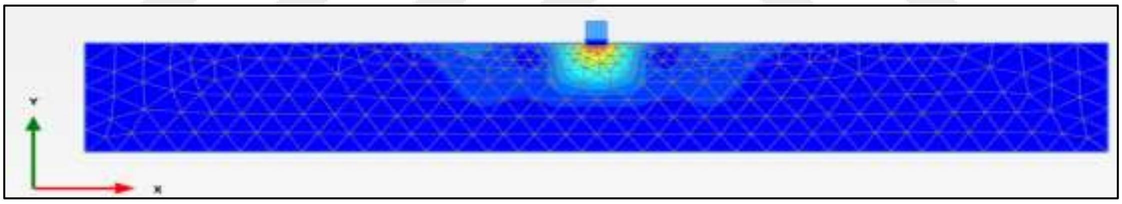

Figure 3.17: Acceleration for Sand in Phase 2 (machine weight with vibration).

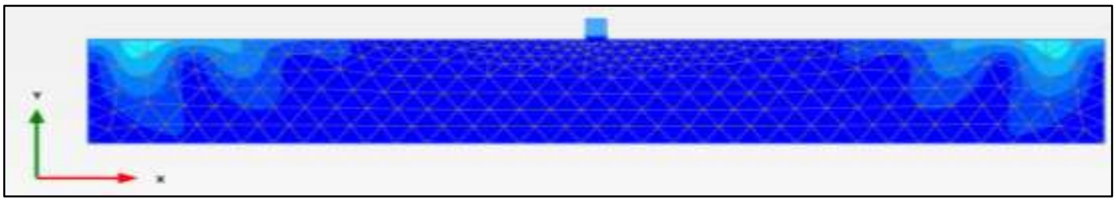

Figure 3.18: Acceleration for Sand in Phase 3 (just machine weight, no vibration).

4. RESULTS AND DISCUSSION

4.1 SOILS MATERIALS BEHAVIORS UNDER DYNAMIC LOADING

In this study, we will conduct a comparative analysis of curves based on varied soil materials. The purpose of this analysis is to investigate how different soil materials, such as clay and sand, affect the dynamic response of foundations under vibrating machines. By comparing the curves resulting from these materials, we aim to gain insights into the behavior of each material and its suitability for specific engineering applications. The analysis will involve keeping the same value of amplitude and permuting the values of frequency for each material to examine their impact on the dynamic response. For clay, we will consider values of the amplitude only for 10 and frequency values of 5 Hz, 10 Hz, and 15 Hz. Similarly, for sand, we will vary frequency values to cover a range of scenarios. We will also apply different loads, such as 5 KN, 10 KN, and 15 KN, and permute them. The results of the analysis will be presented in the form of line charts, with the dynamic time element on the horizontal axis and the vertical axis representing vertical displacements (Uy) and horizontal accelerations (Ax). These charts will allow us to visually compare the behavior of each material under different loading conditions.

Furthermore, we will perform a theoretical analysis to complement the numerical simulations. This analysis will consider the physical properties of each material, such as cohesion, compressibility, and drainage characteristics, to provide a deeper understanding of the results obtained from the curves.

Overall, this comparative analysis will provide valuable insights into how different soil materials behave under dynamic loading, helping engineers make informed decisions when selecting materials for foundation design and construction projects.

4.1.1 Mechanical Properties of Soils

The effect of applying a load to the surface of clay or sand also varies depending on the mechanical properties of certain materials. In our analysis, we used two types of soil: clay and sand.

a. Clay:

Clay can absorb water, leading to swelling and expansion when hydrated, and contraction when drying. When a load is applied to the surface of clay, it tends to deform and compress due to its high cohesion. Therefore, clay is more likely to withstand a load better, but it can also be prone to slow movements or deformations over time.

b. Sand:

Sand is less cohesive than clay, which means it has a limited ability to maintain its shape under a load. When a load is applied to the surface of sand, it tends to flow or compact, but it offers better water permeability, which can allow for a redistribution of the load over time.

4.1.2 Defining Load, Amplitude, Frequency, Vertical Displacement and Horizontal Acceleration

a. Load:

In civil engineering and mechanics, the term "charge" refers to the force exerted on a structure or material. It can be expressed in units such as newtons (N) or kilograms-force (kgf) and generally represents the pressure or weight applied over a certain area or surface.

b. Amplitude:

In physics, amplitude is the maximum value of variation of an oscillating quantity, such as the height of a wave or the maximum distance traveled by an object in periodic motion. In the context of vibrations or waves, amplitude is often used to describe the intensity or strength of the vibration.

c. Frequency:

Frequency is the number of complete cycles of an oscillating quantity that occur in a given unit of time. It is measured in hertz (Hz), where one hertz equals one cycle per second. Frequency is widely used to describe the rate of change of a wave or vibration.

d. Vertical displacement:

Vertical displacement is the vertical movement or deformation of a structure or material under the influence of varying or fluctuating loads. This type of displacement occurs when the applied load changes over time, such as in the case of vibrations, earthquakes, or machinery operating at variable speeds. Vertical displacement is an important consideration in structural engineering, as it can affect the stability, integrity, and performance of a structure.

e. Horizontal acceleration:

We can define horizontal acceleration as the acceleration experienced by a structure or material in the horizontal direction due to varying or fluctuating loads. This type of acceleration occurs when the applied load changes over time, such as in the case of lateral forces from wind or seismic activity.

4.2 GEOMETRY AND NODES COORDINATES

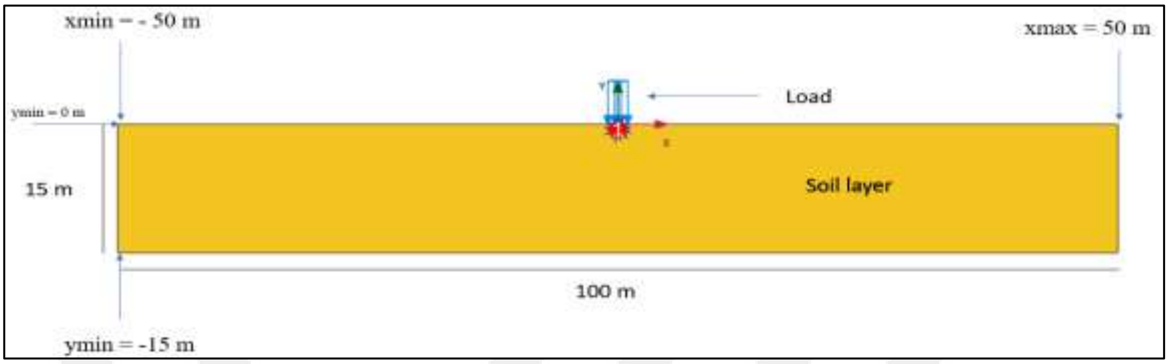

Figure 4.1: Description of Nodes Geometry.

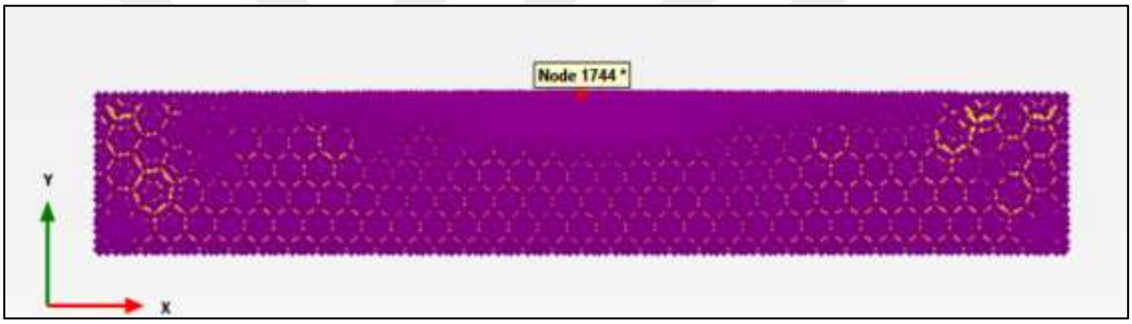

Figure 4.2: The Simulation of Featuring Nodes at Designated Location.

Table 4.1: Node Point and Location for Each Soil such as Clay and Sand.

Point x	Point y
Node 1 (0)	**Node 1 (0)**

4.3 COMPARATIVE ANALYSIS OF GRAPHS BASED ON VARIOUS SOIL MATERIALS, LOADS, AMPLITUDES, AND FREQUENCIES.

All the graphs we will describe will depict clayey and sandy soil with a constant amplitude of 10. However, the applied loads and frequencies will vary across the graphs. The unit of measurement for these different vertical displacements over time will be in millimeters (mm), and for horizontal accelerations will be in m/s², while time will be measured in seconds.

4.3.1 Settlements Graphs for Clay

- For load 5 KN:

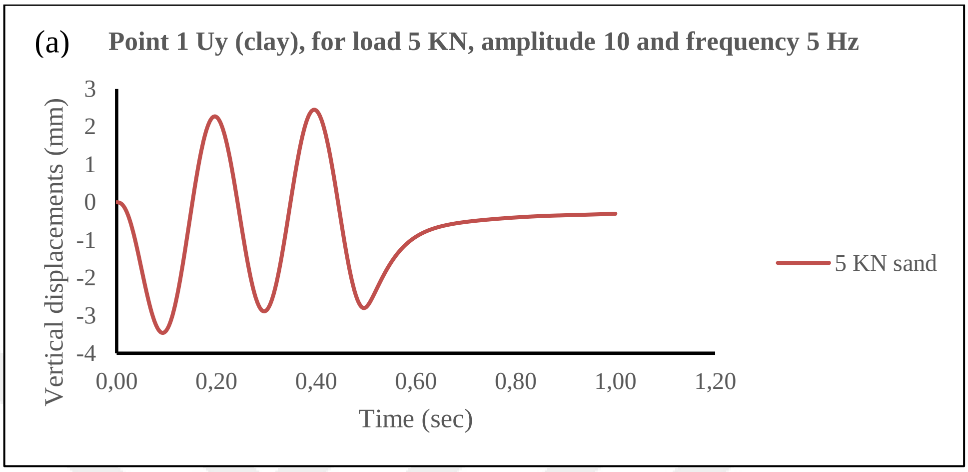

Figure 4.3: Graph (a) Vertical Displacements Uy (mm) for Clay with 5 KN Load, Amplitude 10 and Frequency 5 Hz.

In this graph, we have selected point number 7 for analysis. It represents the vertical displacement Uy as a function of time for this specific point. The soil material is clay, the applied load is 5 KN, with a constant amplitude of 10 and a frequency of 5 Hz. Visually, we can see that the curve is not constant and the vertical displacements vary with time. The curve increases negatively from 0 mm to approximately -3.5 mm between 0 seconds and 0.10 seconds, then increases sharply from - -3.5 mm to 2 mm between 0.10 seconds and 0.20 seconds, and so on.

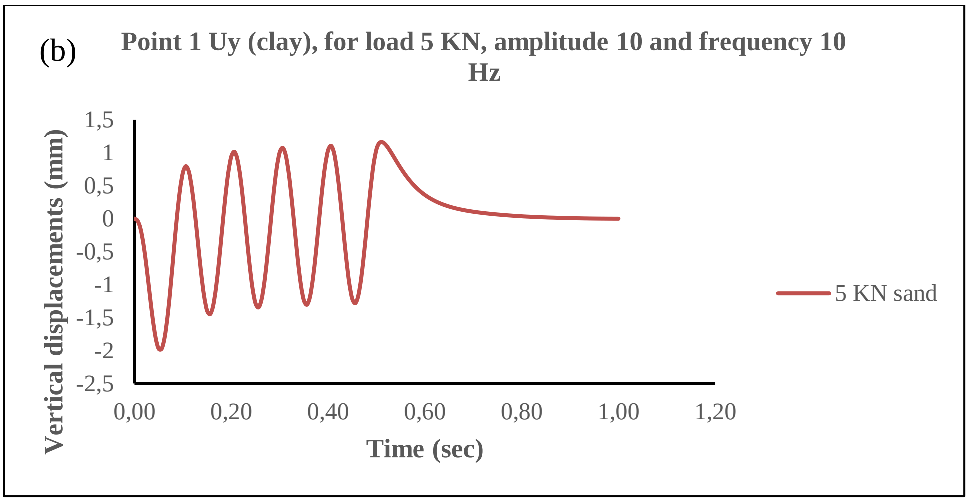

Figure 4.4: Graph (b) Vertical Displacements Uy (mm) for Clay with 5 KN Load, Amplitude 10 and Frequency 10 Hz.

The graph (b) also depicts the vertical displacement Uy over time for point 1, as previously indicated. The soil layer type here is also clay, and the applied load remains the same at 5 KN. However, the frequency has been increased to 10 Hz instead of 5 Hz for the previous graph.

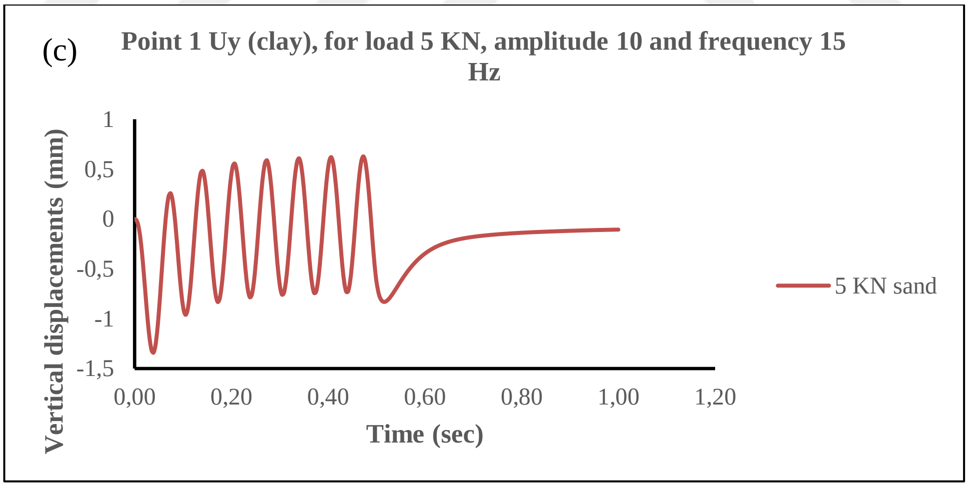

Figure 4.5: Graph (c) Vertical Displacements Uy (mm) for Clay with 5 KN Load, Amplitude 10 and Frequency 15 Hz.

Vertical displacements for graph (c) also feature a 5 KN applied load, but with a frequency of 15 Hz at point 1. The soil layer type remains clay. The curve in this graph is also not constant. The frequency of the curve is almost regular with increases and decreases like the previous graphs.

In summary, for graphs (a), (b), and (c), a constant load of 5 KN was applied to each, with a consistent amplitude of 10. However, the frequencies varied at 5 Hz, 10 Hz, and 15 Hz respectively. What distinguishes these three graphs is the vertical displacements Uy over time, which differ from one another. It is evident that when the applied load remains the same and the frequency increases each time, the vertical displacements gradually decrease. For example, with a frequency of 5 Hz, the vertical displacements reach a maximum value of approximately -3.5 mm for graph (a), while for graph (b), with a frequency of 10 Hz, the vertical displacements decrease, reaching a maximum value of -2 mm. As for graph (c), with a frequency even higher than the previous one, increasing to 15 Hz, the vertical displacements continue to decrease and drop to approximately -1.4 mm at their maximum. So, by applying a constant load on a layer of clayey soil and gradually increasing the frequency, a decrease in vertical displacements is observed.

- For load 10 KN:

For the following graphs, the applied load has been increased compared to the previous ones, but the 10 KN load will remain constant for graphs (d), (e), and (f), as will the amplitude, which is 10.

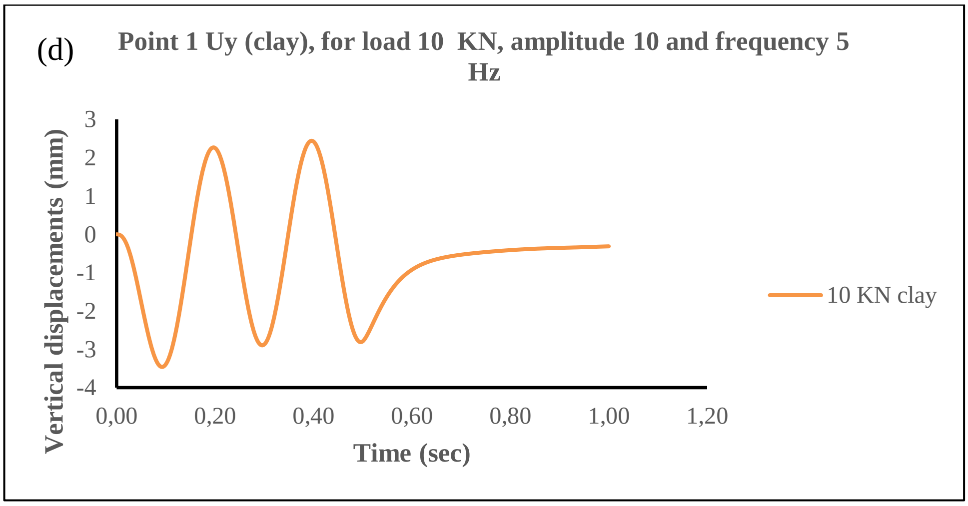

Figure 4.6: Graph (d) Vertical Displacements Uy (mm) for Clay with 10 KN Load, Amplitude 10 and Frequency 5 Hz.

The graph (d) describes the vertical displacements Uy of point 1, with an applied load of 10 KN and a frequency of 5 Hz. It is observed that this graph is identical to graph (a), indicating that the same phenomenon described in graph (a) is observed, despite the two graphs having different frequency values.

