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Numerical Study of Soil-Retaining Wall Behavior Subject to Machine Foundations Loads

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ABSTRACT

A retaining wall was practically developed to provide lateral support for soil, and it is widely used in underground projects, highway barriers, and mines as well as for aesthetic considerations and slope stabilization. This type of earth structure member can carry machine foundation load simultaneously with traditional static load. This study carried out using the finite element program PLAXIS 3D. The linear elastic model for retaining walls and the Mohr-Coulomb model for soil layers were used in this numerical analysis. The study included three layers of soils under the wall with dry condition. The high of the wall was 4m and the dimensions of machine foundation were 3x3m. It can be concluded that the vertical settlement, horizontal displacement and velocity increased when the duration of the machine load increases. Usually, the horizontal displacement increases to highest value and reached to 10 times the original static value when the machine was closed to the wall with 0.5m and 75Hz. This can be taken into account in the design for such geotechnical system in the design stages.

1. Introduction

In practical situation, the stability of gravity walls is usually depending on their weight and the soil resting. In addition, used of earth-retaining structures to support cut near residential areas or roadways.

Yanqui [1] used wall to limit the displacement to the specified level in the case of an earthquake. In this study recommended that the designer must first decide the acceptable degree of wall displacement before calculating the design wall weight. It can be demonstrating that the effects of the dynamic soil thrust and wall inertia are similar.

Green and Ebeling [2] determined the suitability of the Mononobe-Okabe method for calculating the seismically effect induced lateral earth pressures on the stem of the wall, performing a progression of non-linear dynamic reaction investigations of a retaining wall using a numerically modelled and analysed. The induced pressures for the wall were found to be generally consistent with those predicted by the Mononobe-Okabe approach at very low degrees of acceleration. It was discovered that the actuation pressures are higher than those predicted by the Mononobe-Okabe method as accelerations increase to those expected in places of moderate seismicity [3].

Evaluated three various walls conditions, including a cantilever retaining wall, a gravity retaining wall, and an unbending storm cellar wall. All these walls were under simple sinusoidal limit increasing velocities using a

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confirmed restricted component research. The soil was represented using the Drucker-Prager model. The dynamic weight augmentation is seen for various driving frequencies in the hopes of achieving an eliminate and of stage reaction between the soil and structure, leading in both lower and higher than M-O weight esteems [4].

The dynamic response of the cantilever retaining walls under seismic loads using the finite element method with Plaxis program to find out how the retaining wall moves dynamically. The dynamic response of the wall reduces with an increase in the values of friction angle, cohesion, elasticity, and soil damping, although the effects of the source's vibration's frequency and amplitude on the response are similar [5].

A reinforced soil retaining walls was simulated by numerical method under static and dynamic loading. The FLAC finite difference program is used to investigate the retaining wall behavior. Analysis has taken into account the behavior of soil-wall and soil-reinforcement interactions. Several loading and backfill settings were used for the analyses. To determine the impact of strengthening on the retaining wall, the lateral displacement and earth pressure were examined. Unreinforced (traditional) and reinforced soil retaining walls were contrasted. The findings indicate that the length of the reinforcing layer has a considerable impact on both lateral displacement and earth pressures. The length of the reinforcing layer has an impact on the incremental dynamic earth pressure [6].

An experiment study that involving cantilever and propped retaining wall models used centrifuge equipment on saturated sand. The primary goal of the study is to measure the accelerations, and pore pressures, dynamic reaction of those structures when the soil becomes saturated. The relative density of the soil and various geometric configurations used in the tests and compared. Dynamic loading was applied to the centrifuge models in the form of sinusoidal accelerations that were applied at the base of the models [7].

Fattah et al. [8] studied of the dynamic earth pressure due to machine foundations on a retaining wall should places depend on the direction and magnitude of the design forces. For a range of retaining wall and machine foundation shapes, the problem is examined using the meshless local Petrov-Galerkin (MLPG) approach. The foundation of the machine is envisioned as a harmonic sinusoidal dynamic force that is frequently observed in practice. Many analyses have been conducted to determine how the loading frequency, the position and size of the foundation and the velocity of the soil shear wave affect the distribution and amount of the dynamic earth pressure.

