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Dynamic Response of Pile Foundation Subjected to Different Frequencies in Sandy Soil

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ABSTRACT

This research presents an experimental study of the dynamic response of pile foundation as a result of the vibration of a nearby foundation as a source of dynamic load in sandy soil with relative density of 85%. The experiments were conducted on dry and soaked state of soil. The pile raft consisted of a pile cap with dimensions of (100 x 100 x 10) mm, connected with four solid steel piles with a slenderness ratio of 30 and pile diameter is 8 mm, and the machine foundation (vibration source) with dimensions (80 x 80 x 40) mm. After having completed the soil layers preparation inside a steel container with suitable dimensions is used, the machine that generated vibration was operated by the rotating mass, as this vibration reached the pile raft. The results showed that the displacement amplitude, acceleration, velocity and settlement of the pile raft decreased with increasing distance with the vibration source (from 0.5B to 2B) for the three frequencies (10,15 and 20) Hz, while the decrease for displacement was (48%,23.83% and 42.48%) respectively in the dry state of soil. On the other hand, the decrease for displacement was (37%, 23.16% and 46.27%) in the soaked state of soil. Regarding acceleration, it was decreased to (29.66%, 45.79% and 40.38%) respectively in the dry and (100%, 21.88% and 34.04%) in the soaked state of soil. Furthermore, the velocity reached (45.38%, 42.96% and 38.18%) respectively in the dry and (54.05%, 11% and 28%) in the soaked state of soil, the settlement was (63.82%, 52.1% and 38.18%) respectively.

1. Introduction

Designing structures that are subjected to dynamic loads requires a deep understanding of structural, mechanical, geotechnical, and vibration theory [1]. Machines and equipment are considered to be major sources of vibrations in the cities. These vibrations are transmitted through the soil and affect its engineering properties. Deep foundations frequently use piles, which are structural units built using a drive or in-situ building process. As a result, piles are the optimum solution for transmitting loads from the soil surface into more stable layers [2]. Dynamic loads are created by heavy machinery, moving vehicles, or moving trains, among other things, leading foundations to behave in a variety of ways under these pressures. The problem of interaction between adjacent foundations is critical in practice. Even though many existing foundations are not isolated and frequently interact with one another due to their close spacing. Thus, structural damage can occur in both strong and serviceable conditions, particularly under dynamic conditions. Dynamic loading tests were conducted by Puri and Prakash (2008) on a wide reinforced concrete pile that was driven into a homogeneous clay sand soil layer and had dimensions of (17m) in length and (450mm) in