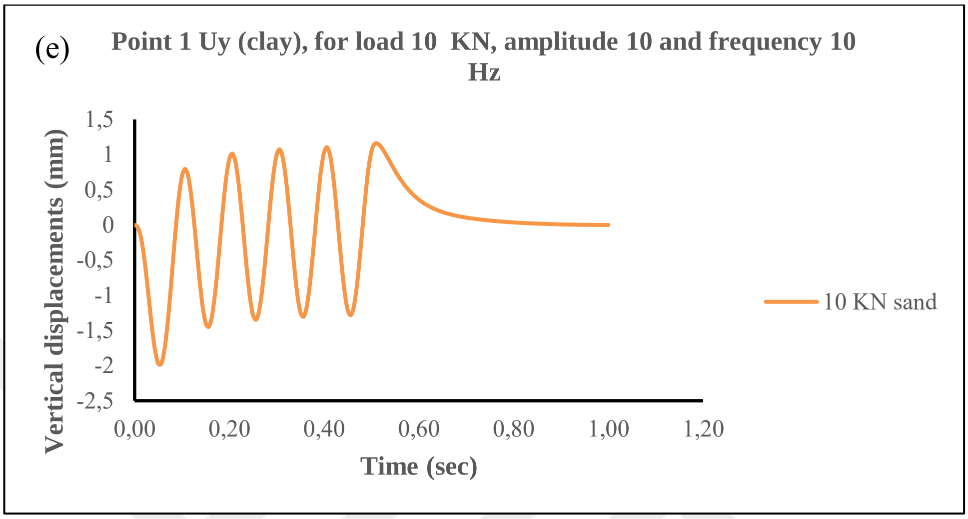

Figure 4.7: Graph (e) Vertical Displacements Uy (mm) for Clay with 10 KN Load, Amplitude 10 and Frequency 10 Hz.

The graph (e) also describes the vertical displacements Uy of point 1, with the same applied load as the previous graph, namely 10 KN, and a frequency of 10 Hz. The same phenomenon as in graph (b) is observed, despite the two graphs having different frequency values.

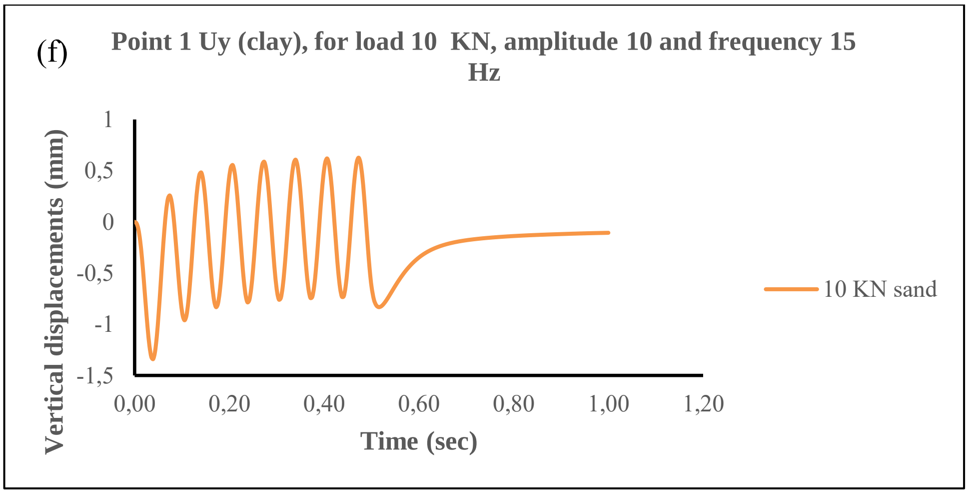

Figure 4.8: Graph (f) Vertical Displacements Uy (mm) for Clay with 10 KN Load, Amplitude 10 and Frequency 15 Hz.

At point 1, graph (f) also describes the vertical displacements Uy over time, with the same applied load as the previous graph, namely 10 KN, and a frequency of 10 Hz. The same phenomenon as in graph (c) is observed, despite the frequency values being different.

- For load 15 KN:

The following graphs, the applied load has been increased compared to the previous ones, but the 15 KN load will remain constant for graphs (g), (h), and (i), as will the amplitude, which is 10.

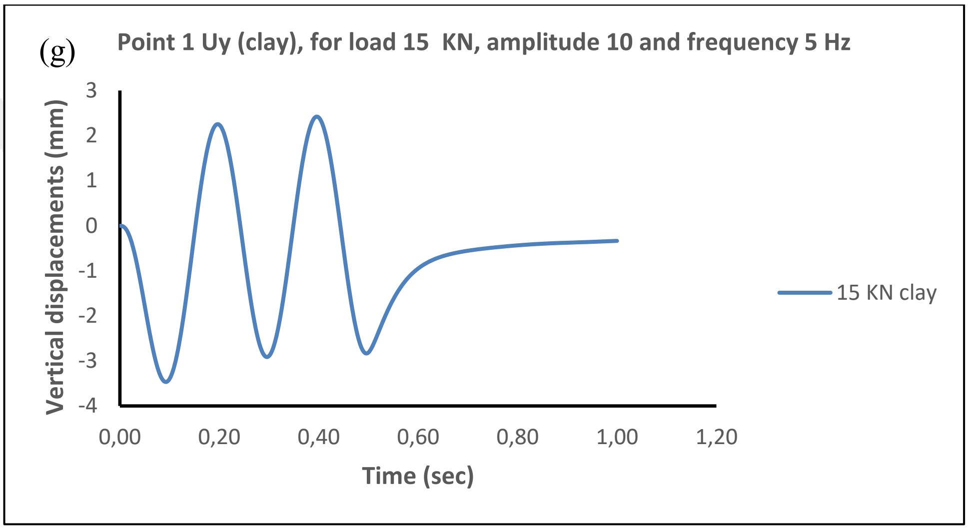

Figure 4.9: Graph (g) Vertical Displacements Uy (mm) for Clay with 15 KN Load, Amplitude 10 and Frequency 5 Hz.

The same phenomenon is observed for graph (g) as for graphs (a) and (d), despite their frequency values being different.

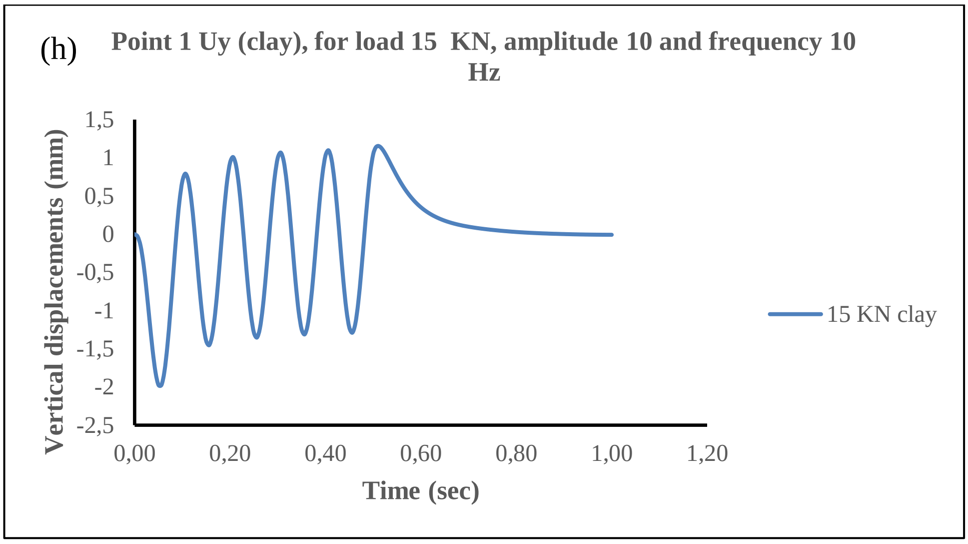

Figure 4.10: Graph (h) Vertical Displacements Uy (mm) for Clay with 15 KN Load, Amplitude 10 and Frequency 10 Hz.

Here too, we can say that the same phenomenon occurs for graph (h) as for graphs (b) and (e), despite their frequency values being different.

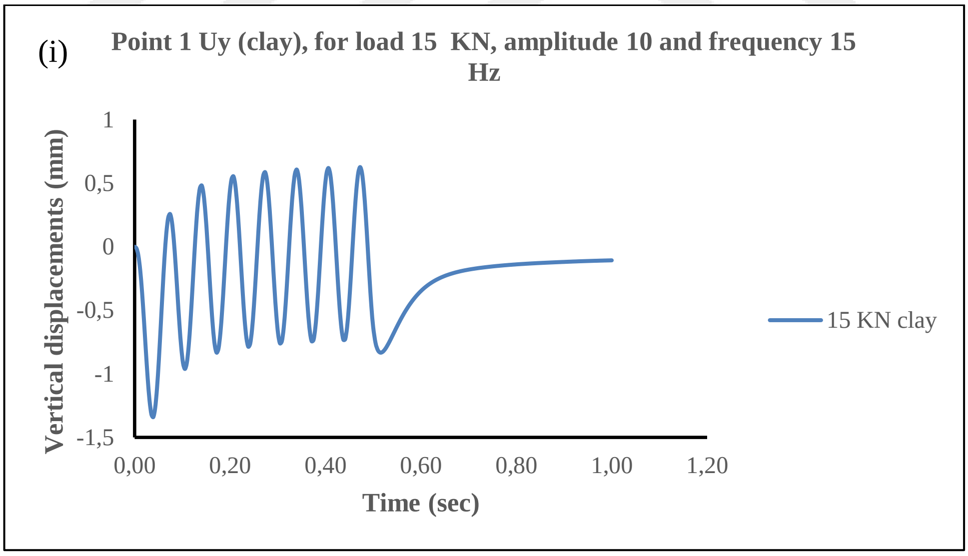

Figure 4.11: Graph (i) Vertical Displacements Uy (mm) for Clay with 15 KN Load, Amplitude 10 and Frequency 15 Hz.

It is noticeable that graph (i) is similar to graphs (c) and (f), indicating that the same phenomenon is observed for all three despite their different frequency values.

4.3.2 Comparison of results for the settlements graphs for clay

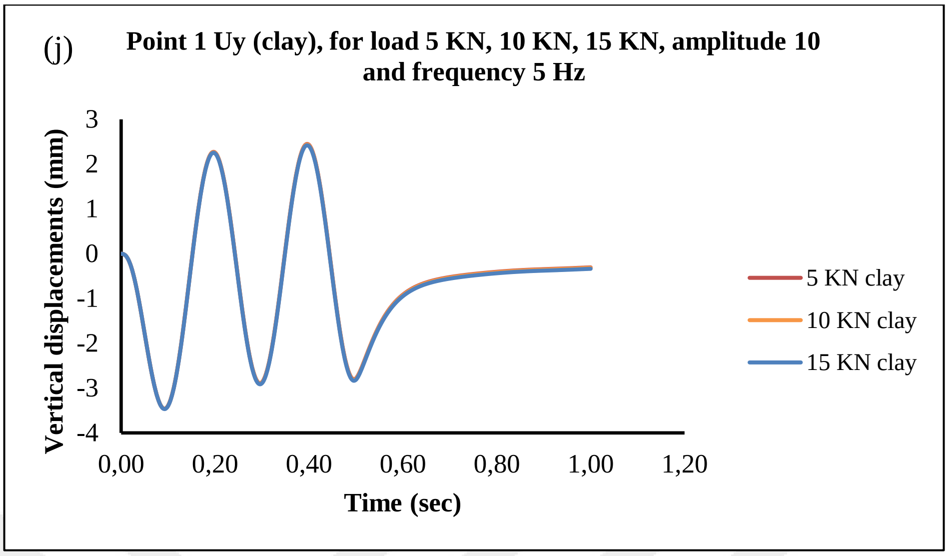

Figure 4.12: Graph (j) Vertical Displacements Uy (mm) Clay, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 5 Hz.

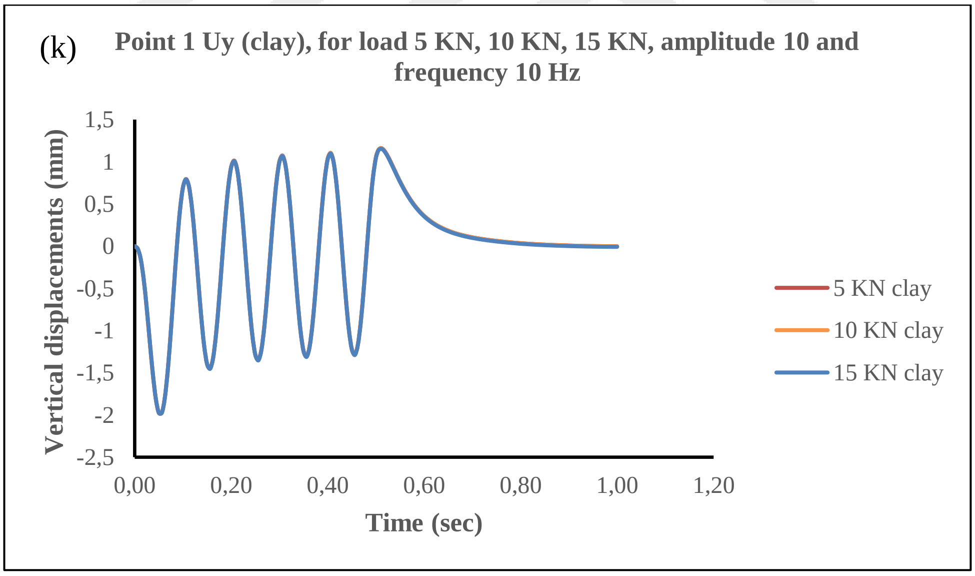

Figure 4.13: Graph (k) Vertical Displacements Uy (mm) clay, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 10 Hz.

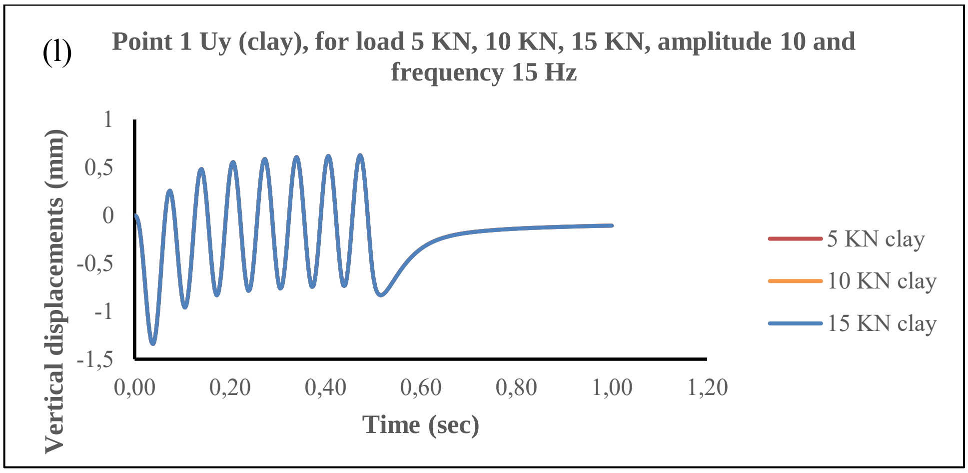

Figure 4.14: Graph (l) Vertical Displacements Uy (mm) Clay, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 15 Hz.

For graphs (j), (k), and (l), we have vertical displacements at point 1 for each of these graphs. Three types of loads (5 KN, 10 KN, 15 KN) are applied to each, with the same amplitude value of 10. However, the differences lie in the frequency values. Graph (j) has a frequency of 5 Hz, graph (k) has 10 Hz, and graph (l) has 15 Hz. It is noticeable that the graphs differ based on the frequency types, but the loads applied in these graphs have no effect on the results. Therefore, it can be said that increasing the loads or weights of machines does not affect the vertical displacements of a layer of clay soil.

4.3.3 Settlements Graphs for Sand

- For load 5 KN:

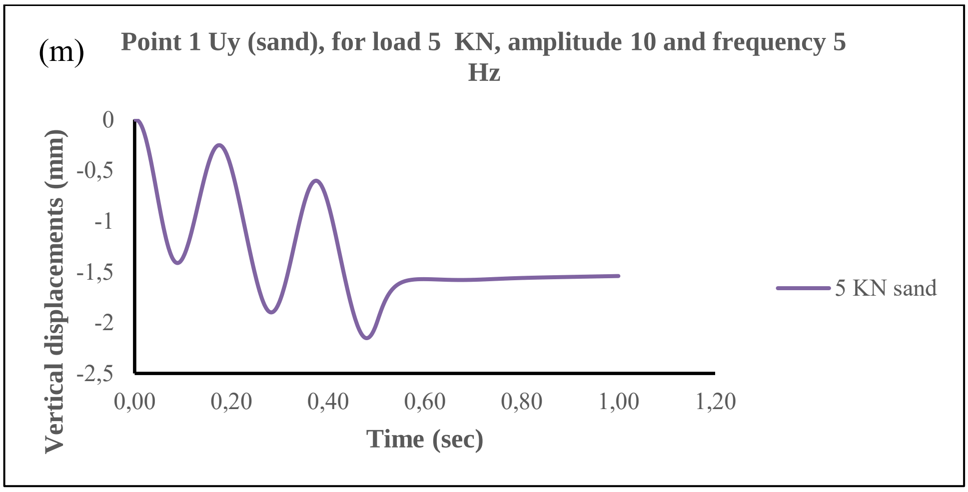

Figure 4.15: Graph (m) Vertical Displacements Uy (mm) for Sand with 5 KN Load, Amplitude 10 and Frequency 5 Hz.

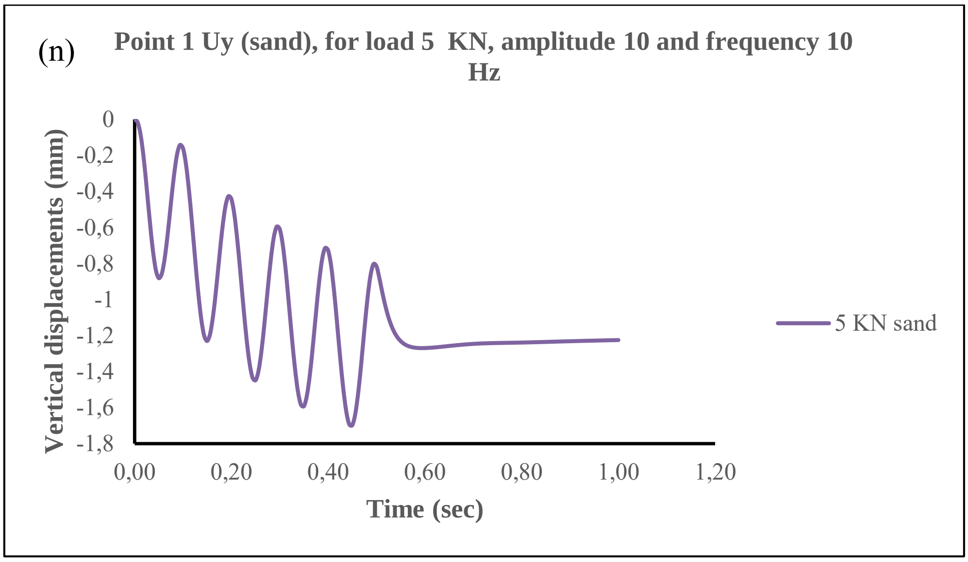

Figure 4.16: Graph (n) Vertical Displacements Uy (mm) for Sand with 5 KN Load, Amplitude 10 and Frequency 10 Hz.