In addition, a study by Gabar [9] on the seismic evaluation of retaining walls has long been considered by a few tactics based on the fundamental enhancement of Coulomb's limit equilibrium research. These methods cannot measure the removal of the wall-supported replenishment dirt. To consider the vertical settlement on sandy soil under dynamic loads with varying burden amplitudes, vibration frequencies, relative densities, and various separations between the foundation and holding divider, a trial examination is accomplished. The investigation's model balance is a square one.

A study by Babak and Farahani [10] that investigated and conducted on the influence of soil and bedrock conditions on the behavior of retaining walls. The retaining wall's structural plan takes soils on its front and back into account. The structural design of the wall does not take the bedrock conditions or the soils beneath the wall into account. This study examined the effects of soils beneath the wall on behaviors such as wall deformations, wall bending moments, and anchor force. Investigations have been done into how the behavior of the wall is affected by factors such as soil strength, bedrock depth, bedrock slope, wall height, and anchor angles. Numerical modeling and analysis were conducted to assess the structural reaction and behavior of the retaining wall using the finite element software package PLAXIS.

The seismic displacement of gravity wall was studied using conventional static methods for controlled displacement design. The Plaxis dynamic program was used to do a numerical analysis of plane strain, where a predetermined displacement was provided at the soil's bottom boundary to simulate applied seismic stress. The tested soil, dense granular sand, was modeled as an elastic-plastic substance following the Mohr-Columb criterion. whereas the gravity wall was supposed to be elastic. It was found that comparable numerical seismic displacements were more than or equal to corresponding pseudo-static values. Ad-additionally, it was found that for stiff walls, seismic wall sliding was more relevant than rotation and that the slope of the wall's back surface's positive angle is directly in proportion to the seismic wall displacement. Seismic wall rotation that is cumulative Pugliese and Troncone [11].

Conducted the experimental analysis of the seismic response of gravity retaining walls [13] supported by both rigid and compliant bases. The earthquakes used in the two tests are relatively comparable in size, duration, and frequency content, and in both instances, they cause the wall to move permanently. The wall is unable to slide over its base in the first test (rigid foundation), but in the second test (compliant foundation), sliding and rotation of the wall are observed, which cannot be separated from a bearing failure mechanism of the subsurface soil. It was discovered that the wall displacements caused by the latter mechanism are significantly greater than those produced by simple sliding. These results imply that, depending on the mechanical characteristics of the sliding block process used in Newark. The critical acceleration of the wall, which acts as its supporting soil, may be much lower than that of a sliding mechanism.

Therefore, the objective of the current study is to find the behavior of retaining wall settlement and displacement due to the effect of machine foundation load.

2. Numerical modeling

For the three-dimensional analysis code, finite element analyses were used. By dividing the objects into small elements (volumes), each of which contains several nodes with many degrees of freedom that correspond to the discrete values of the boundary value problem's unknowns, finite element analysis is an excellent technique for obtaining approximations of solutions for boundary value problems. The finite element approach, which supports the analysis and design of engineering structures, has been successfully applied in a variety of computer program packages.

2.1 Plaxis 3-D program

Plaxis 3D program is a finite element designed for geotechnical problems in which soil models were used to illustrate soil behavior and developed to assess structure constructions, including foundations and superstructures. The soil characteristics in the site, as well as the construction method, are used, and determine settlements.

The geometry of the soil and the geometry of the structures can both be determined using PLAXIS 3D. Solid models can be produced through the intersection and mesh generation procedures.

The staged construction mode also assists in simulating the construction by activating and deactivating clusters of soil volume and structural masses, load application, water table change, and other factors. A complete set of visualization tools for examining the internal 3D soil-structural model is included in the output findings [14].

2.2 Formulation problem of study in the Plaxis-3D 2020 program

The Gravity retaining walls are made of plain concrete or stonemasonry they rely on their weight and any soil that is resting on the masonry for support. For tall walls, this method of building is not cost and effective. In the case of semi-gravity walls, according to this investigation, the behavior of the wall under any loads must be taken into account especially when embedded.