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diameter. The pile's tip was subjected to horizontal and anchored stimulation, and the amplitude response of the pile was noticed across its frequency range. To forecast soil qualities, field and laboratory studies were also carried out [3]. El kasabgy et al. (2010) investigated foundations supported on helical screw piles, and damping rigidity evaluation. This investigation entailed looking at interaction. The forces between the soil and the pile along the pile and at the shaft spirals necessitate a thorough grasp of the study of the mechanism of dynamic loading transmission. Snails have not been thoroughly researched for the dynamic behaviour of large capacity with one or more helix piles [4]. Al-Saffar (2015) examined the dynamic response of pile foundations stimulated by two opposing rotating machines in soft, medium-density sandy soil with a relative density of (60%) in both dry and saturated states of soil. To appropriately achieve the group response, the double cone model and the dynamic reaction factor can be determined for the pile group analysis. As a result, the double cone model can be used to construct machine foundations on piles as an early stage [5]. Fattah et al. (2016) conducted an experimental research on the response and behaviour of the machine's foundations at various operating frequencies that rest on dry and saturated sand. According to their findings, the foundation's maximum displacement amplitude reaction based on dry sand models was greater than the response of saturated sand. By doubling the footing for both dry and saturated sand, the maximum displacement capacity of the footing was reduced by half. With increasing dynamic force amplitude, operating frequency, and saturation level, the foundation's final settlement (St) also increased. Simultaneously, it was decreased by raising the relative density of the sand, the elasticity modulus, and the amount of embedding into the soil [6]. In a viscoelastic soil layer, two nearby stiff foundations were studied by Sbartai (2016) for their dynamic interference. The source of the vibrations was one of the strong foundations that was buried in the ground layer and disturbed by harmonic stresses of translation, rocking, and torsion. The author believed that it is clear how different elements, such as the foundation's shape, the soil's heterogeneity, and the load intensity in relation to other elements, affect the dynamic response of two adjacent foundations. The dynamic reactions of the two foundations also became less apparent as the distance between them increased, whereas the response of the second foundation seemed more apparent if the first foundation was subjected to greater loads [7]. Fattah, et al. (2017) studied experimentally the dynamic response of pile foundations in dry sandy soils stirred with two opposite rotating machines. All tests were carried out in medium-density fine sandy soil with a relative density of 60%. The results showed that before the machine was started, the pile tip load was approximately equal to the static load (machine and pile cap), whereas during the operation of the machines, the pile tip load decreased for all embedding depth ratios and operating frequencies. This decrease was due to the effect of skin friction that was moved along the pile during the procedure, as a result of which the safety factor against pile bearing failure increased. For all operating frequencies and outrigger lengths, the safety factor against bearing failure increased while the machine was in operation, as the pile tip load became less than its value before starting. During operation, the skin friction resistance mobilized along the length of the pile reduced the bearing load. The main focus of this study was to evaluate the effects of pure vertical vibration caused by two opposite rotating devices on the resistance capacity of a stable pile foundation in clean and dry sandy soil. The reduction in the final load was small as compared to the initial static load before the machines were started (no more than 10%) [8]. Al-Ezzi and Zakaria (2019) presented an experimental study on the dynamic response of a rectangular foundation under the influence of the dynamic load resulting from a neighbouring base called ‘the source of vibration’. Both foundations were constructed on collapsible soil (gypsum soil) containing 60% gypsum. The research was conducted on dry and wet conditions. The tests were performed under dynamic response of three frequencies (10, 20, and 30) Hz, and the displacement amplitude and second baseline acceleration were determined, at different distance between the baseline (2B, 4B, and 6B). The results showed that when the distance between the foundations was increased, the displacement (amplitude, acceleration, and velocity) decreased. Moreover, the value of these parameters in the dry case was higher than in the soaked state [9]. The performance by Ibrahim and Zakaria (2019) was accompanied by a dynamic reaction of three frequencies. The findings demonstrated that the second base's capacitance and acceleration decreased as the distance between them grew longer. Additionally, these parameters had a higher value in the dry condition than in the soaked state [10]. The dynamic response of a single pile to a dynamic load caused by a motor placed on the cover pile, also known as the vibration source, was experimentally studied by Abd and Abid Awn (2021) in gypseous soils (30%) that collapse easily. This experiment involved dehydrated and soaked four different substrate thinness ratios. The results demonstrated that, in both the dry and soaked conditions, the velocity, acceleration, and displacement amplitude decreased as the pile thinness percentage increased. Additionally, the values of velocity, acceleration, and displacement amplitude were lower in the soaked condition than in the dry condition [11]. Al-Ezzi and Zakaria's (2020) empirical investigation on the dynamic response of a circular foundation examined how it reacted to the dynamic load brought on by the placement of a square-shaped nearby base that is said to be ‘a source of vibration’ on top of it. Both foundations were built on gypsum soil, which was bendable and contained 65% gypsum. Three frequencies of dry and wet circumstances were used for the research. The findings demonstrated that both second baseline's acceleration and amplitude decreased as the interval between inspirations widened. Additionally, these factors had a higher value in a dry state than in a wet state [12]. Ling et al. (2021) used a dynamically effective finite element to investigate the effects of the frequency content of the input motion and the amplitude of both the horizontal and vertical components of the input motion on pile settlement in saturated sand sediments. To represent the dynamic behavior of different sand densities, a modified generalized plasticity model was used to investigate how the permeability of the soil affected the pile-soil system's seismic reaction. According to the findings, under otherwise identical conditions, the relatively far-off earthquake caused more severe liquefaction at the sand deposit than the close earthquake, leading to more settling of the pile group. Additionally, the vertical ground motion should be considered in engineering design as it may greatly exacerbate the coseismal liquefaction-induced settling of the pile group (ρ_E) [13]. However, there haven't been many experiments on how pile foundations behave next to machine foundations. By using a small-scale experimental model, this study seeks to explain the impact of dynamic interference between two closely spaced foundations lying on sandy soils. The investigation on the dynamic reaction of a pile foundation next to another footing under a dynamic load has been presented in this work (vibration source).

2. Methodology

2.1 Soil used

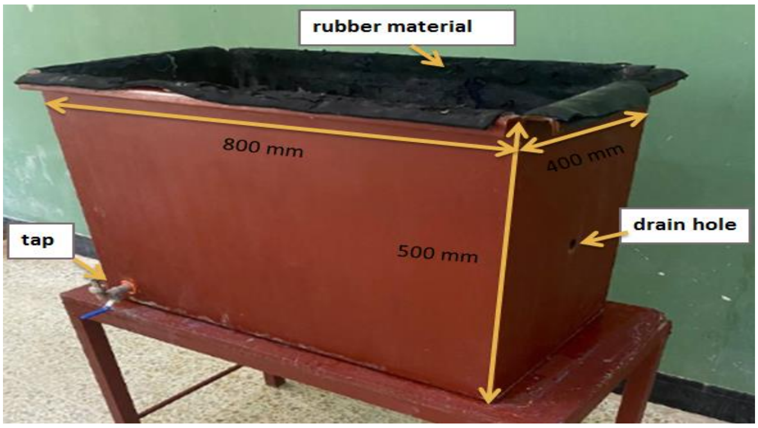
Sandy soil was brought in from the Iraqi governorate of Karbala, then essential tests were conducted on soil laboratory at the College of Engineering University of Diyala. The properties of sand are represented in Table 1.