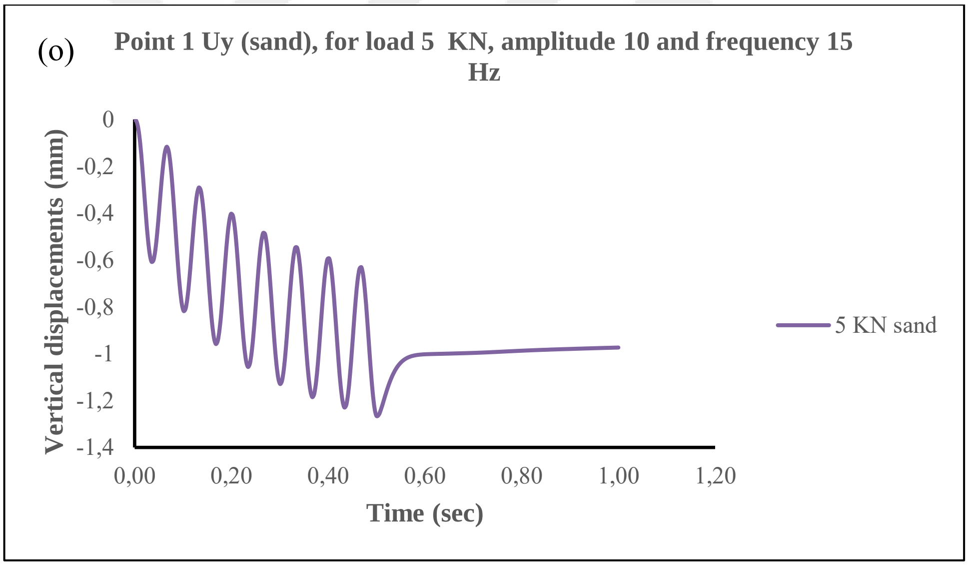

Figure 4.17: Graph (o) Vertical Displacements Uy (mm) for Sand with 5 KN Load, Amplitude 10 and Frequency 15 Hz.

- for load 10 KN:

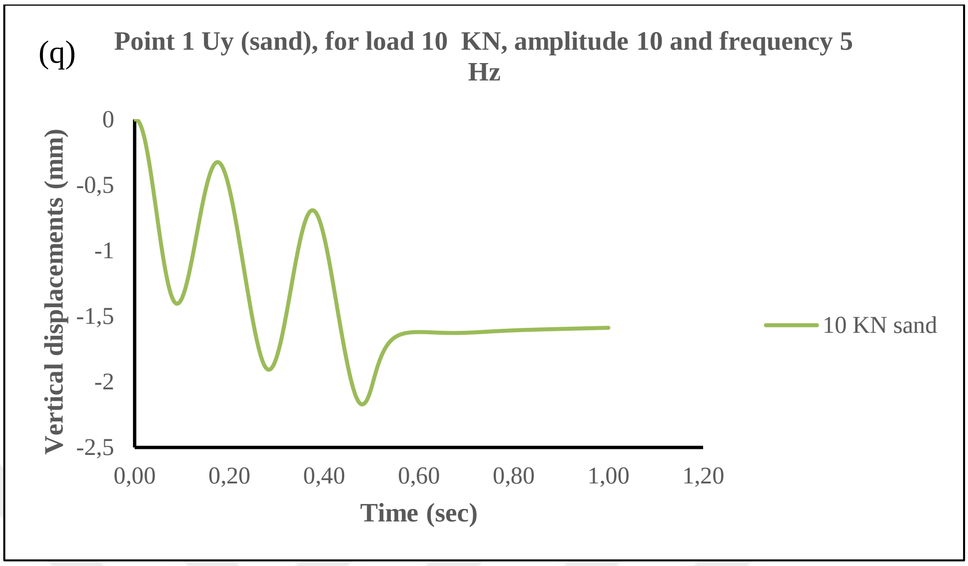

Figure 4.18: Graph (q) Vertical Displacements Uy (mm) for Sand with 15 KN Load, Amplitude 10 and Frequency 5 Hz.

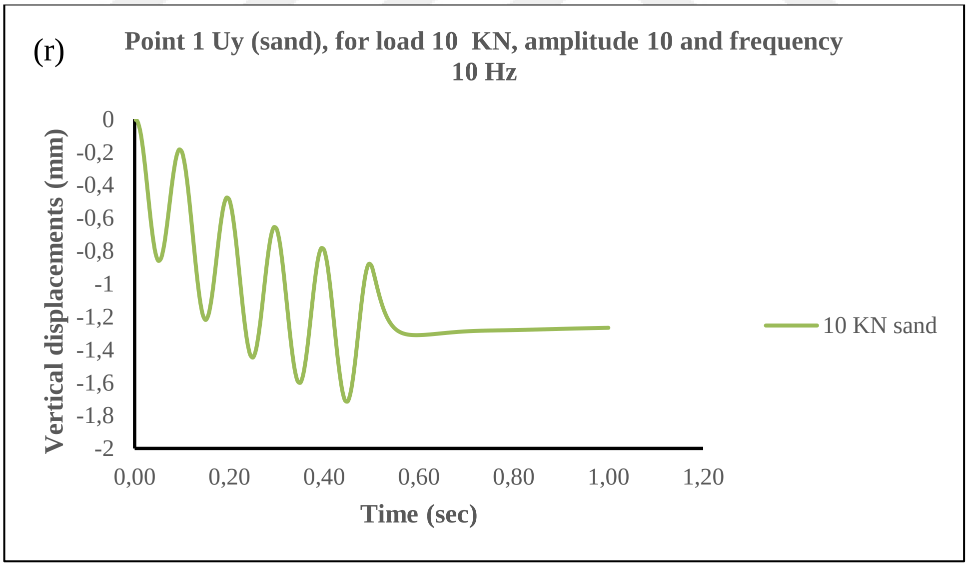

Figure 4.19: Graph (r) Vertical Displacements Uy (mm) for Sand with 10 KN Load, Amplitude 10 and Frequency 10 Hz.

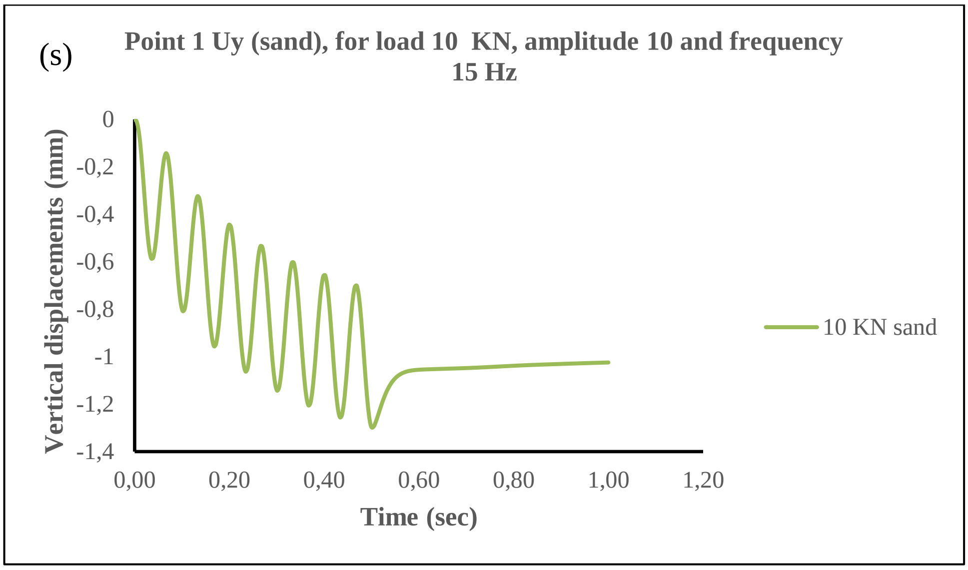

Figure 4.20: Graph (s) Vertical Displacements Uy (mm) for Sand with 10 KN Load, Amplitude 10 and Frequency 15Hz.

- for load 15 KN:

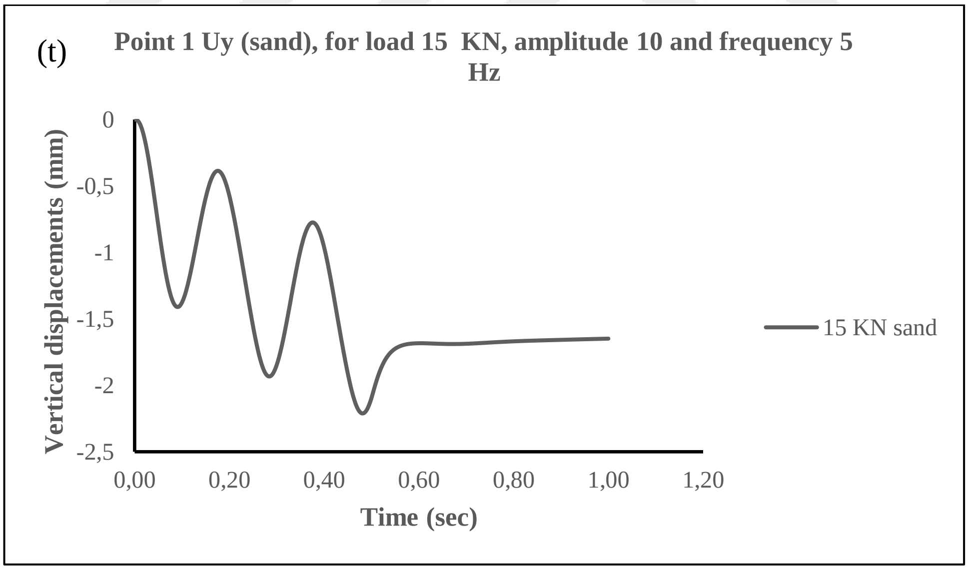

Figure 4.21: Graph (t) Vertical Displacements Uy (mm) for sand with 15 KN Load, Amplitude 10 and Frequency 5 Hz.

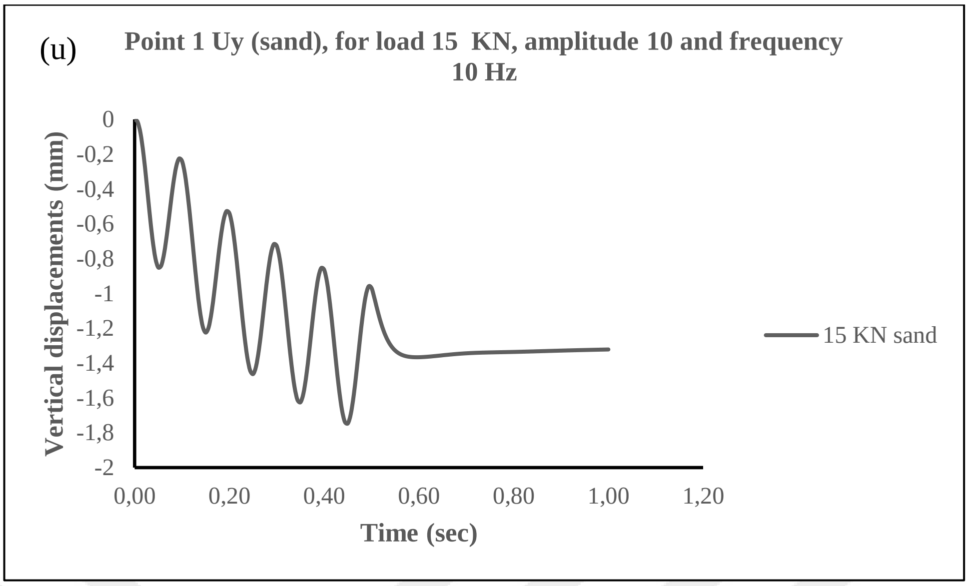

Figure 4.22: Graph (u) Vertical Displacements Uy (mm) for Sand with 15 KN Load, Amplitude 10 and Frequency 10 Hz.

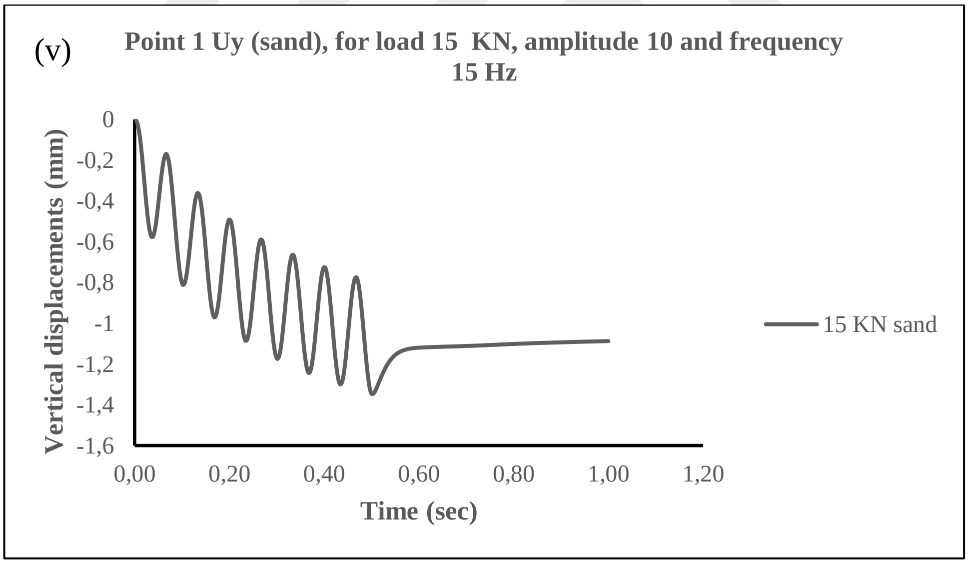

Figure 4.23: Graph (v) Vertical Displacements Uy (mm) for Sand with 15 KN Load, Amplitude 10 and Frequency 15 Hz.

In these various graphs for sand, where the applied load is 5 KN, with an amplitude of 10 and varying frequencies of 5 Hz, 10 Hz, and 15 Hz. The curves show more decrease than increase, unlike the curves for the clay graphs. It is also observed that all vertical displacements are negative, despite varying frequencies, and as the frequency increases, the vertical displacements decrease.

4.3.4 Comparison of Results for the Settlements Graphs for Sand

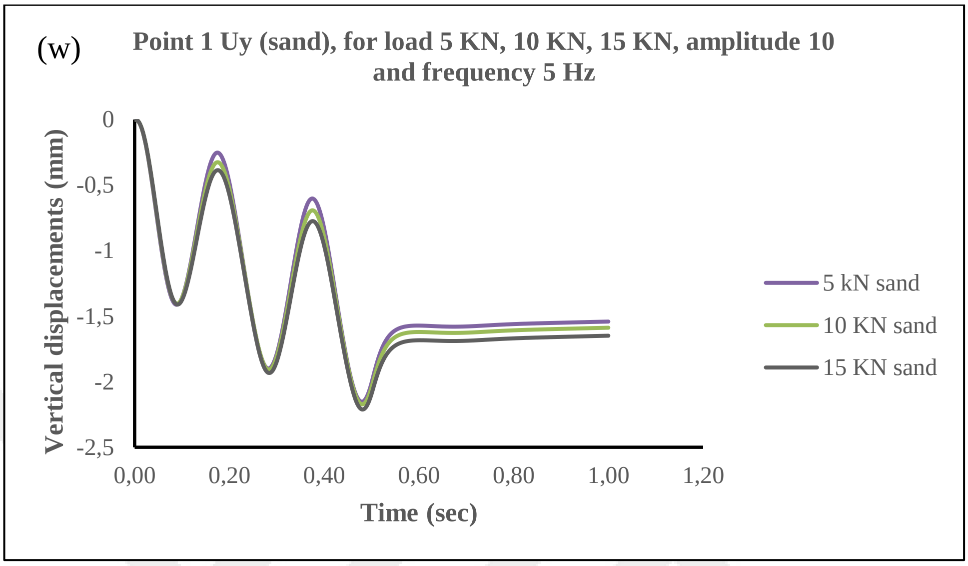

Figure 4.24: Graph (w) Vertical Displacements Uy (mm) Sand, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 5 Hz.

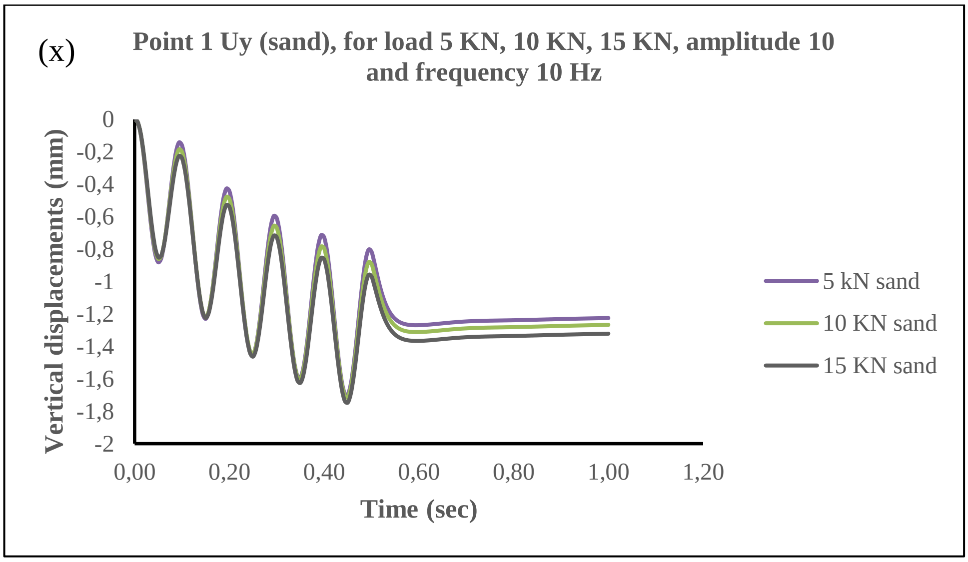

Figure 4.25: Graph (x) Vertical Displacements Uy (mm) Sand, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 10 Hz.