The case study of the soil–wall system of the building was formulated with Plaxis. The boundary condition for the finite element method for the wall into soil media (60x60x30) m, and use this dimension to show the behavior of the wall with 60malong y-axis under the effect of machine foundation and the dimensions of the soil body of a wall shape start at 26 from the x-axis and the high is 4m in the z-axis, with width 2m illustrated in Figure1.

2.2.1 Constitutive model

The actual geometry model is automatically subjected to a set of general boundary conditions by Plaxis software. It also covers the development of the geometry model, as well as the creation of the mesh, and the calculation.

The process of creating a finite element model begins with the creation of a geometric model. Points, lines, and clusters are the building blocks of geometry models. Points and lines are produced in the drawing area by inputting the coordinates on the command line

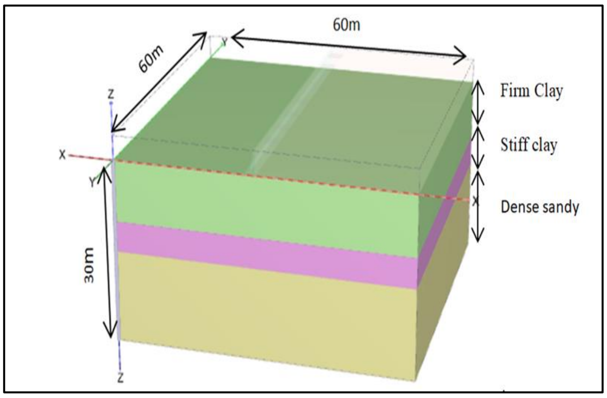

Figure 1. The geometry of soil layers

The length of a wall in the y-axis is 60 m on the clay soil layer 15 m resting on 15 m sandy soil. In addition, the backfill from the side retaining wall is high at 4m, Φ=35, ν=0.35, and γ=18kN/m^3 so they were used for the FEM analysis in the present study. Figure 2 demonstrated the retaining wall system and backfill of this study.

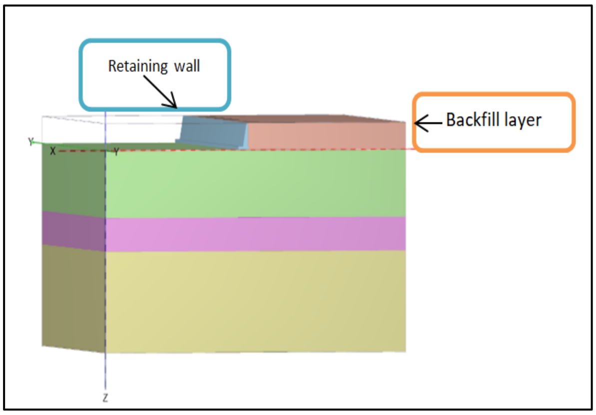

Figure 2. Retaining wall system and backfill

The model for this investigation is divided into two parts: the soil simulation with elastic completely plastic with three square layers (Mohr-Coulomb model). While two-part (wall-foundation). The stress spots under the line represent elastic behavior, according to the Mohr-Colomb failure eve-lope, and when the stress circles meet the failure line, soil behavior switches from elastic to plastic. This indicates that the behavior of the material is ideal elastic up to the mobilization of the shear strength, at which point load increments result in plastic stresses.

This study's model consists of two parts: material soil simulates with elastic perfectly plastic with three-square layers (Mohr-Coulomb model). While two-part (retaining wall) with linear elastic. Another component of the model with linear elasticity is the foundation of the machine.

Without considering pore pressure development, an undrained soil's short-term response to changes in stress will result in an increase in pore water pressure over time. The Plaxis software may simulate clay soil with short-term behavior (undrained A) when the water level is (-30) m below the surface of the ground. Sandy soil with long-term or drained behavior made of a highly permeable substance.

Following completion, the geometry component is allocated to the relevant geometry component, and the wall and backfill parameters are assigned to the corresponding geometry component. Tables 1 and 2 contain a list of the values for the soils and wall parameters that were used in this study.