2.2 Steel container specification

The container used in the study was made of steel plates with a thickness of (4) mm, and its overall dimensions were (800*400) mm by (500) mm as a depth. The container manufactured in the local market was equipped with a copper tube with a length of (350) cm and a diameter of (1) cm, placed in a spiral shape with small works at the bottom of the container to saturate the soil during the tests. A layer of rubber (4) mm thick was installed on the inner walls of the container to reduce the effect of vibration of the machine foundation. It is worth mentioning that the container was reinforced with cross steel corner welding to prevent side bending. A hole at the bottom of the model has also a tap installed to control the amount of water entering the container and delivering it to the copper tube for regular water distribution. The container was depicted in Figure 1.

Table 1: The results of the Sand Properties used in the study.

Item	Properties	Value According to
	Grain size analysis	
1	Effective size, D10 (mm)	0.16 ASTM D422 and ASTMD 2487 (2006)
2	D30 (mm)	0.27 ASTM D 422 and ASTM D2487(2006)
3	Mean size, D50(mm)	0.41 ASTM D 422 and ASTM D 2487 (2006)
4	D60 (mm)	0.52 ASTM D 422 and ASTM D 2487 (2006)
5	Coefficient of uniformity, Cu	3.25 ASTM D 422 and ASTM D 2487 (2006)
6	Coefficient of curvature, Cc	0.89 ASTM D 422 and ASTM D 2487 (2006)
7	Classification (USCS)	SP ASTM D 422 and ASTM D 2487 (2006)
8	Specific gravity, Gs	2.67 ASTM D 854 (2006)
9	Angle of Internal Friction (Ø)	34.3^{o} ASTM D3040 -04(2006)
10	Cohesion(c) $(kN/m2)$	0 ASTM D3040- 04 (2006)



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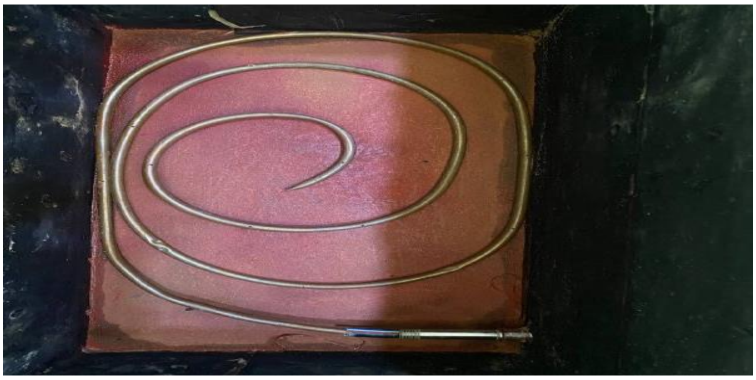


(b)

Figure 1. Steel Container: (a) General View, (b) Top View

2.3 Pile and pile cap

Solid steel piles have been used with a circular cross-section of 8 mm in diameter and 250 mm in length as a group as shown in Figure (2).