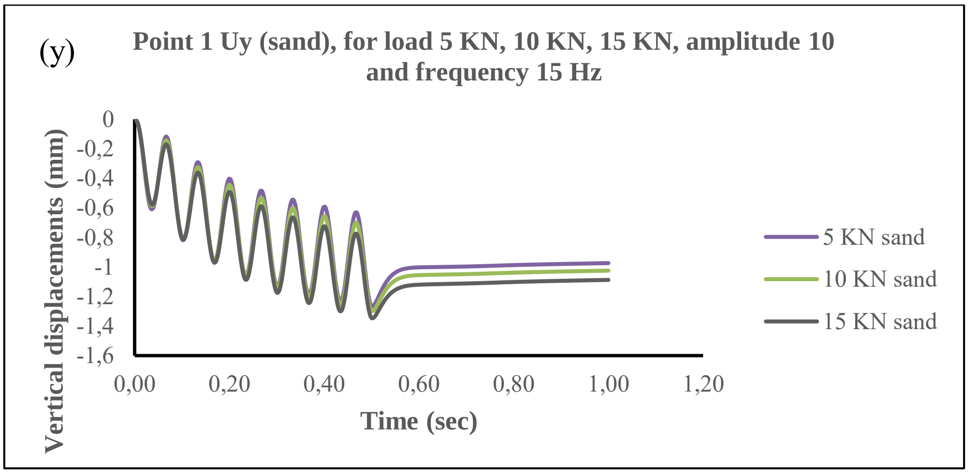

Figure 4.26: Graph (y) Vertical Displacements Uy (mm) Sand, for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 15 Hz.

Through the previous graphs (w), (x), (y), it can be observed that the vertical displacements over time differ for each based on the applied loads. As the loads increase, the vertical displacements also increase. However, differences in frequencies do not affect the results of the graphs.

In conclusion, applying a load or increasing the weight of machines increases the vertical displacements of a layer of sand soil.

4.3.5 Comparison of Results for the Settlements Graphs for Clay and Sand

- Settlements graphs for 5 KN load:

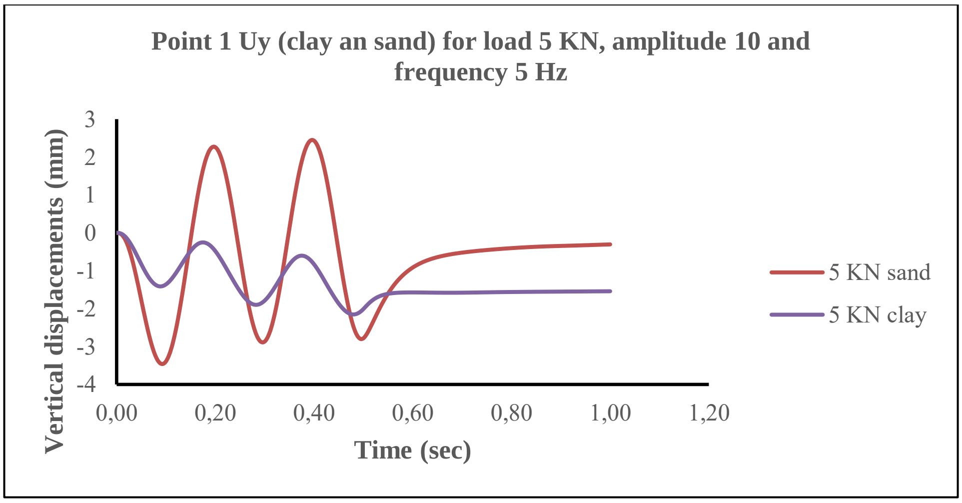

Figure 4.27: Uy (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 5 Hz.

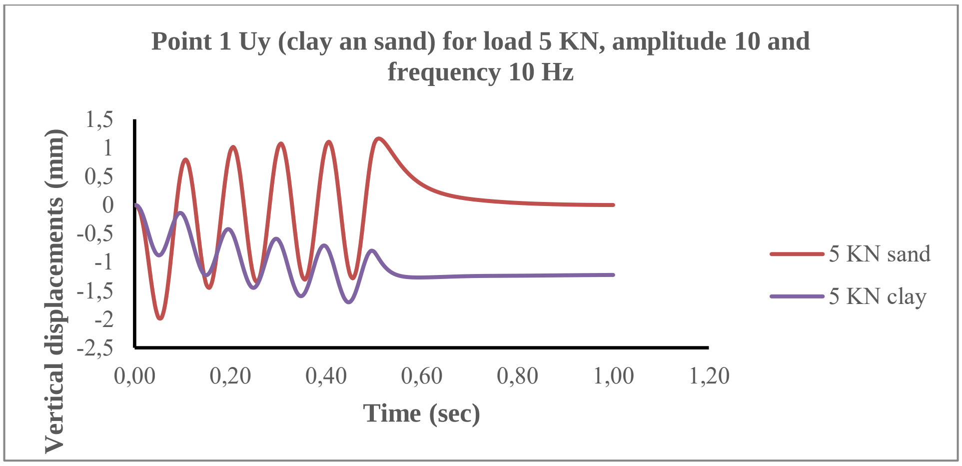

Figure 4.28: Uy (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 10 Hz.

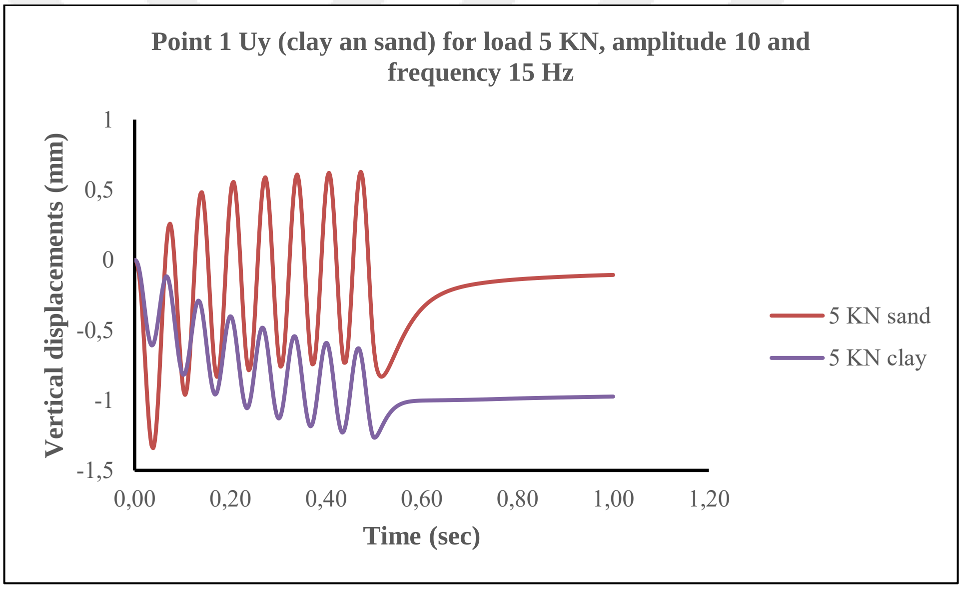

Figure 4.29: Uy (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 15 Hz.

- Settlements graphs for 10 KN load:

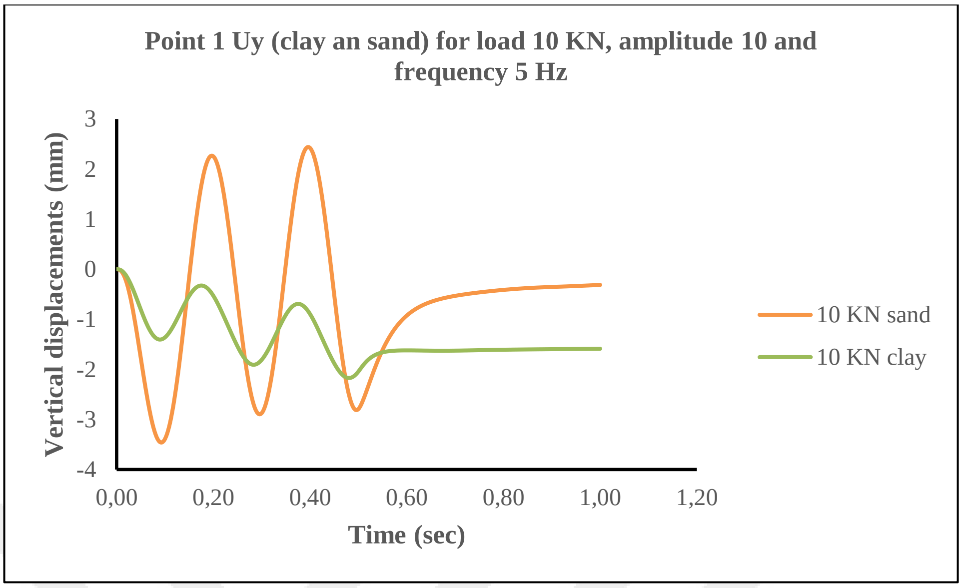

Figure 4.30: Uy (clay and sand) for Load 10 KN, Amplitude 10 and Frequency 5 Hz.

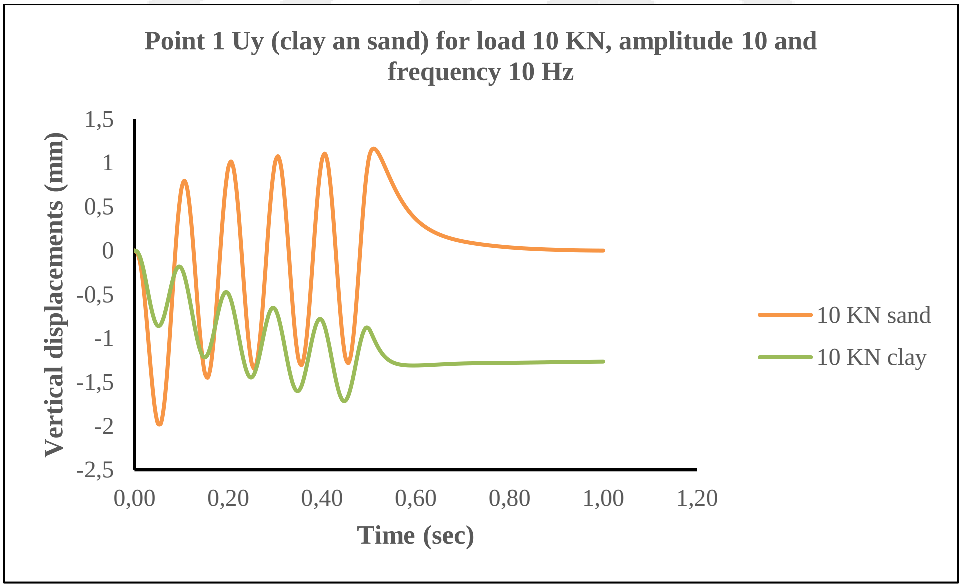

Figure 4.31: Uy (clay and sand) for Load 10 KN, Amplitude 10 and Frequency 10 Hz.

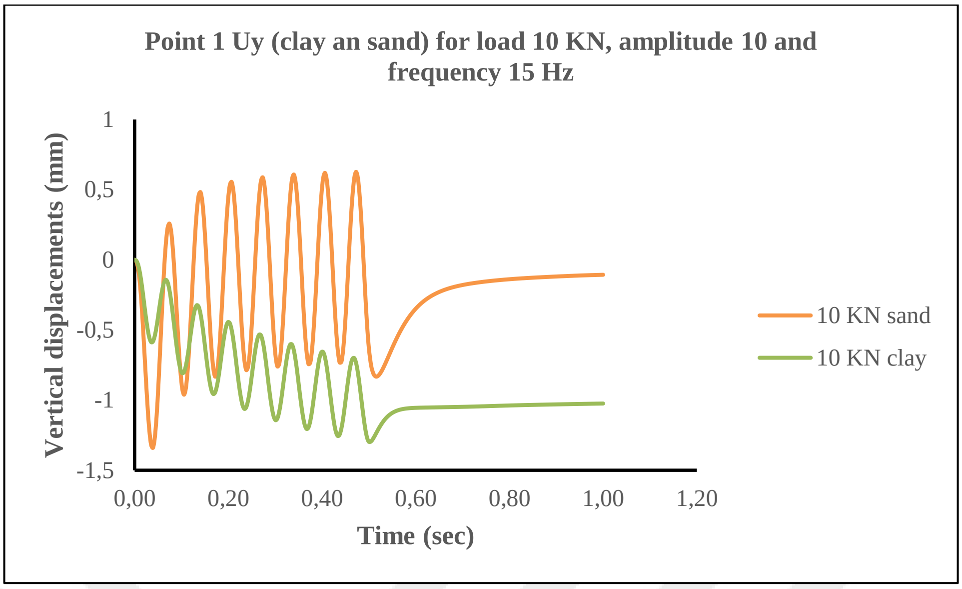

Figure 4.32: Uy (clay and sand) for Load 10 KN, Amplitude 10 and Frequency 15 Hz.

- Settlements graphs for 15 KN load:

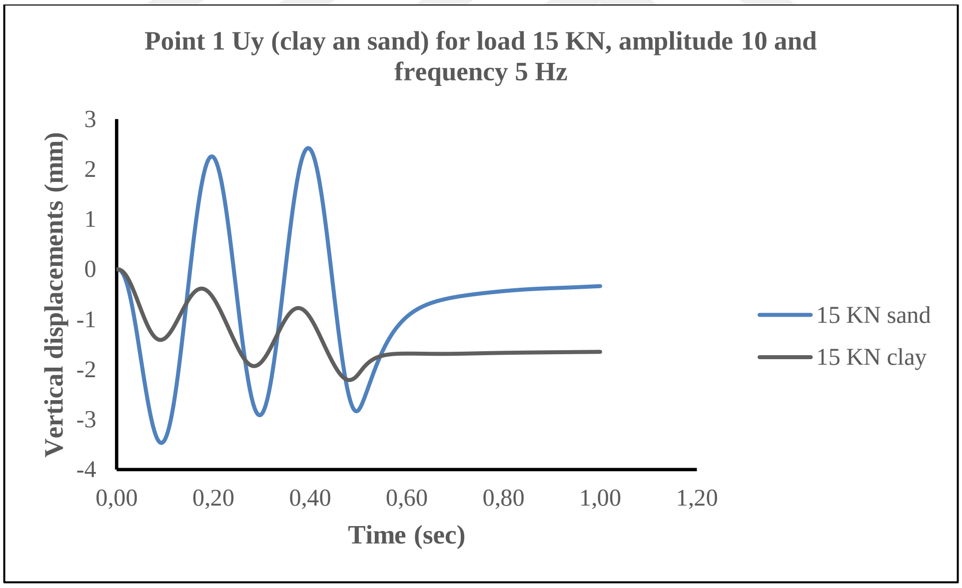

Figure 4.33: Uy (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 5 Hz.

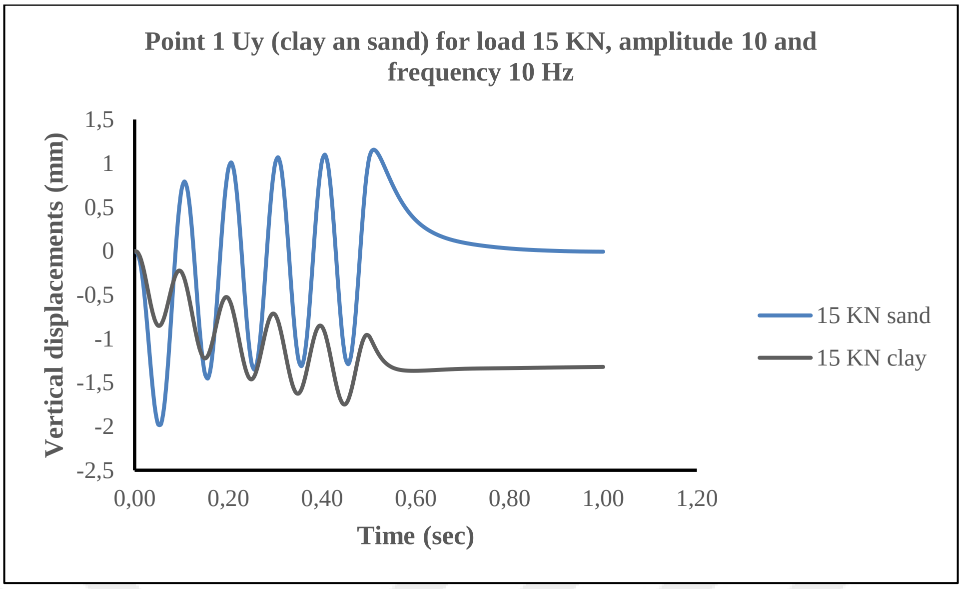

Figure 4.34: Uy (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 10 Hz.

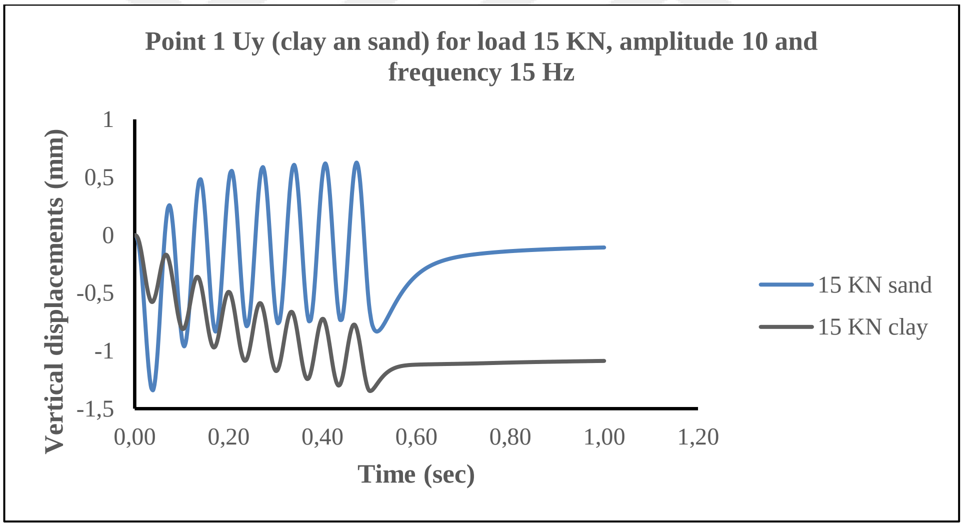

Figure 4.35: Uy (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 15 Hz.

In the previous graphs, it is noticeable that the vertical displacements on a layer of sand soil are greater than on a layer of clay soil. In summary, it can be said that sand promotes vertical displacements more than clay, which provides greater stability. According to the graphs sand shows higher settlement because its permeability is higher, also clay has plasticity that prevents settlement.