2.2.2 Machine loading and boundary condition

The input motion used in this study is defined as dynamic surface load (load multipliers). The acceleration time history for the machine selected in this search machine foundation, which is applied along the y-direction at the bottom boundary of the 3-D model in m/s^2 and respectively at three amplitudes have been used (25,50,75) Kpa as shown in Figure 3.

By selecting the standard absorbent boundaries (Normally fixed boundaries) in the Plaxis program. The absorbent boundaries are applied at the (x, y direction) boundary and the free boundary in (z-direction) in this model. The characters of the machine used in this study are demonstrated in Table 3.

Table 1: Properties of retaining wall and foundation of the machine [12]

Property	**Unit**	**Value**
Material of Wall, machine	-	concrete
Elastic Modulus (E)	kN/m^2	$2x10^7$
Poisson's Ratio(υ)	-	0.17
Unit Weight (γ)	kN/m^3	23

Table 2: Properties of soil layers for the numerical analysis [15]

Property	**Firm Clay**	**Stiff Clay**	**Dense sandy**
Elastic Modulus, E (MPa)	25	55	50
Poisson's Ratio, υ	0.4	0.4	0.3
Unsaturated Unit Weight, γ_{unsat} (kN/m^3)	16.8	17	17
Saturated Unit Weight, γ_{sat} (kN/m^3)	18	19	20
Cohesion, c (kPa)	55	100	-
Friction Angle, (φ)	-	-	33
Interface Strength	Rigid	Rigid	Rigid

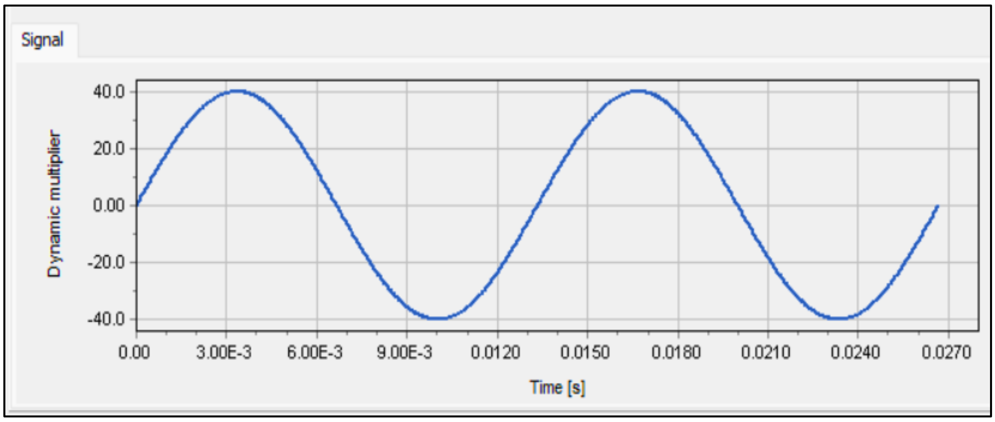

Figure 3. Load multipliers [12]

Table 3: The data of the machine used in this study

Machine Type	**Machine foundation**
Machine dimensions	3*3
Thickness	0.2
The magnitude of surface load-1 In z-direction	$40kN/m^2$
The magnitude of Dyn surface load-1 In z-direction	1
Load Multiplier	Multipliers
Amplitude	40
Frequency (Hz)	25,50 and 75

2.2.3 Mesh generation and calculations

To perform finite element calculations, the PLAXIS application divides the geometry of the soil wall into elements using an unstructured mesh that is constructed automatically using global settings.

There are five possibilities for the mesh element distribution: very coarse, coarse, medium, fine, and very fine mesh. The mesh can be fine-tuned in specific regions where significant stress is anticipated to increase the accuracy of the results.

In this study, a medium-mesh was chosen to avoid lengthy calculations of time with fine or very fine-mesh as demonstrated in Figure 4. After completing the generation of the finite element mesh, the proper finite element calculations are carried out. The calculation process is divided into multi phases.