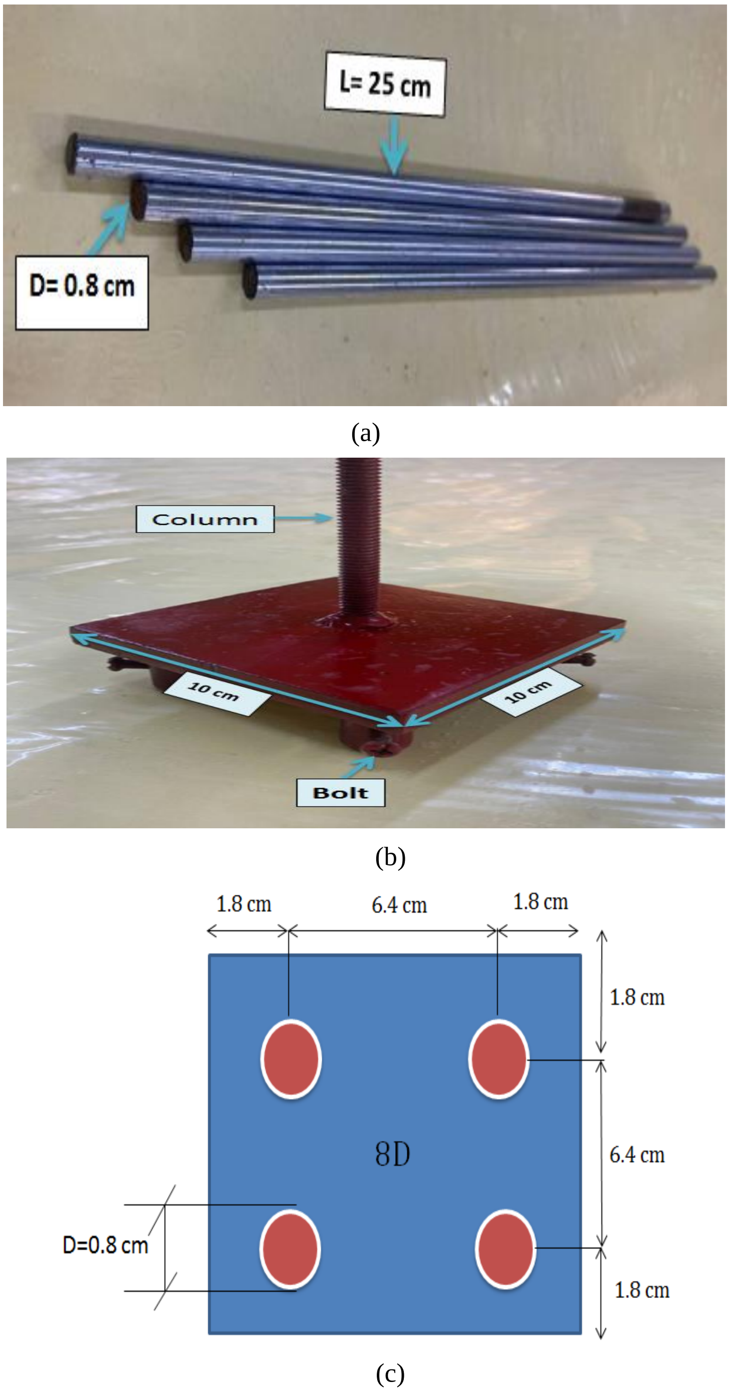


Figure 2. Piles used in model tests (a): dimension of Piles (b): dimension of cap (c): pattern of pile

2.4 Soil preparation

Sandy soil is the soil bed used in the container, it has been arranged into four layers to fill the model box with (400*400*800) mm as (high *width and *length) of volume, respectively. Each layer has dimensions of (100*400 and *800) mm, and the weight of the total volume of soil is calculated using the dry unit weight of the soil. The weight of each layer is estimated using the calculated volume and dry unit weight of the soil. The soil layer is compacted to the desired depth using a vibrating hammer. A thick plastic pad covers the vibration hammer's base to prevent or reduce soil particle crashing. When adding the next layer, each layer is leveled after compacting. The compaction effort and several hits are fixed in all prepared soil layers to achieve uniform density across all layers, as illustrated in Figure 3.

(a)

(b)

Figure 3. Preparing Soil Bed (a): During soil preparation (b): After completing the soil preparation

2.5 Apparatuses of model

In experimental model of work, many devices and equipment are used (Figure 4) as follows:

1. The first Footing (Mechanical oscillator).
2. The second pile foundation
3. Variable frequency drive
4. Vibration meter
5. Digital Tachometer
6. Steel model
7. Water Tank
8. Dial Gauge
9. Static Weight
10. AC automatic voltage regulator
11. Camera stand
12. Dial gage stand
13. Tank stand

A Diagram of the test device including details of the device parts showed in the Figure 5.

Figure 4. Equipment and devices of laboratory model testing

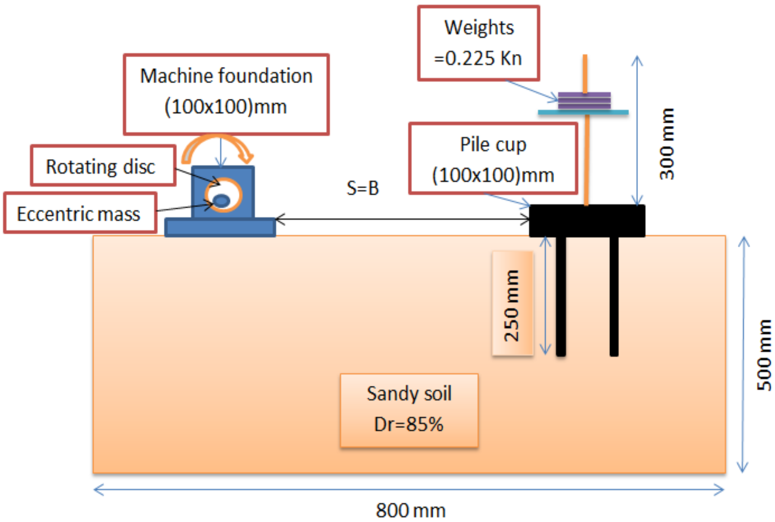


Figure 5. Diagram of test device with details

2.6 Test setup

After screening previous studies by diverse researchers, the experimental model was designed where the pile raft is subject to static load weight of 23kg. The idealization of the problems is derived in the following differential equation:

$$mz + k\ddot{z} + c\dot{z} = Q_o \sin(wt + \beta) \qquad (1)$$

The oscillator is mechanical with a rotating mass instead of the first base to generate a dynamic variable load. This mechanical oscillator consists of a rotating disk made of steel with a diameter of 60 mm and a thickness of 13 mm, as well as a small deflection mass (I) instead of a rotating disk at deflection (E) of 15 mm from the axis of rotation. In this study, only one type of eccentric setting with a value of 50 g was used. A DC motor is used to drive a mechanical oscillator at various frequencies ranging from (100 rpm - 12000) rpm. The controller is placed outside the model to control the speed of the DC motor. Before demonstrating a dynamic response such as displacement amplitude, velocity, or acceleration, the piezoelectric accelerometer is connected directly to the computerized model of the digital vibrometer (6063). The DT-2234A+