4.3.6 Horizontal Accelerations Graphs for Clay

- For load 5 KN:

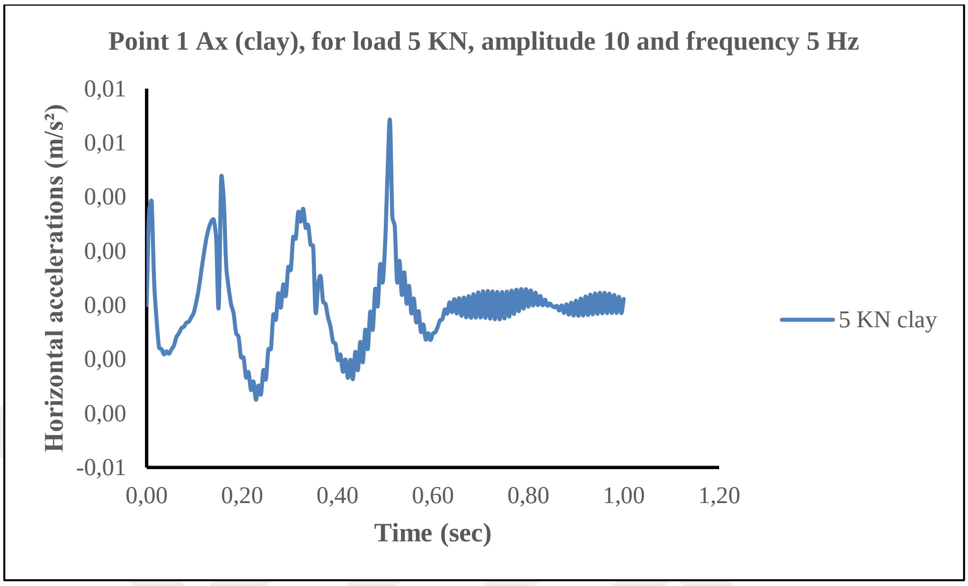

Figure 4.36: Ax (clay) for 5 KN, Amplitude 10 and Frequency 5 Hz.

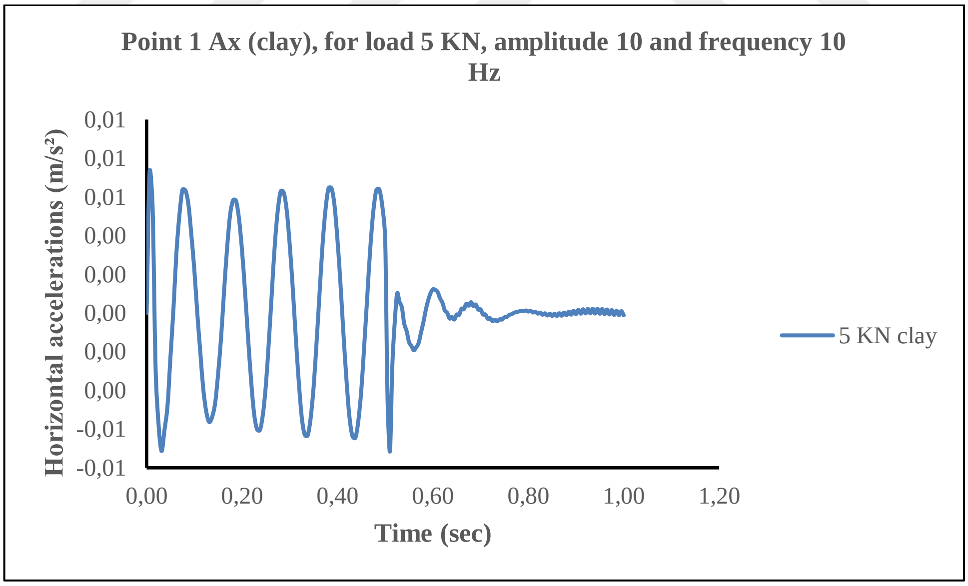

Figure 4.37: Ax (clay) for 5 KN, Amplitude 10 and Frequency 10 Hz.

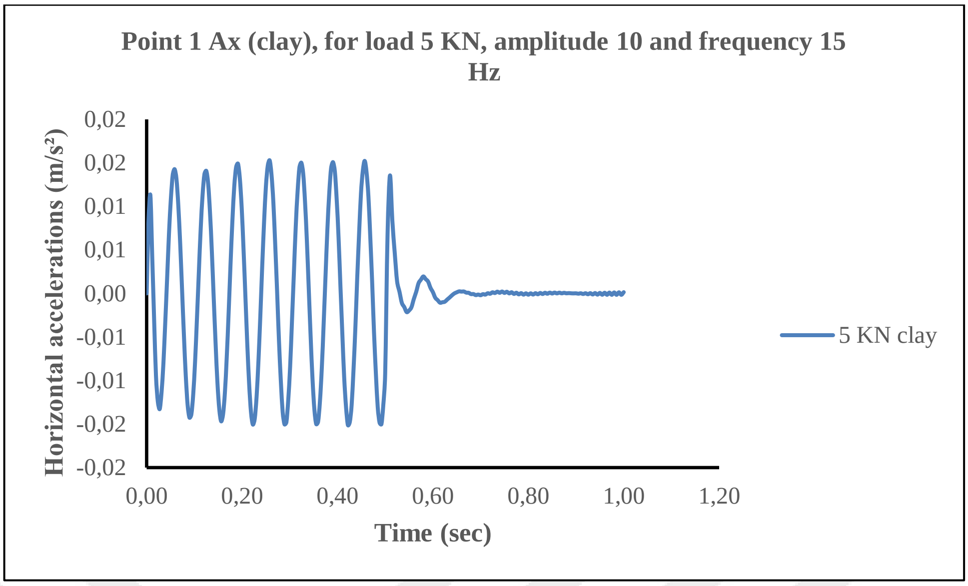

Figure 4.38: Ax (clay) for 5 KN, Amplitude 10 and Frequency 15 Hz.

- For load 10 KN:

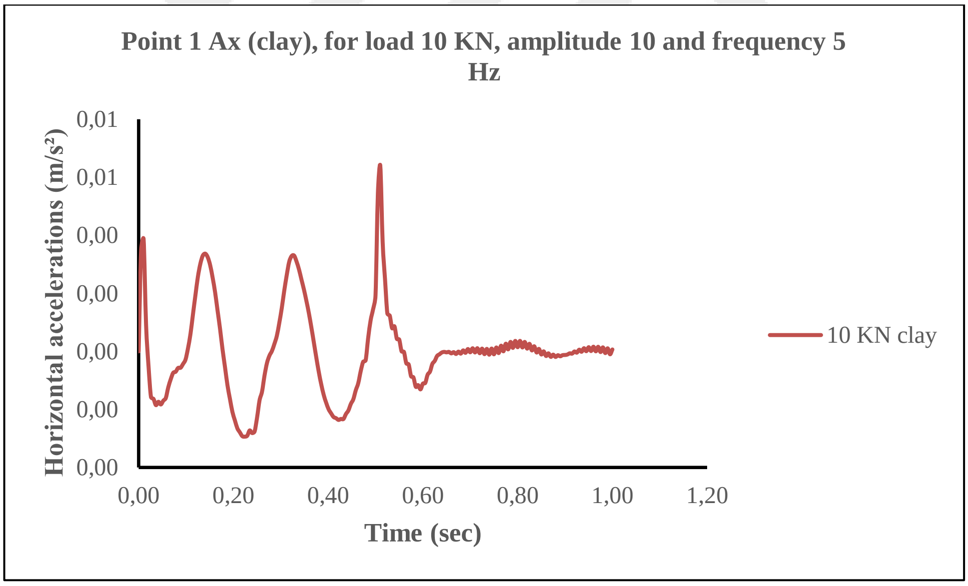

Figure 4.39: Ax (clay) for 10 KN, Amplitude 10 and Frequency 5 Hz.

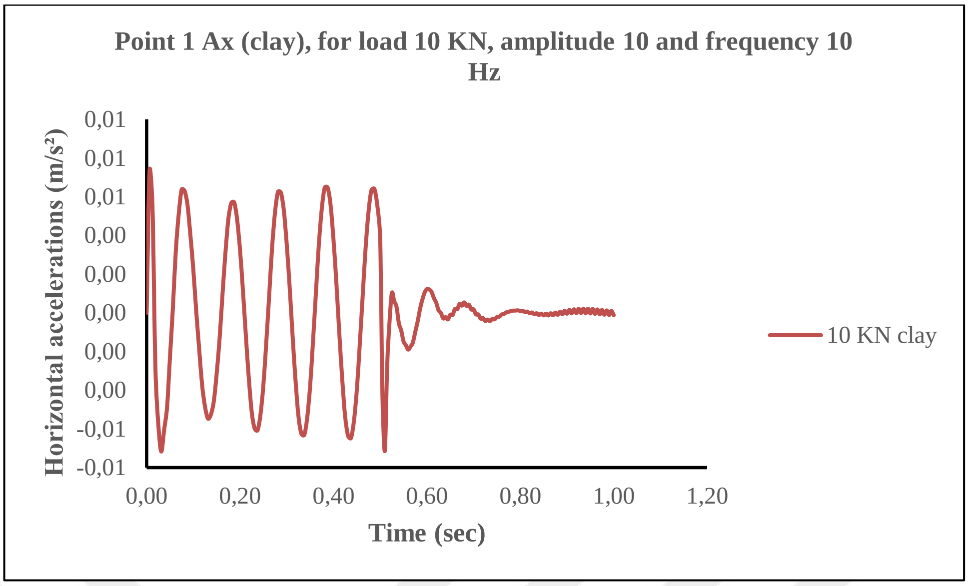

Figure 4.40: Ax (clay) for 10 KN, Amplitude 10 and Frequency 10 Hz.

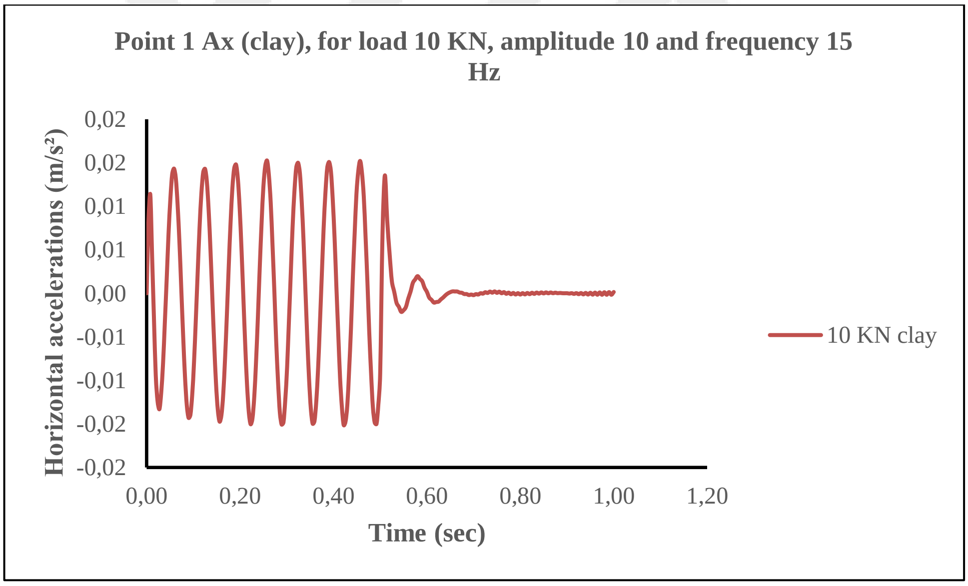

Figure 4.41: Ax (clay) for 10 KN, Amplitude 10 and Frequency 15 Hz.

- For load 15 KN:

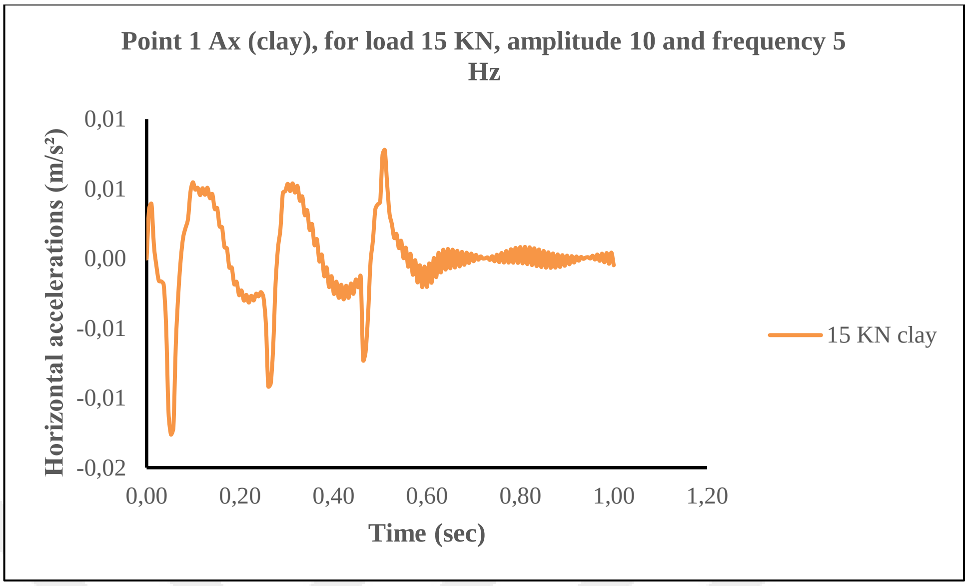

Figure 4.42: Ax (clay) for 15 KN, Amplitude 10 and Frequency 5 Hz.

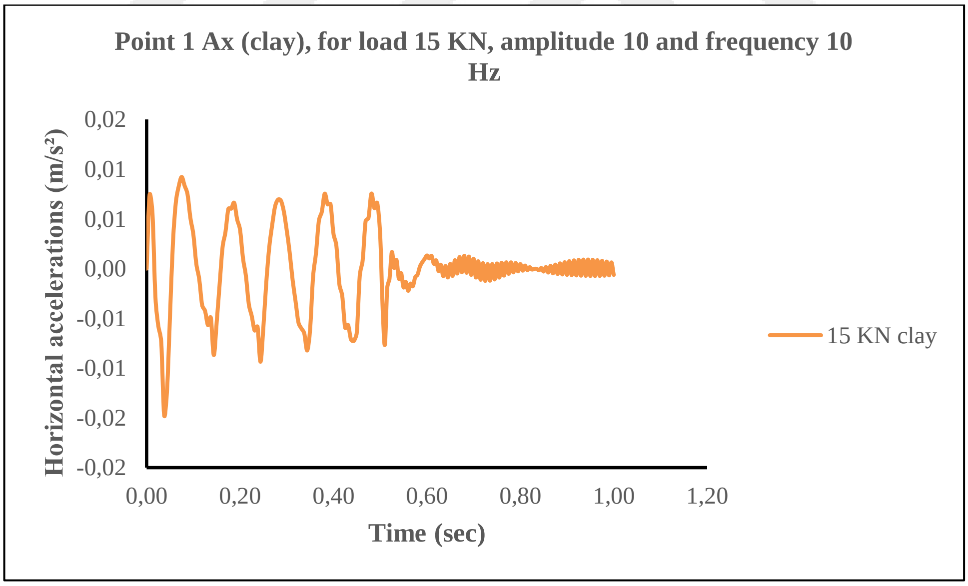

Figure 4.43: Ax (clay) for 15 KN, Amplitude 10 and Frequency 10 Hz.

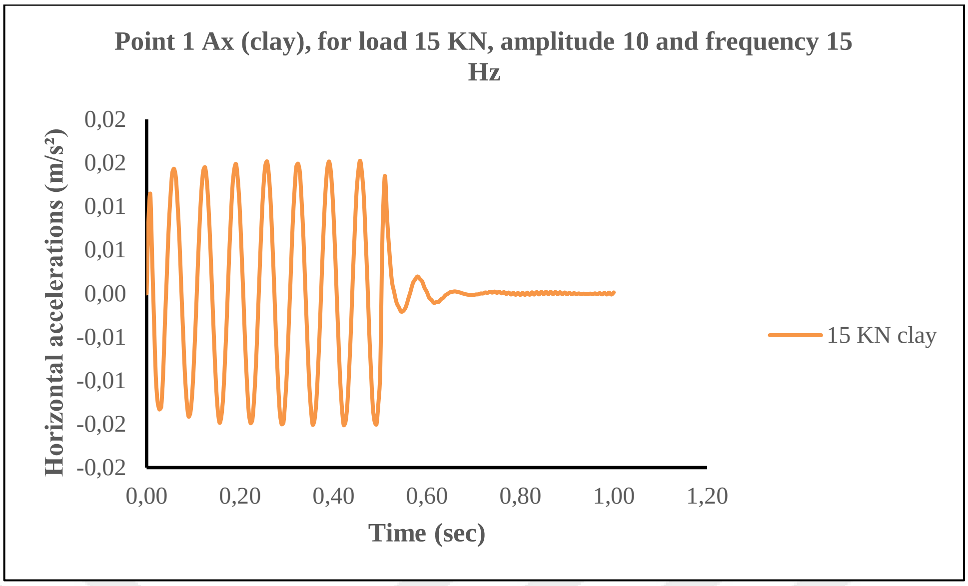

Figure 4.44: Ax (clay) for 15 KN, Amplitude 10 and Frequency 15 Hz.

4.3.7 Comparison of Results for the Horizontal Accelerations Graphs for Clay

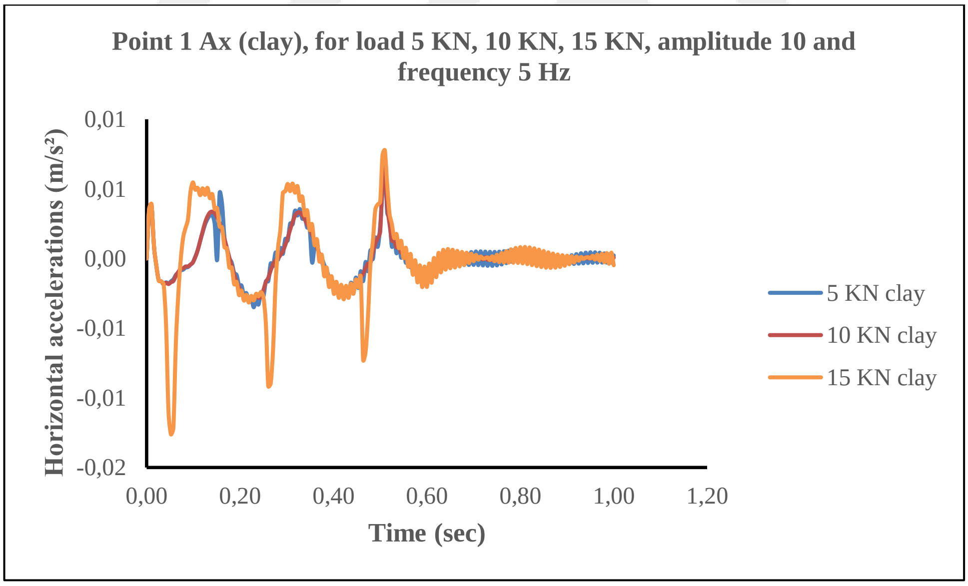

Figure 4.45: Ax (clay), for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 5 Hz.