1. In the initial phase (Initial Stress Generaton) the initial stress of the soil body can be determined based on the weight of the material and its history of formation
2. Second phase construction of the retaining wall.
3. Finally, the phase for the dynamic calculations is a dynamic analysis of the machine foundation on the structural model, as well as a dynamic selection calculation after creating dynamic load multipliers with a dynamic time interval equal to 15 (s).

After the analysis carried out for the soil-wall system, the variations of the settlement and maximum displacement of the retaining wall are observed.

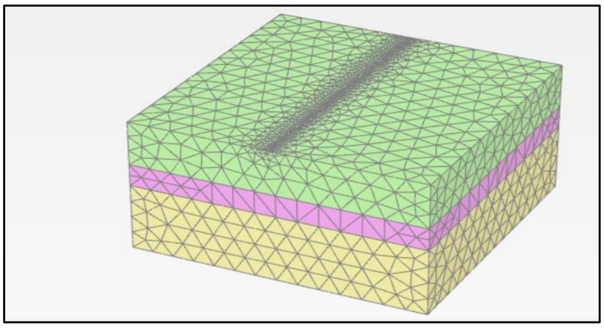

Figure 4. Finite element mesh for retaining wall foundation and three layers of soil.

3. Results and discussion

The finite element analyses of the retaining wall behavior under the machine foundation load with a Different frequency are studied by using depth-deflection curves and depth-stress curves. The curves are drawn for vertical and horizontal displacement and horizontal stress and for given dynamic loads.

Based on the model of the retaining wall is symmetrical, and the direction of the input is applied in the z-direction, the results of the numerical analysis after completing all stages of construction of calculations, include initial stress, wall construction, static and machine loads of this study are presented in Figure 5.

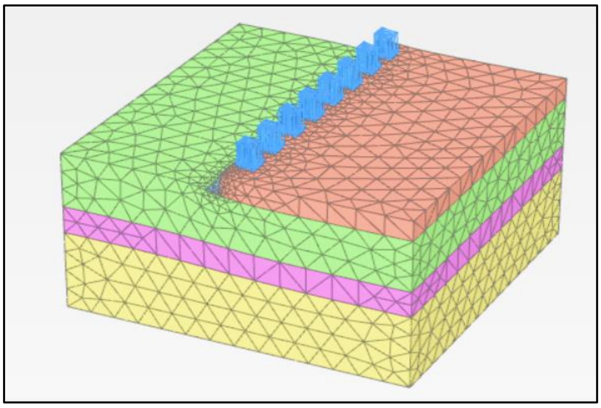

Figure 5. Machine foundation load

Figure 6 shows the relationship between the vertical settlement of the retaining wall with depth in the clay soils under the wall when the first layer cu is equal to 55 firm clay at rest on clay cohesion 100 stiff clay. the classification of the layer according to [13] all input values decrease with depth. for static from 7.5 mm decrease with depth to near zero when layers of clay are stiff. also, the 25Hz value of it from 35mm decrease with depth at 50Hz, and 75Hz far beyond all trend of behavior decrease with depth the slope of the settlement changes slope.

Figure 7. For the same case study but the section beside the wall from high 4m to layers of soil, illustrated the relationship between the horizontal displacement drown all static from 4.1mm to left, and the axis shows movement to the left if move to the right it will be incorrect. we can see the static near to active zone on sand=5 when it is equal to 11mm in frequency

25 Hz is going away from an active zone in the sand and near to passive. The clay layer and trend of the behavior of 50, and 75 Hz also decrease with depth and it is in the active zone for clay=60m this is natural starting from 20, 38 mm and La/H refer to the active zone for sand =5mm and Lp/H refer to passive zone for sand =30mm as shown in the figure below