(Digital Tachometer) model has been applied to ensure that the frequencies do not change as shown in figure 4. Both feet are placed centrally over the prepared soil. After checking the results obtained by previous studies, and performing the 1-hour initial tests, the 30-minute dry zone run test, and the 30-minute soak test time, it is worth noting that the steel container was left for 4 hours to soak. In this study, dynamic loading was simulated using eccentricity (m_e). Then the oscillator was slowly driven by the speed controller to avoid a sudden high dynamic load. So, the first foundation was subjected to vertical vibration. The dynamic reaction (displacement amplitude and acceleration) of the second base was evaluated and recorded simultaneously using a piezoelectric accelerometer. The operating frequency (600, 1200 and 1800) was considered equal to (10, 15 and 20) Hz, and the dynamic response parameters were recorded every 2 minutes during the time of running the test. Device used for measuring vibration response is shown in Figure 6.

(a)

(b)

Figure 6. Devices used for measuring test (a): vibration response (b): Digital tachometer

3. Results and discussion

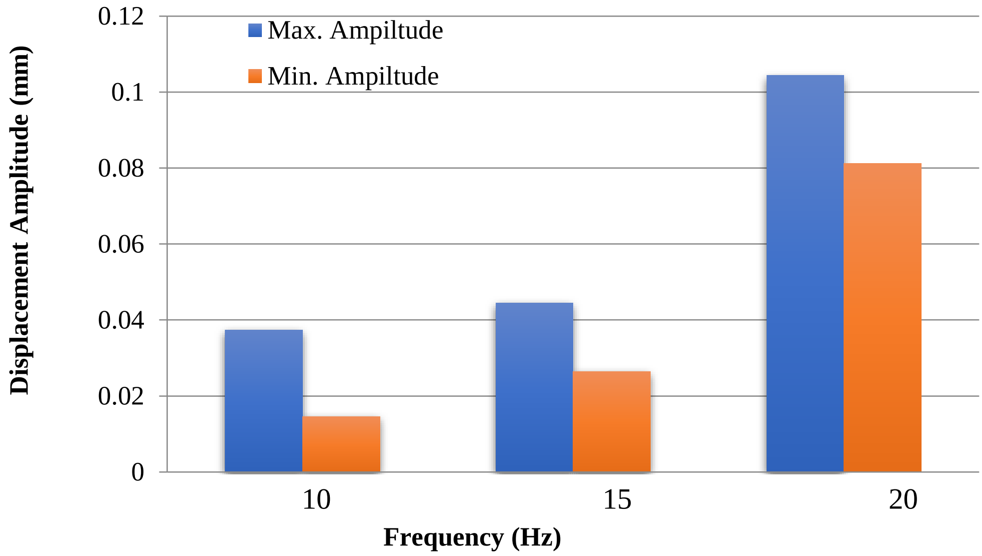
Results are presented in this paper in two styles

3.1 Columns method

The results of displacement amplitude, acceleration, velocity and settlement with frequency were presented

3.1.1. Displacement amplitude

Figures 7 and 8 show the maximum and minimum displacement amplitudes for both dry and soaked sandy soil conditions versus frequency. At (0.5B), the displacement amplitude increased in both the dry and soaked cases with an increase in the frequency from 10 Hz to 15 Hz. A slight increase compared to the frequency of 20 Hz is considered to be the most dangerous in both cases (dry and soaked), due to the role of water as a wave damper. It has been shown that in soaking conditions, the displacement amplitude value of the three frequencies was lower than it would be in the dry condition. The displacement amplitude was smaller at B spacing than it was at (S = 0.5B). The reason for this was that the vibrations travelled away from the vibration source (machine foundation) to the adjacent pile raft. In other words, the amplitude decreased with increasing distance, and the energy of the vibrations decreased as it moved through the sandy soil. The maximum displacement amplitude in the dry state increased by two time from 10 Hz to 20 Hz at the 2B spacing and three time in value at 20 Hz. While the displacement amplitude value increased by 2.5 times, the frequency increased from 10 Hz and 20 Hz. When the frequency was increased from 10 to 20 Hz, the displacement amplitude increased by 5.5 times in soaked state. With respect to the dry state, the displacement amplitude values were lower than in the soaked state. The maximum amplitude increased 3 times when the frequency increased from 10 to 15 Hz, but 4 times upon reaching frequency 20 Hz. While the minimum displacement amplitude increased two times, the frequency increased from 10 to 15 Hz. However, it increased by four times when reaching the frequency of 20 Hz. Hence, when comparing the displacement amplitude values of the three frequencies (10, 15, and 20) Hz in the soaked condition with their value in the dry condition, they decreased due to the decrease in the amplitude of the first base (vibration source) which was caused by water as a vibration damper. It has been noted that as the operating frequency rises, the first base's (the source of vibration) amplitude increases as well, leading to an increase in the second base's amplitude. In reality, these variations in the displacement amplitude are caused by the various forces that result in various stress levels under the excited basis, as defined by (Mandal and Bedia, 2003) [14].