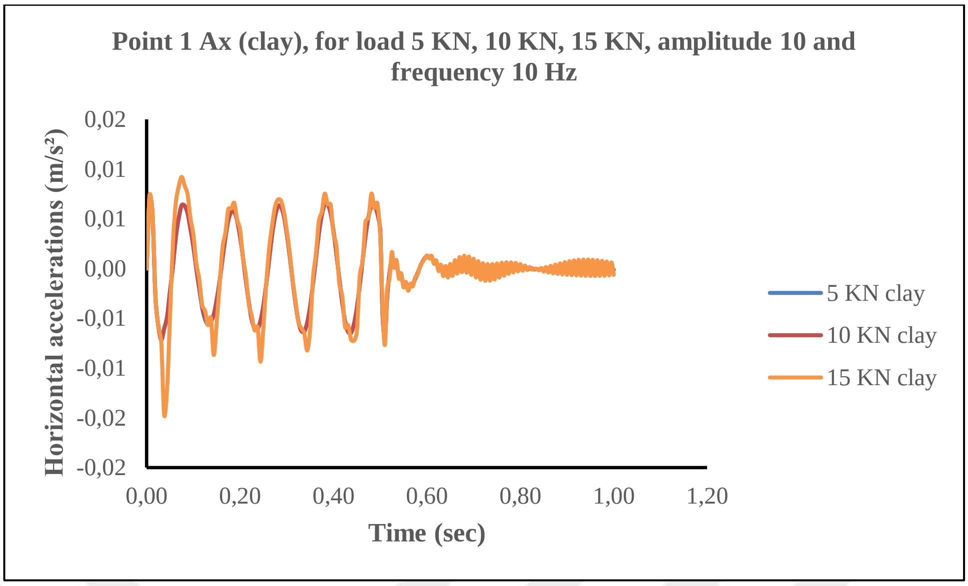

Figure 4.46: Ax (clay), for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 10 Hz.

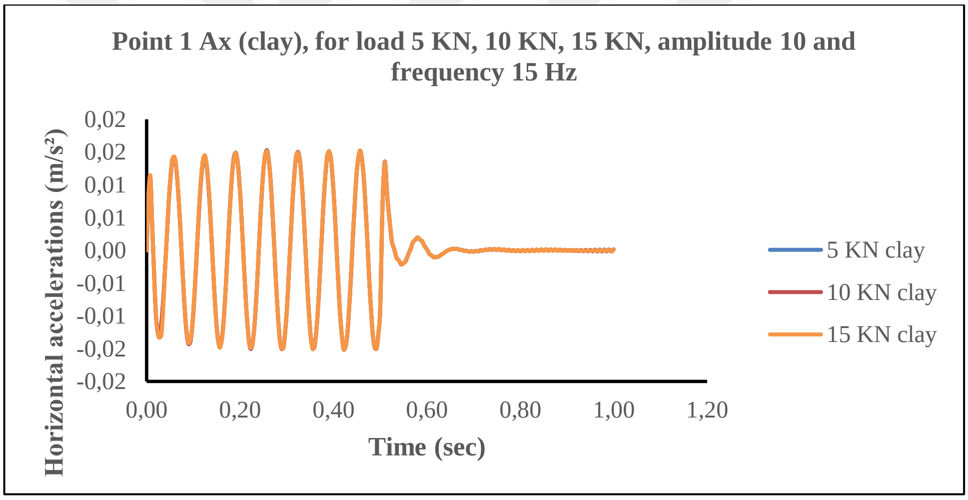

Figure 4.47: Ax (clay), for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 15 Hz.

Throughout all these graphs, we observe the same findings for vertical displacements as for horizontal accelerations. we have horizontal accelerations at point 1 for each of these graphs. Three types of loads (5 KN, 10 KN, 15 KN) are applied to each, with the same amplitude value of 10. However, the differences lie in the frequency values. It is noticeable that the graphs differ based on the frequency types, but the loads applied in these graphs have no effect on the results. Therefore, it can be said that increasing the loads or weights of machines does not affect also the Horizontal accelerations of a layer of clay soil.

4.3.8 Horizontal Accelerations Graphs for Sand

- For load 5 KN:

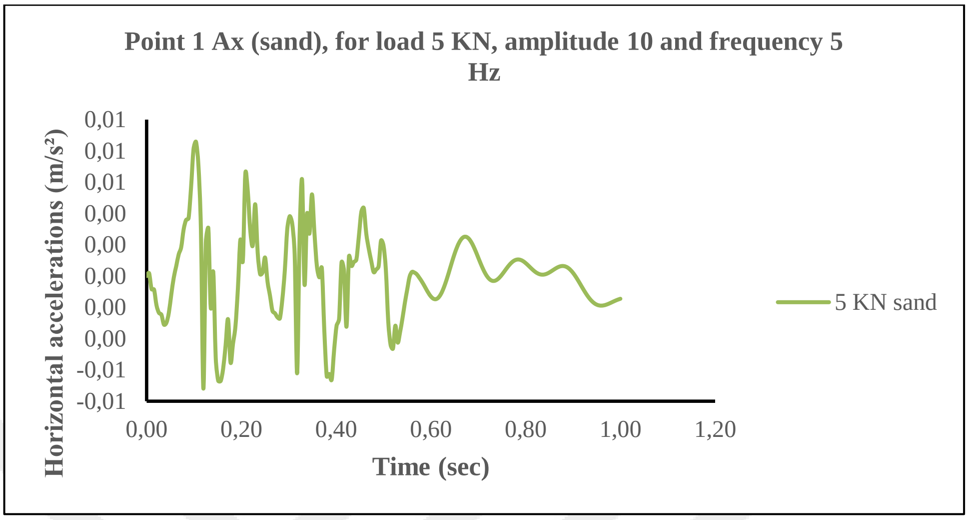

Figure 4.48: Ax (sand) for 5 KN, Amplitude 10 and Frequency 5 Hz.

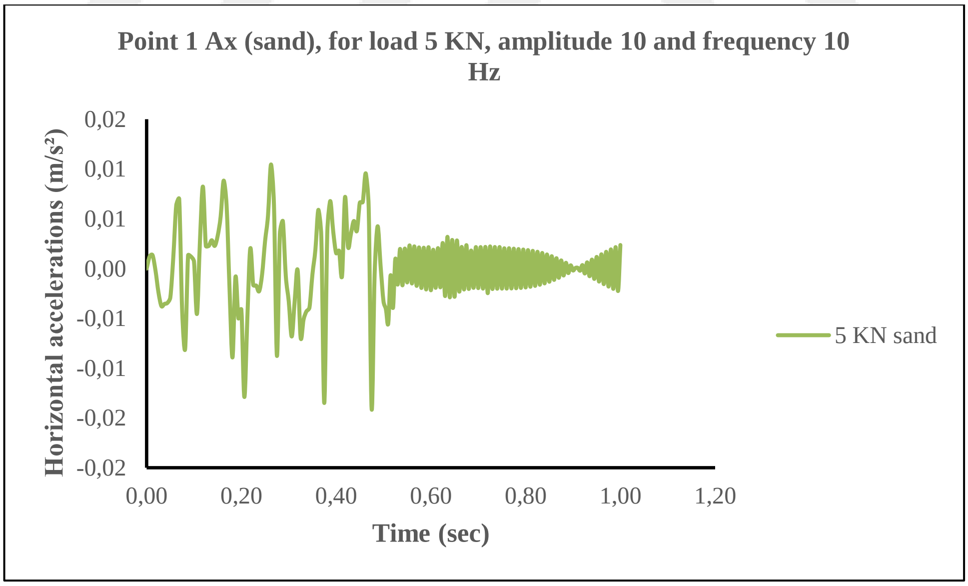

Figure 4.49: Ax (sand) for 5 KN, Amplitude 10 and Frequency 10 Hz.

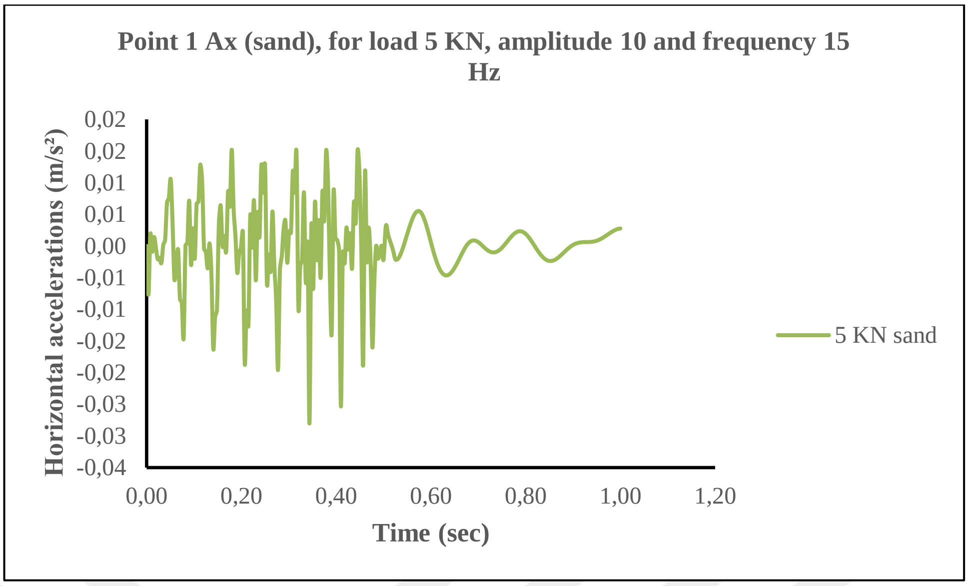

Figure 4.50: Ax (sand) for 5 KN, Amplitude 10 and Frequency 15 Hz.

- For load 10 KN:

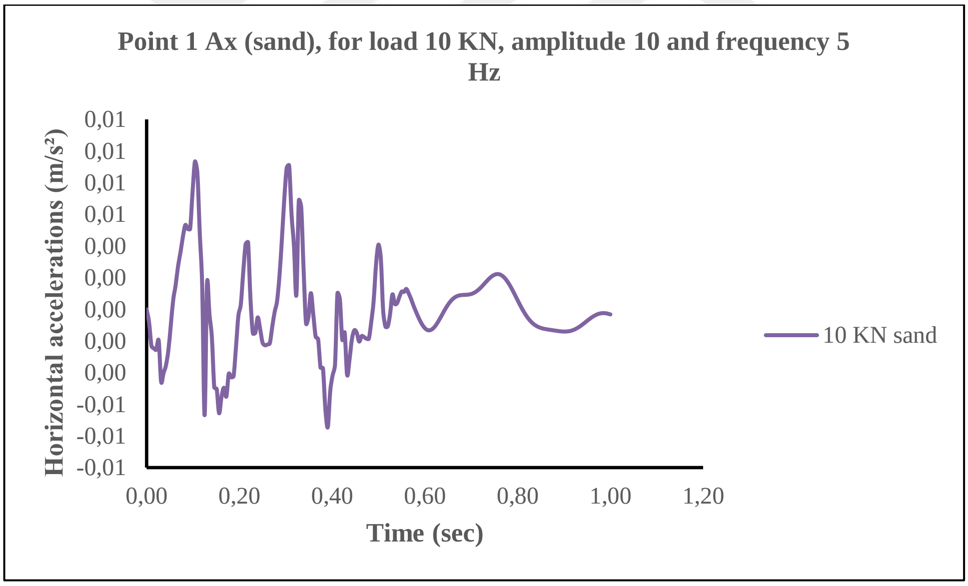

Figure 4.51: Ax (sand) for 10 KN, Amplitude 10 and Frequency 5 Hz.

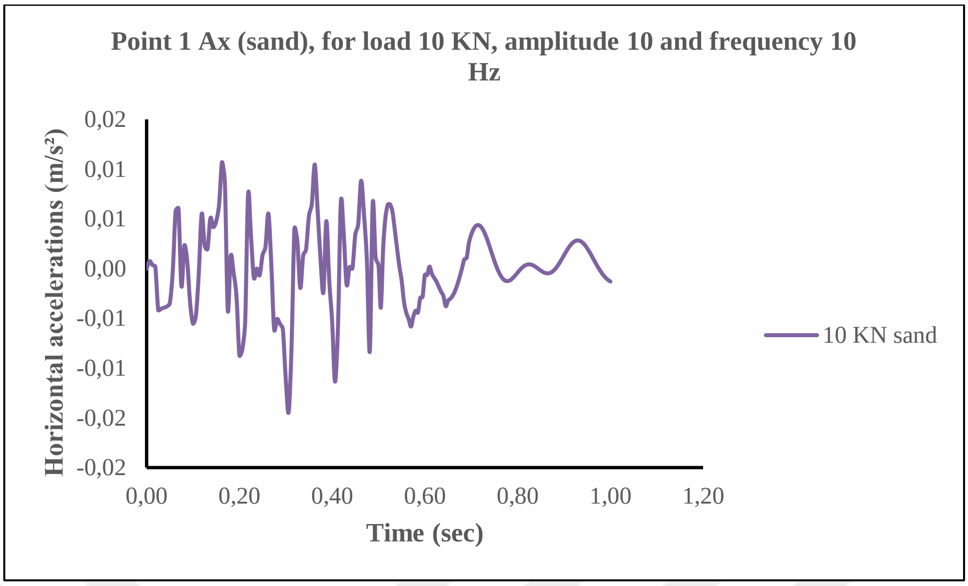

Figure 4.52: Ax (sand) for 10 KN, Amplitude 10 and Frequency 10 Hz.

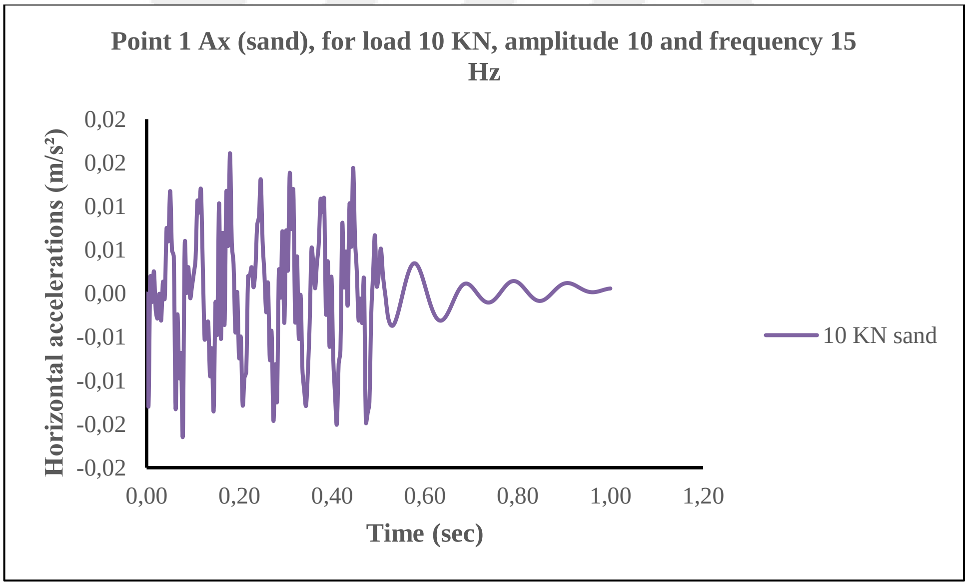

Figure 4.53: Ax (sand) for 10 KN, Amplitude 10 and Frequency 5 Hz.

- For load 15 KN:

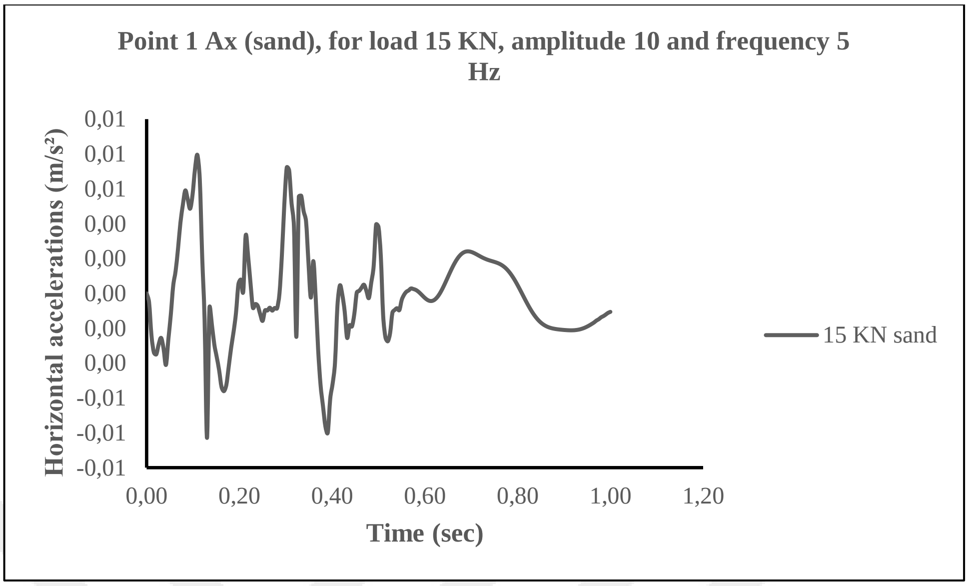

Figure 4.54: Ax (sand) for 15 KN, Amplitude 10 and Frequency 5 Hz.

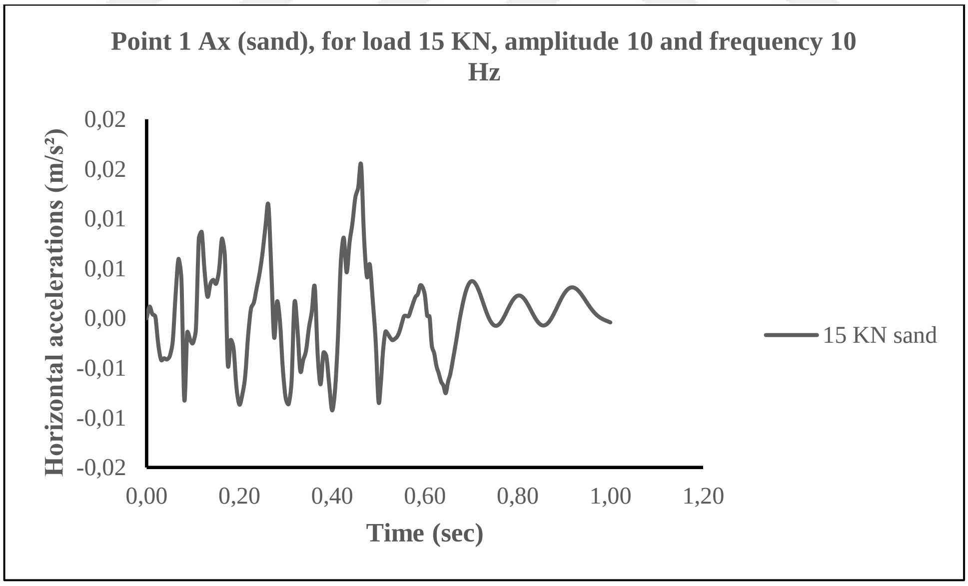

Figure 4.55: Ax (sand) for 15 KN, Amplitude 10 and Frequency 10 Hz.