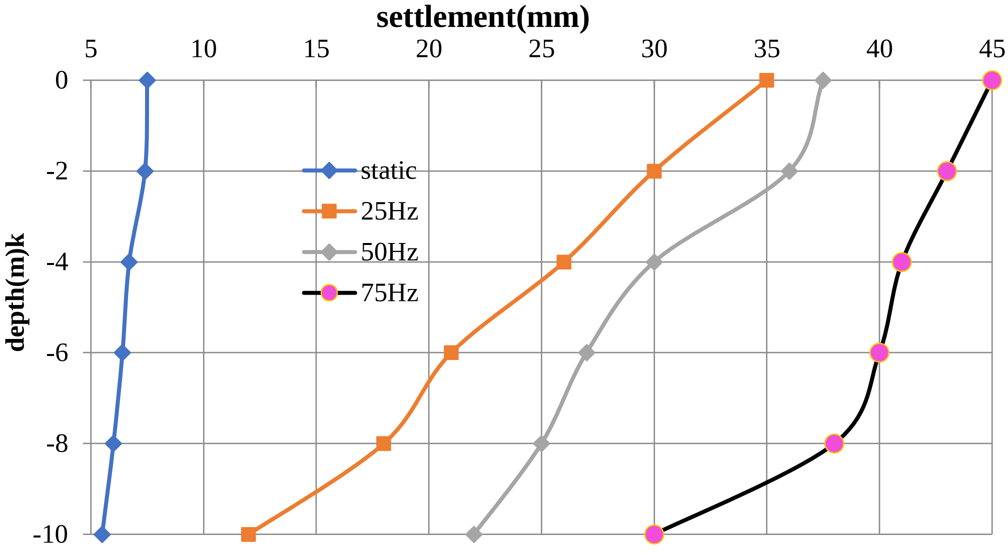

Figure 6. Vertical settlement varies with depth in soil layers under the Retaining wall

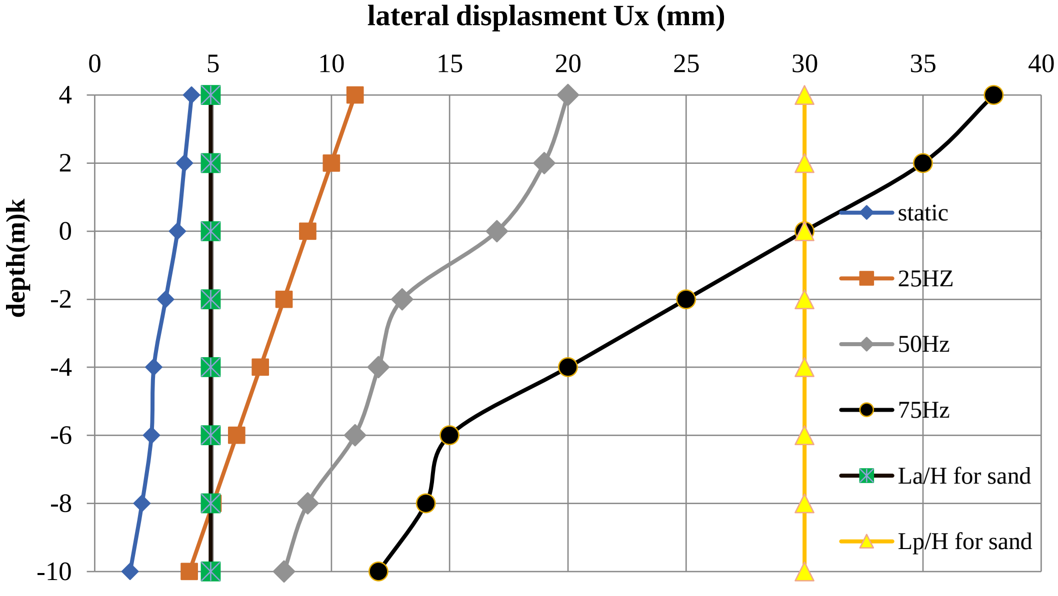

Figure 7. Lateral displacement varies with depth in soil layers beside the retaining wall

Figure 8 shows the relationship between the vertical settlements of the retaining wall with depth in the clay soils beside the wall, all input values decrease with depth. for static from 9.5 mm decrease with depth to near zero when layers of clay are stiff. also, the 25Hz value of it from 11mm decrease with depth at 50Hz, and 75Hz far beyond all trend of behavior decrease with depth the slope of the settlement changes slope.