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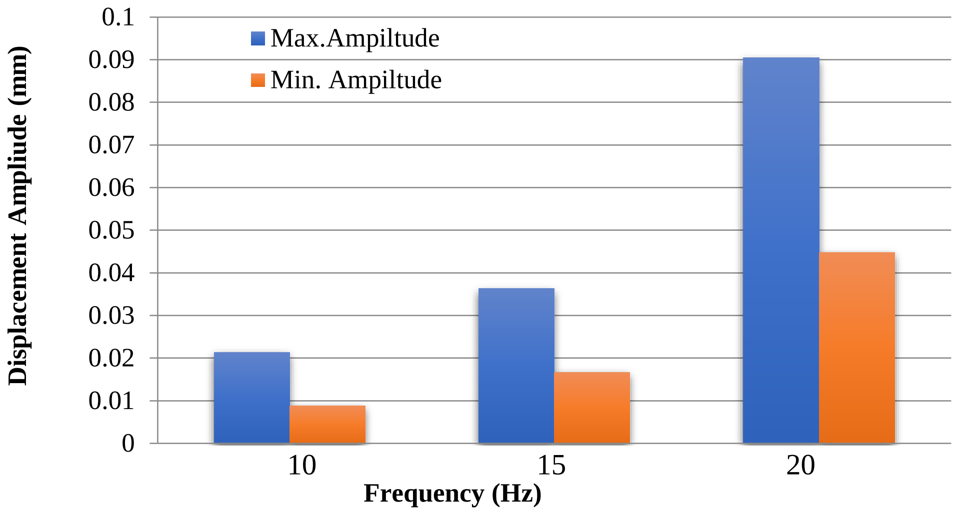

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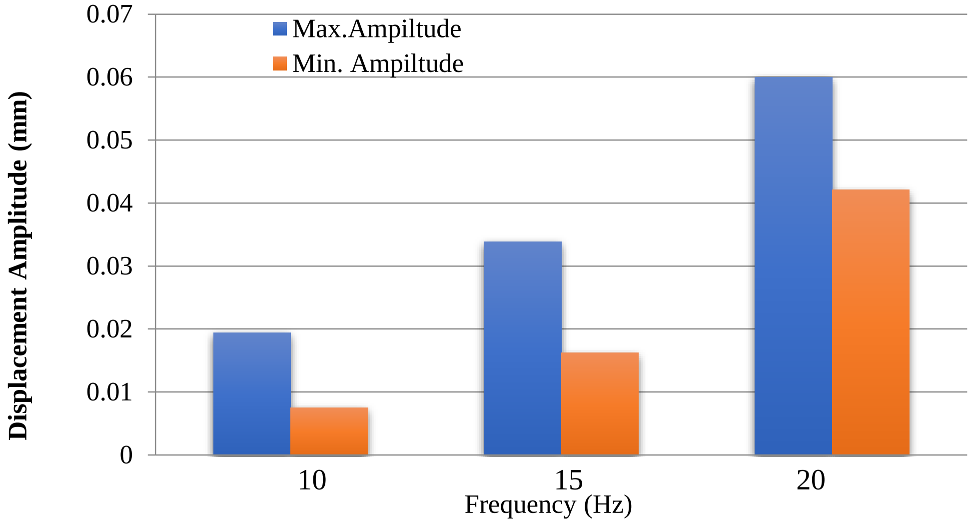
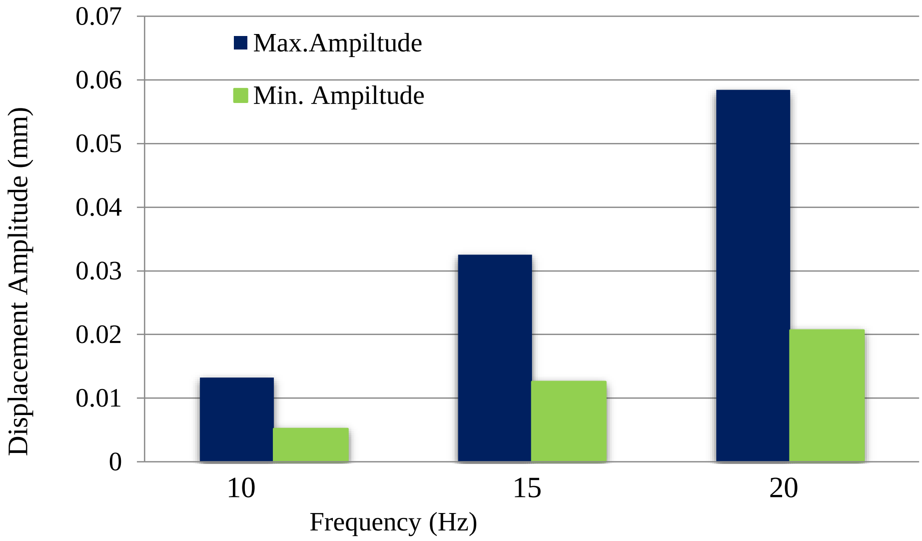