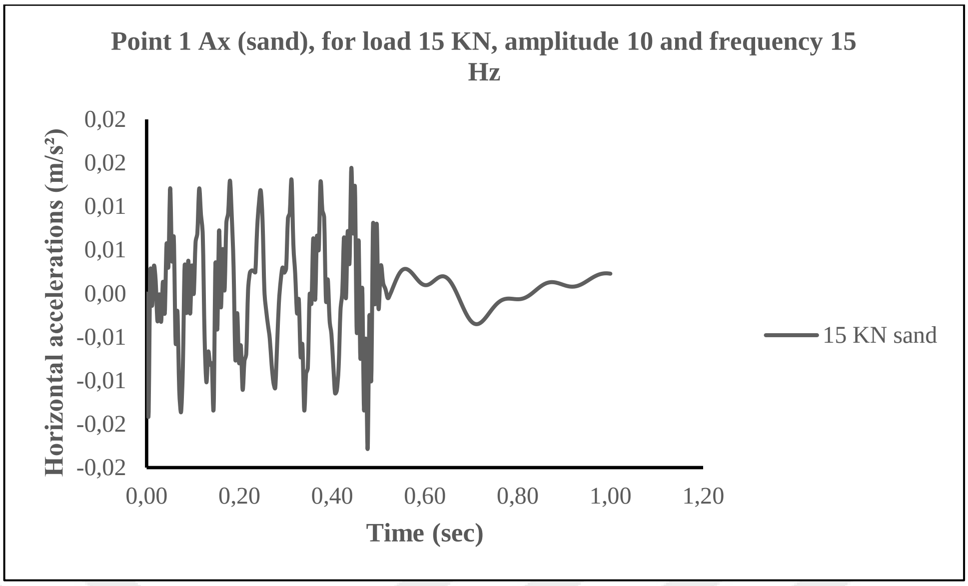

Figure 4.56: Ax (sand) for 15 KN, Amplitude 10 and Frequency 15 Hz.

Throughout all these graphs, we observe different results for vertical displacements and horizontal accelerations.

4.3.9 Comparison of Results for the Horizontal Accelerations Graphs for Sand

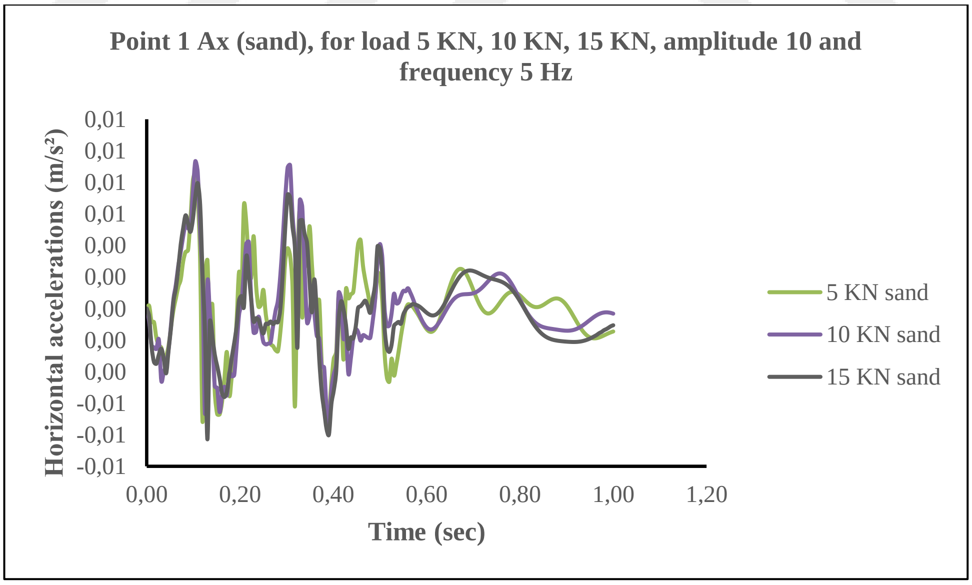

Figure 4.57: Ax (sand), for load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 5 Hz.

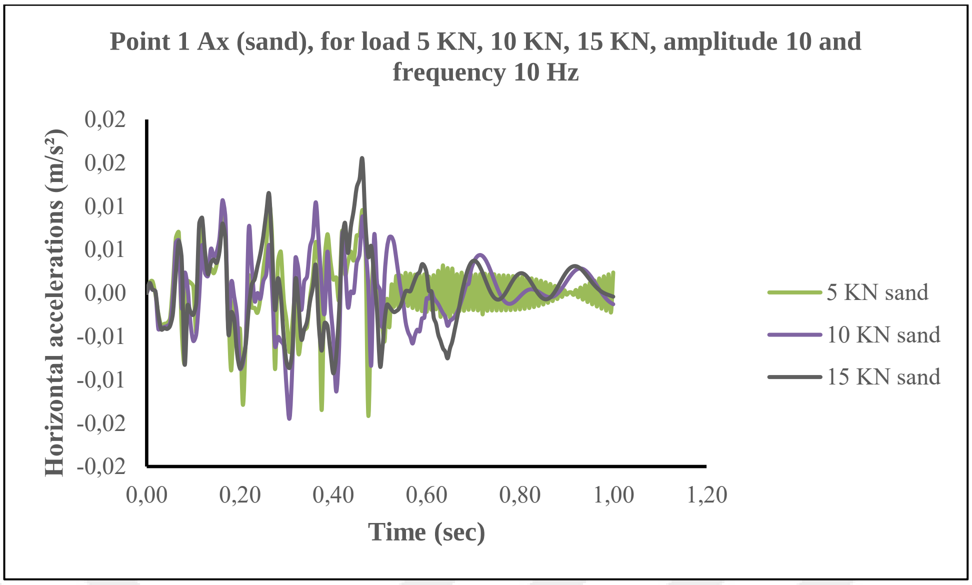

Figure 4.58: Ax (sand), for load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 10 Hz.

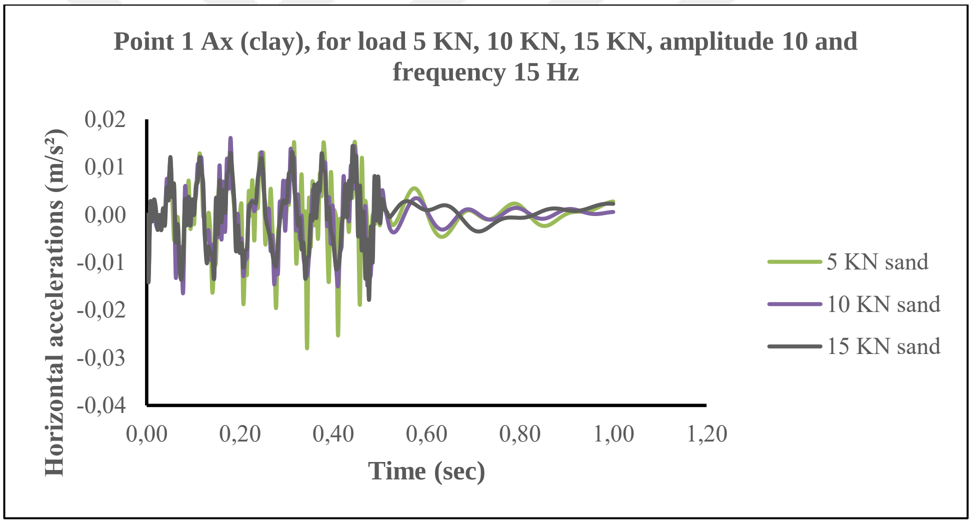

Figure 4.59: Ax (sand), for Load 5 KN, 10 KN, 15 KN, Amplitude 10 and Frequency 15 Hz.

It can be observed that the horizontal accelerations over time differ for each based on the applied loads. As the loads increase, the horizontal accelerations also increase. However, differences in frequencies do not affect the results of the graphs.

In conclusion, applying a load or increasing the weight of machines increase the horizontal accelerations of a layer of sand soil.

4.3.10 Comparison of Results for the Vertical Accelerations Graphs for Clay and Sand

- For 5 KN:

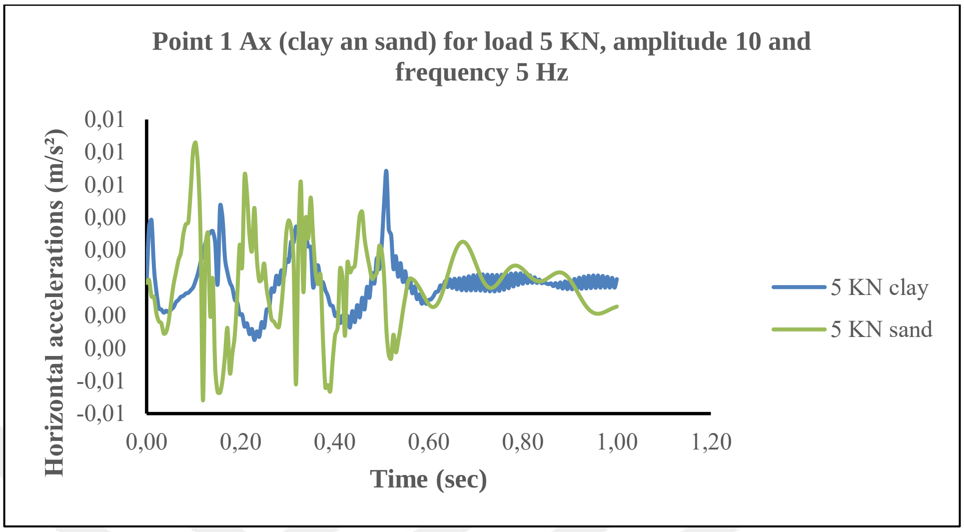

Figure 4.60: Point 1 Ax (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 5 Hz.

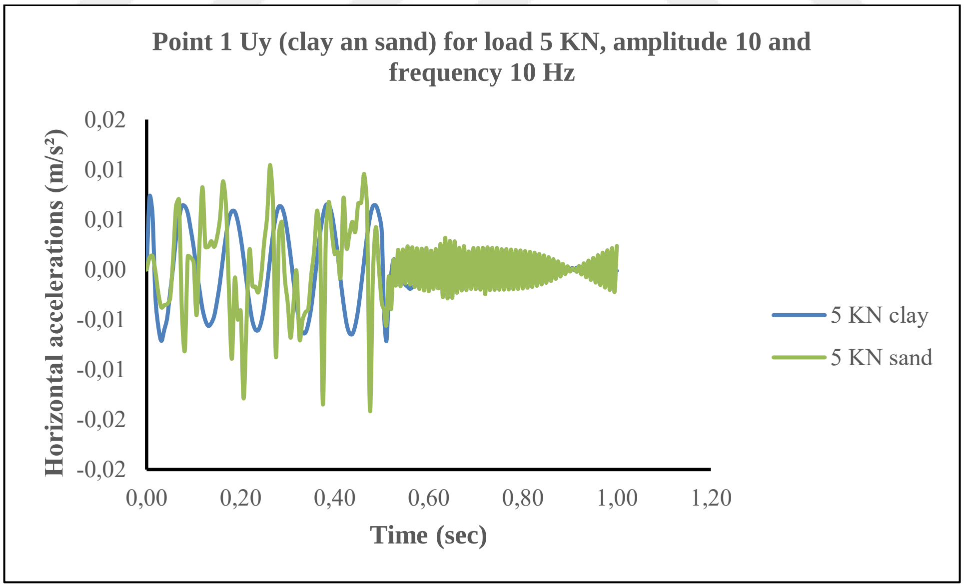

Figure 4.61: Point 1 Ax (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 10 Hz.

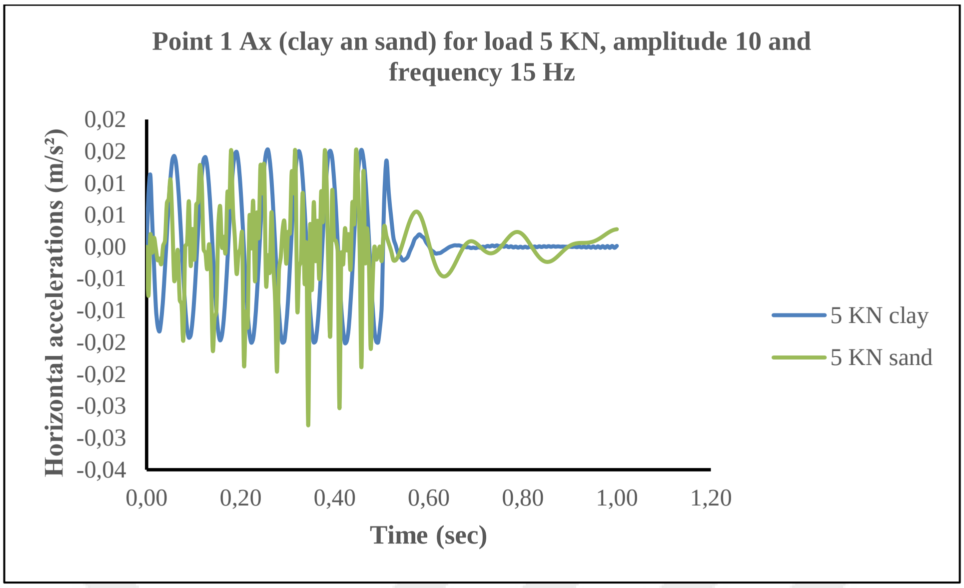

Figure 4.62: Ax (clay and sand) for Load 5 KN, Amplitude 10 and Frequency 5 Hz.

- For 10 KN:

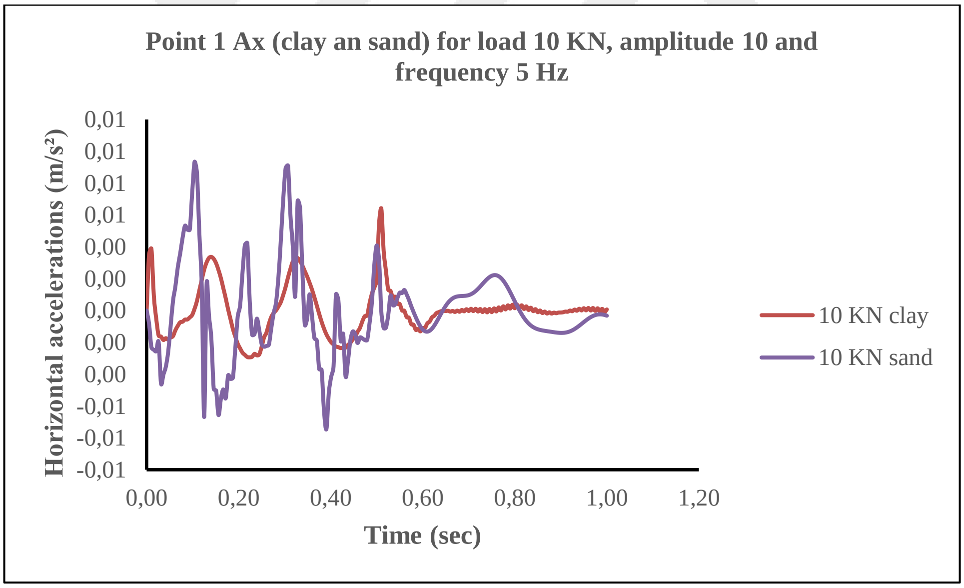

Figure 4.63: Ax (clay and sand) for Load 10 KN, Amplitude 10 and Frequency 5 Hz.

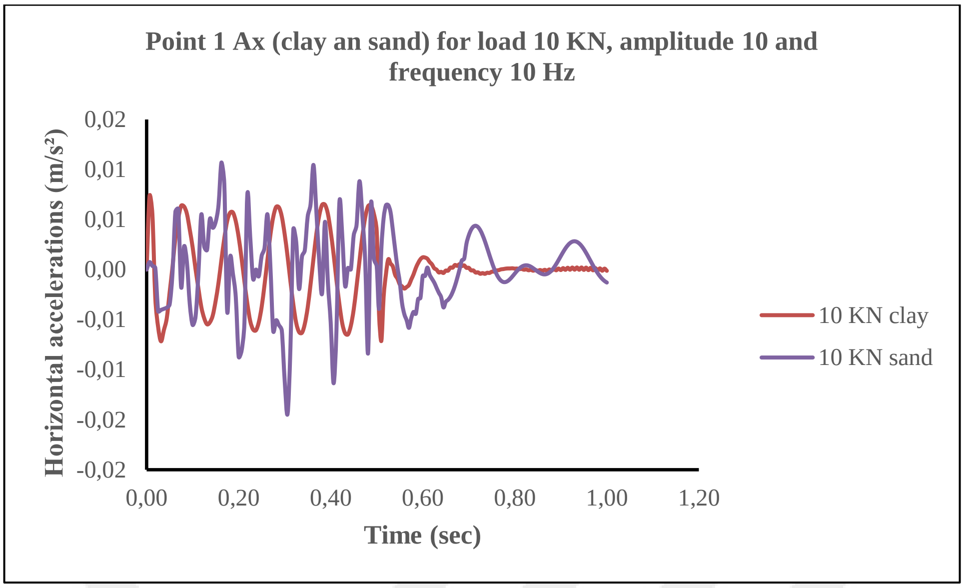

Figure 4.64: Ax (clay and sand) for Load 10 KN, amplitude 10 and Frequency 10 Hz.