Figure 9. The relationship between the horizontal displacement with depth in point under the machine foundation drowns all static from 4 mm to left and the axis shows movement to the left if moves to the right it will be incorrect. we can see the static near to active

zone on sand=5 when it is equal to 7.5mm in frequency 25 Hz is going away from the active zone in the sand and near to passive. The clay layer and trend of the behavior of 50, and 75 Hz also decrease with depth and it is in the active zone for clay=60m this is natural starting from15, 40 mm shown in the Figure below.

Figure 10 shows the relationship between the vertical settlement of the retaining wall with depth in the clay soils under the machine foundation, all input values decrease with depth. for static from 15 mm decrease with depth to near zero when layers of clay are stiff. also, 25Hz value of it from 23.7mm decrease with depth at 50Hz, 75Hz far beyond all trend of behavior decrease with depth the slope of the settlement changing slope.

The velocity (Vx) under amplitude = 40kPa. placed at a point inside the retaining wall this velocity shows the maximum velocity of the wall due to the effect of the machine that equals 0.005m/s in time 15sec that is far beyond of maximum of Permissible velocity =2.5mm/sec according to [15] and when used to frequency 50,75Hz in frequency 50 Hz the maximum value equal to 3.8m/s and in frequency 72 Hz maximum value equal to 4m/s two above velocity cross the permissible velocity.