(c)

Figure 7. The displacement amplitude versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for dry condition



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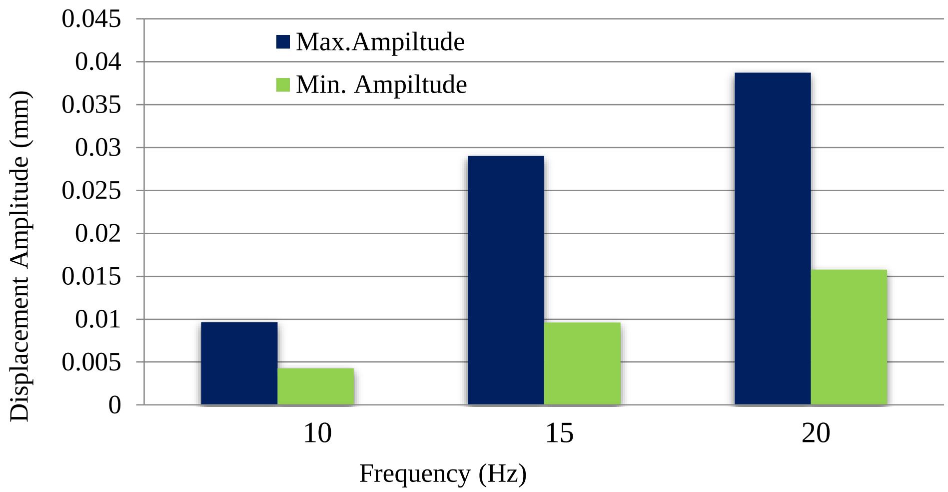

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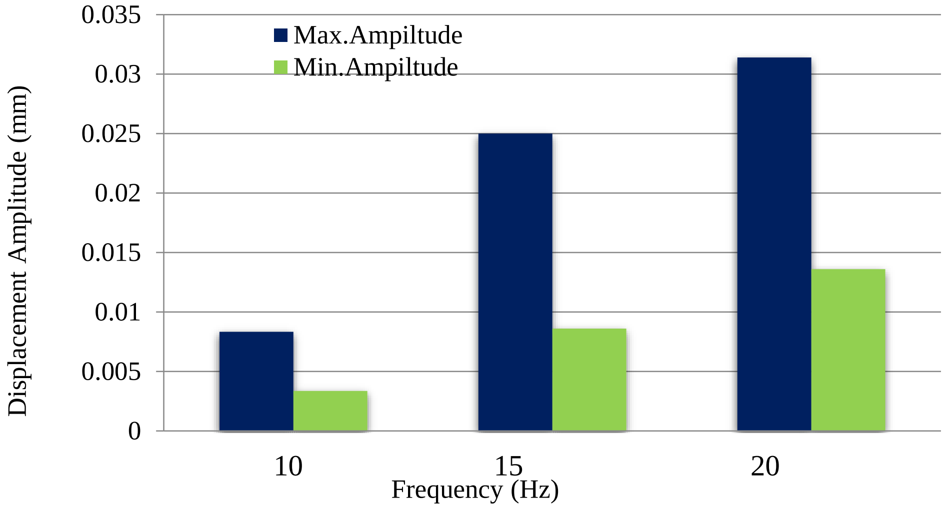
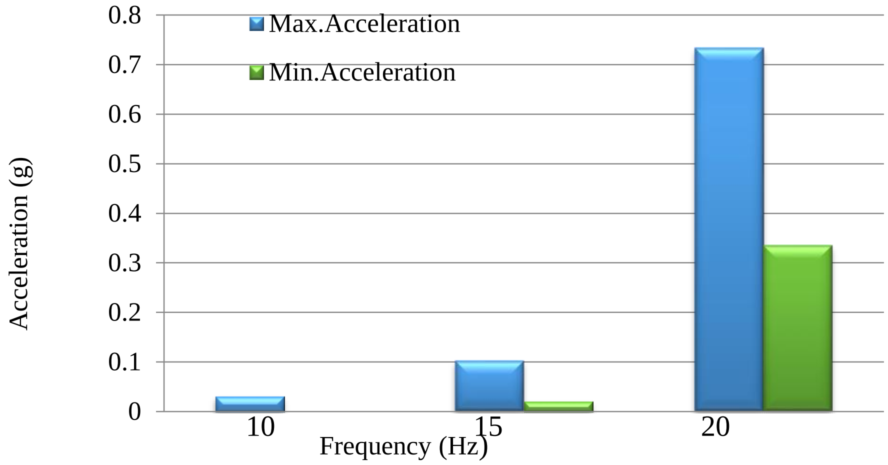