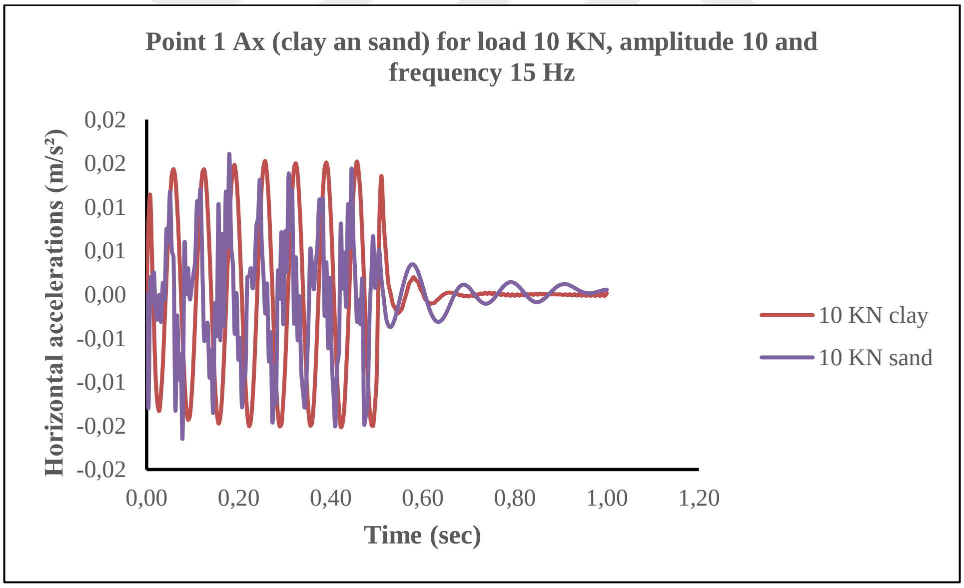

Figure 4.65: Ax (clay and sand) for Load 10 KN, Amplitude 10 and Frequency 15 Hz.

- For 15 KN:

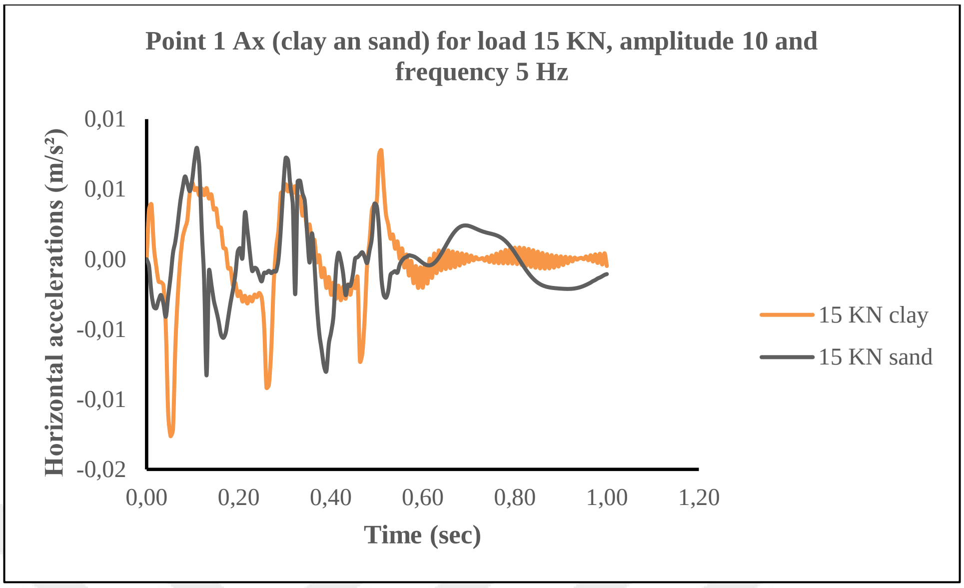

Figure 4.66: Ax (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 5 Hz.

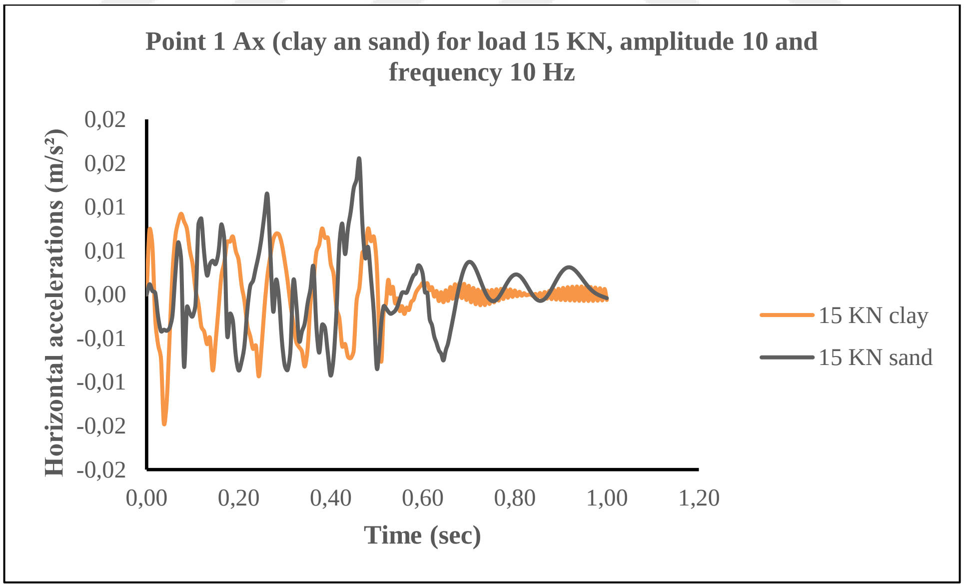

Figure 4.67: Ax (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 10 Hz.

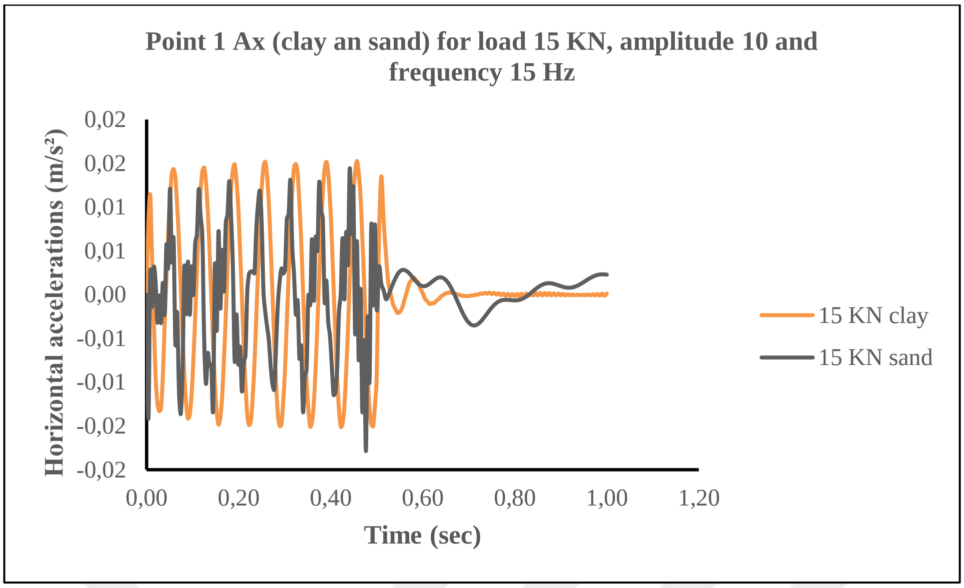

Figure 4.68: Ax (clay and sand) for Load 15 KN, Amplitude 10 and Frequency 15 Hz.

Throughout all these graphs, we observe the same findings for vertical displacements as for horizontal accelerations. Horizontal accelerations on a layer of sandy soil are generally higher than on a layer of clayey soil because sand is more likely to move horizontally and compress under load, resulting in higher horizontal accelerations. On the other hand, clay has higher cohesion and lower permeability, limiting its ability to move horizontally and compress under load, leading to lower horizontal accelerations.

Settlements and accelerations differ between clay and sand under machine vibration due to their differing mechanical properties.

For clay:

a. Higher Cohesion: Clay has higher cohesion, meaning its particles are more strongly bonded. This cohesion allows clay to resist deformation and settlement to some extent, resulting in lower settlements compared to sand.

b. Lower Permeability: Clay has lower permeability than sand, meaning water flows through it more slowly. This can affect how quickly excess pore water pressure, induced by vibrations, dissipates. Slower dissipation can contribute to lower settlements.

c. Compressibility: Clay is more compressible than sand. When subjected to vibration, clay can deform and compress, but its higher cohesion limits the extent of this deformation, leading to lower settlements.

For sand:

a. Lower Cohesion: Sand has lower cohesion compared to clay, meaning its particles are not as strongly bonded. This lower cohesion allows sand to deform more easily under load and vibration, leading to higher settlements.

b. Higher Permeability: Sand has higher permeability, allowing water to flow more freely through it. This can result in quicker dissipation of excess pore water pressure induced by vibrations, which can lead to higher settlements.

c. Particle Size and Shape: The larger, more irregular particles of sand allow for easier compaction under load compared to the smaller, smoother particles of clay. This can contribute to higher settlements in sand.

Additionally, the differing properties of clay and sand can also affect their dynamic responses to vibrations, with clay often exhibiting more damping characteristics and sand showing more amplification of vibrations.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, the dynamic response of foundations under vibrating machines is influenced significantly by the characteristics of the underlying soil. The comparative analysis between clay and sandy soils has revealed distinct behaviors, particularly regarding vertical displacements and the effect of varying frequencies.

For clay soils, there is a notable decrease in vertical displacements as the frequency of vibration increases. This behavior indicates that the clay soil becomes stiffer and less prone to significant deformations under higher frequency vibrations. On the other hand, sandy soils exhibit an increase in vertical displacements with higher frequencies, suggesting a more pronounced dynamic response and potential for greater settlement under vibrating loads. The analysis also indicates that variations in applied loads have minimal effects on vertical displacements in both soil types. This finding underscores the importance of considering the dynamic properties of the soil, particularly its response to varying frequencies, when designing foundations for vibrating machinery. Practically, these findings have significant implications for foundation design in civil engineering. Engineers and designers should carefully consider the dynamic characteristics of the soil, especially its response to vibrations, to ensure the stability and longevity of structures built on such foundations.

When loads are applied to a layer of sand, vertical displacements can become greater than on a layer of clay due to the different mechanical characteristics of these two types of soils. Sand has a higher permeability than clay, meaning water can flow more easily through sand. When a load is applied, water can move more freely out of the path of the load, reducing compression resistance and allowing for greater vertical displacements. Clay is generally more compressible than sand. This means that under a given load, clay is more likely to deform than sand, which can limit vertical displacements. Sand has a loose granular structure, which means it can compact more easily under load, leading to greater vertical displacements. Clay, on the other hand, has a more organized structure with finer particles, which can limit the magnitude of deformations. Sand generally has a greater bearing capacity than clay. This means that sand can support heavier loads before experiencing excessive deformations, but once these deformations begin, they can be more significant than those in clay. Ultimately, the soil's response to the load depends on various factors, including soil composition, density, permeability, and other geotechnical characteristics.

5.2 RECOMMENDATIONS

Case studies will be presented to illustrate the importance of considering dynamic response in foundation design and the potential consequences of neglecting this aspect. Among these case studies, we will present three to better understand these concepts.

1st case: Bridge Foundation on Sandy Soil

Scenario: A bridge is built on sandy soil without considering the dynamic response.

Result: Vehicle vibrations cause excessive vertical movements of the bridge, leading to premature deterioration of the structure.

Lesson: Inadequate attention to dynamic response in sandy soil can result in higher maintenance costs and reduced infrastructure lifespan.

2nd case: High-Rise Building on Clayey Soil

Scenario: A high-rise building is constructed on clayey soil without considering the dynamic response of the foundation.

Result: Due to the high frequency of vibrations from heavy machinery nearby, the building experiences excessive settlement and structural damage over time.

3rd case: Industrial Plant on Mixed Soil

Scenario: An industrial plant is established on a site composed of a mixture of clay, sand, and gravel.

Result: Inadequate assessment of dynamic response leads to differential settlements and structural problems in different parts of the plant [30].

Lesson: A thorough analysis of the dynamic response, taking into account the variable soil conditions, is essential to ensure consistent performance and longevity of industrial structures.

To reduce the effects of dynamic loads on foundations, several mitigation measures can be implemented: Damping devices, such as mass dampers, friction dampers, viscous dampers, or fluid-based damping systems, are used to absorb the energy from vibrations and reduce deformations and induced forces in the foundation. The design of foundations can be modified to better resist dynamic loads. For example, using deeper foundations, such as piles, can reduce the effects of vibrations by dissipating them into deeper and more stable soil layers. To reduce the effects of dynamic loads, the soil can be reinforced or stabilized. This can be achieved by compacting the soil, adding reinforcing materials such as geotextiles or reinforcements, or injecting stabilizing materials into the soil to improve its capacity to support loads. In addition to structural measures, noise and vibration reduction techniques can be used to mitigate the effects of dynamic loads [31]. This can include the use of acoustic insulation materials or vibration absorption devices. These mitigation measures can be used individually or in combination, depending on the specific needs of the project and site conditions.

REFERENCES

[1] M.Y. Fattah, M.A. Al-Neami, N.H. Jajjawi. Prediction of liquefaction potential and pore water pressure beneath machine foundations.

[2] Seed H.B., Idress I.M., Soil Moduli and Damping Factors for Dynamic Analysis, EERC Report No. 10- 70, University of California, 1970.

[3] /K. Rainer Massarsch on 30 May 2020.

[4] International Journal of GEOMATE, Nov, 2022, Vol.23, Issue 99, pp.141-150.

[5] Tileylioglu S., Stewart J. P., and Nigbor R., Dynamic Stiffness and Damping of a Shallow Foundation from Forced Vibration of a Field Test Structure, Journal of Geotechnical and Geo-environmental Engineering, Vol. 137, Issue 4, 2010, pp. 344-353.

[6] Alzabeebee S., Dynamic response and design of a skirted strip foundation subjected to vertical vibration, Geomechanics and Engineering, Vol. 20, Issue 4, 2020, pp. 345– 358.

[7] Fattah M.Y., Al-Neami M.A., Jajjawi N.H., Prediction of liquefaction potential and pore water pressure beneath machine foundations, Central European Journal of Engineering Vol. 4, Issue 3, 2014, pp. 226-249.

[8] Javdanian H., Behavioural interference of vibrating machines foundations constructed on sandy soils, International Journal of Engineering, Transactions B: Applications, Vol. 31, Issue 4, 2018, pp. 548–553.

[9] Choudhury D, Rao K.S.S, (2005) Seismic bearing capacity of shallow strip footings, Journal of Geotechnical and Geological Engineering, Vol. 23, 2005, pp. 403–418.

[10] Bhatia K., Foundations for Industrial Machines: Handbook for Practicing Engineers, 1st Edition, D-CAD Publishers, New Delhi, 2008, pp. 1-675.

[11] Fattah M. Y., Salim, N. M., Haleel, R. J., Liquefaction Potential of Sandy Soil from Small Laboratory Machine Foundation Model, International Review of Civil Engineering (I.RE.C.E.), Vol. 9, Issue 1, 2018, pp. 11-19.

[12] Fattah M. Y., Al-Neami M. A., Jajjawi N. H., Prediction of Liquefaction Potential and Pore Water Pressure beneath Machine Foundations, Central European Journal of Engineering, Vol. 4, Issue 3, 2014, pp. 226-249.

[13] Fattah M. Y., Al-Mosawi M. J., Al-Ameri, A. F. I., Dynamic Response of Saturated Soil – Foundation System Acted upon by Vibration, Journal of Earthquake Engineering, Taylor & Francis Group.Vol. 21, Issue 7, 2017, pp. 1158-1188.

[14] Journal of Engineering and Development, Vol. 19, No.1, January 2015, ISSN 1813-7822.

[15] Murthy, V. N. S. (2006): "Geotechnical Engineering, Principles and Practices of Soil Mechanics and Foundation Engineering", Marcel Dekker, Inc. New York.

[16] Leonards, G.A. (1962): "Foundation Engineering", McGraw-Hill Book Co., Inc., New York, USA.

[17] IOP Conf. Series: Materials Science and Engineering 888 (2020) 012055 doi:10.1088/1757-899X/888/1/012055

[18] Mohammed Y. Fattah, Mohammed A. Al-Neami and Nora H. Jajjawi.

[19] Mohammed Y. Fattah, Nahla M. Salim, Rusul J. Haleel. International Review of Civil Engineering, Vol. x, N. x.

[20] Abd Al-Kaream, K. W. (2013), "The Dynamic Behavior of Machine Foundation on Saturated Sand", M.Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

[21] Vivek P, Ghosh P (2012) Dynamic interaction of two nearby machine foundations on homogeneous soil. GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering. ASCE, Reston, U.S.A., pp 21–30.

[22] Vivek P, Ghosh P (2012) Dynamic interaction of two nearby machine foundations on homogeneous soil. GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering. ASCE, Reston, U.S.A., pp 21–30.

[23] PLAXIS 2D - Tutorial Manual.

[24] M. A. M. AL-Dulaimi and M. Seyedi, “Numerical analysis of geogrids and recycled concrete aggregate for stabilizing road embankments,” Annales de Chimie - Science des Materiaux ´, vol. 47, no. 4, pp. 219–223, 2023. https://doi.org/10.18280/acsm.470404.

[25] Naimi, S., and Hrizi, H. (2019). Risk Analysis of Slaving Floor in Construction Sites. International Journal of Electronics Mechanical and Mechatronics Engineering, 9(1), 1637-1645.

[26] Mahmood, L., and Naimi, S. (2022). Investigating the potential of liquefaction issue of some Turkish dams during earthquakes. Periodicals of Engineering and Natural Sciences, 10(6), 57-66.

[27] Mohsin, A. A., Naimi, S., and Mustafa, A. S. (2023). Effects of domestic sewage sludge on Gypseous Soil's geotechnical properties. Journal homepage: http://iieta. org/journals/ijdne, 18(2), 361-368. 10.18280/ijdne.180213.

[28] Nimr, A. H. N., and Naimi, S. (2023). Improving performance of project through utilizing statistical control chart based on adaptive management and scientific engineering. International Journal of Intelligent Systems and Applications in Engineering, 11(4s), 587-593.

[29] Olbak, M., and Naimi, S. (2016). Kentsel Dönüşüm Uygulanmış 5 Katlı İki Yapı Örneğinin Deneysel Verileri Kullanılarak Doğrusal Olmayan Analiz Yöntemleri İle Güçlendirme Sonuçlarının İrdelenmesi. İstanbul Aydın Üniversitesi Dergisi, 8(31), 145-166.

[30] Al Musawi, L., and Naimi, S. (2023). The management of construction projects in Iraq and the most important reasons for the delay. Acta Logistica, 10(1), 61-70.

[31] Abdulwahhab, R., Naimi, S., and Abdullah, R. (2022). Managing Cost and Schedule Evaluation of a Construction Project via BIM Technology and Experts’ Points of View. Mathematical Modelling of Engineering Problems, 9(6), 1515-1522.