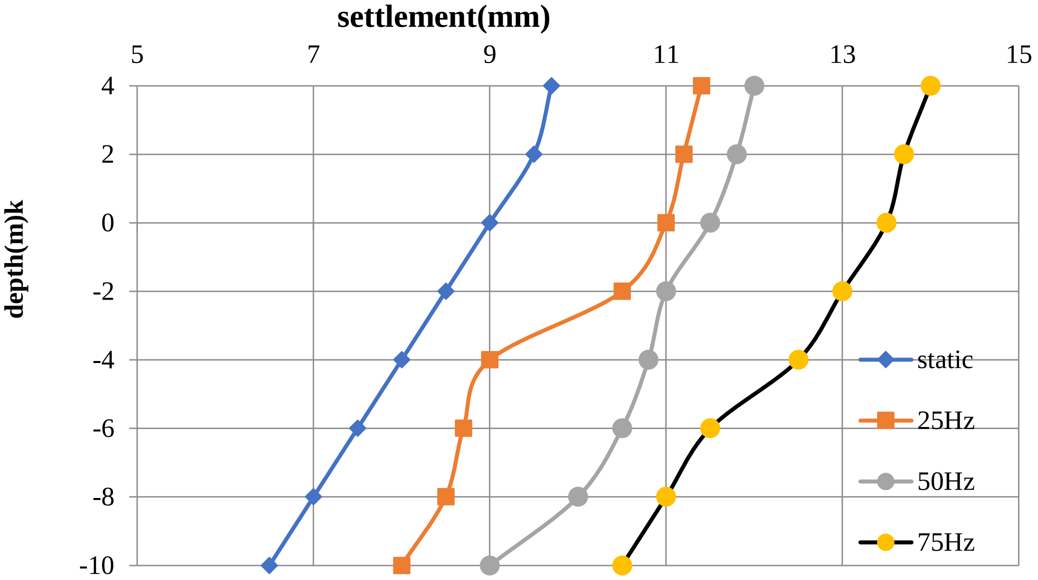

Figure 8. The vertical settlements beside the retaining wall

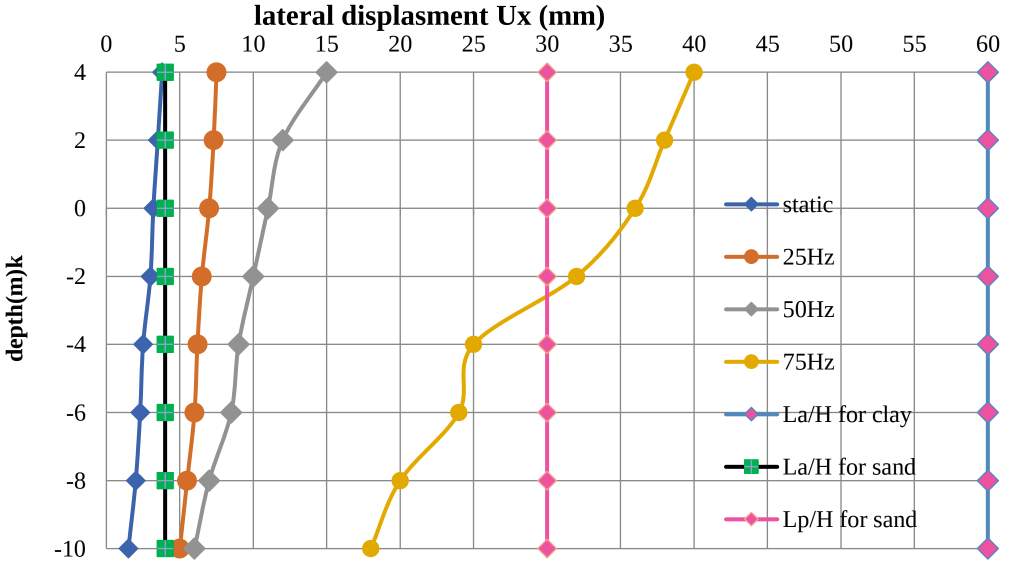

Figure 9. Lateral displacement varies with depth in soil layers under the machine foundation

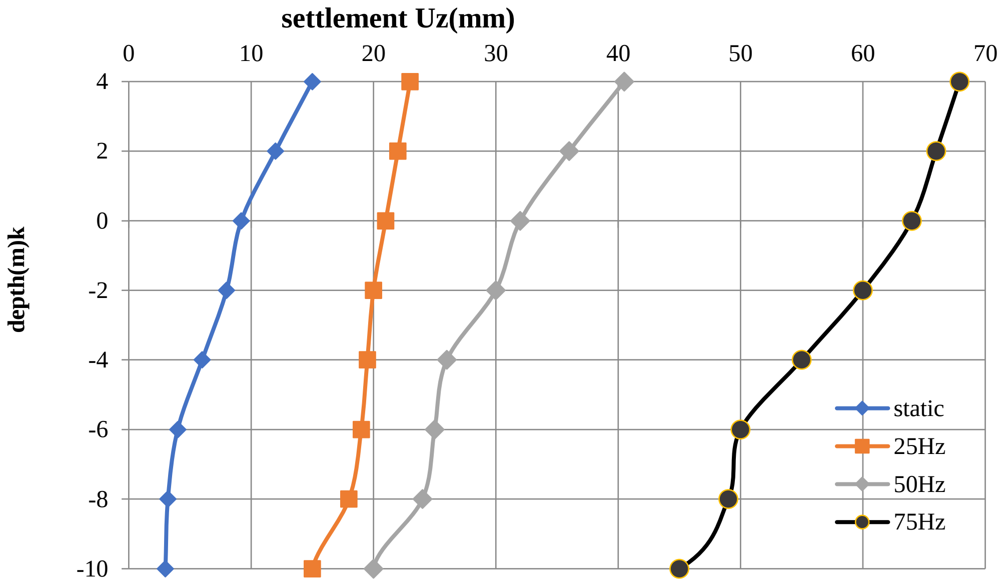

Figure 10. The vertical settlements with depth under the machine foundation

4. Conclusions

This paper evaluates the effect of machine foundation with amplitude stress of 40 kPa on the vertical and horizontal displacement and velocity of a wall in clayey soil over layer-dense sand. The conclusions from this study can be drawn as the following:

1. The vertical settlement decreases for25,50 and 75 Hz with depth when frequency increases and it is well below the failure settlement which is about 0.1s/B=200mm even after the depth increase.
2. The horizontal displacement increases when the frequency of the machine increases (25, 50 and75) Hz is when an increase displacement that is well below the active zone for clay=60m,
3. The horizontal displacement for 50 and 90 mm near to active zone for sand and cross it in point under the machine foundation
4. The difference between vertical settlement and horizontal displacement. Is the shown in the values of settlement less than displacement in a different section
5. The trend of behavior under the retaining wall varies beside the wall due to the machine because the stress under the machine is much and vanishes down the wall
6. The velocity in the retaining wall in all frequencies is far beyond the maximum Permissible velocity.

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