(c)

Figure 8. The displacement amplitude versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for soaked condition

3.1.2. The acceleration

Figures 9 and 10 show the relationship between the maximum and minimum accelerations with three frequencies (10, 15 and 20) Hz in both soaked and dry conditions for three distances (0.5B, B and 2B). We notice that the maximum and minimum acceleration patterns are similar in the dry and soaked cases. In both cases, the acceleration value rises with increasing frequency. Given the lower energy of vibrations propagating through the soil, the effects of increasing the distance between the machine foundation and pile foundation on the accelerated volume are comparable to the effects of decreasing the displacement amplitude and acceleration as the distance increases. In addition, the acceleration is greater in the dry state compared to the soaked state. As can be seen, increasing the frequency from 10 Hz to 20 Hz over a distance of (0.5B) leads to a fairly large increase in the amount of acceleration in the dry state. Similar rules apply for periods (1B) and (2B). At frequencies of 10 Hz and 15 Hz, the minimum acceleration is neglected. When the frequency rising from 10 Hz to 15 Hz, the maximum and minimum rates of acceleration in the soaking state rise. As the exponents diverge, the hesitation that exists between the greatest and lowest accelerations diminishes. The values of acceleration decreased in the soaked case for three frequencies (10, 15 and 20) Hz, at a spacing of (0.5B, B and 2B) compared to their values at the dry level due to the presence of water, which (as mentioned earlier) acts as a wave damper in the soil and increases with its frequency. No matter if it is soaked or dry. In both states, the acceleration decreases as the distance between the foundations increases, as shown in Figure 9 and 10.



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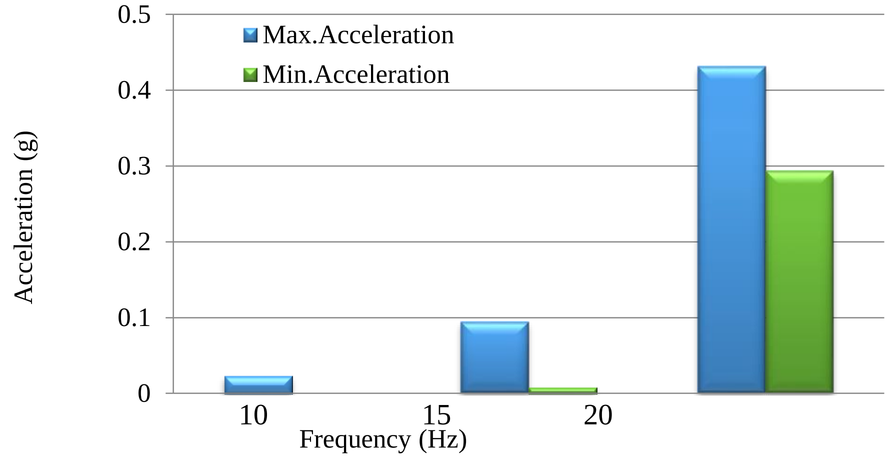

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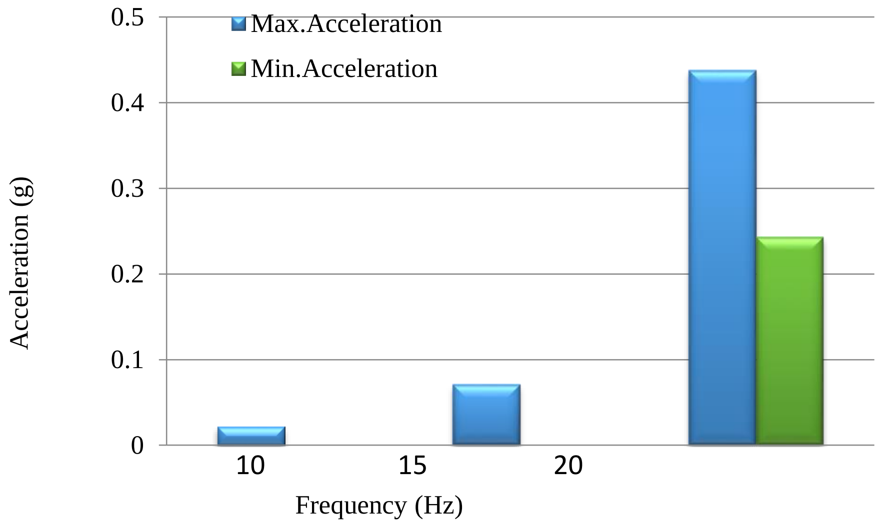

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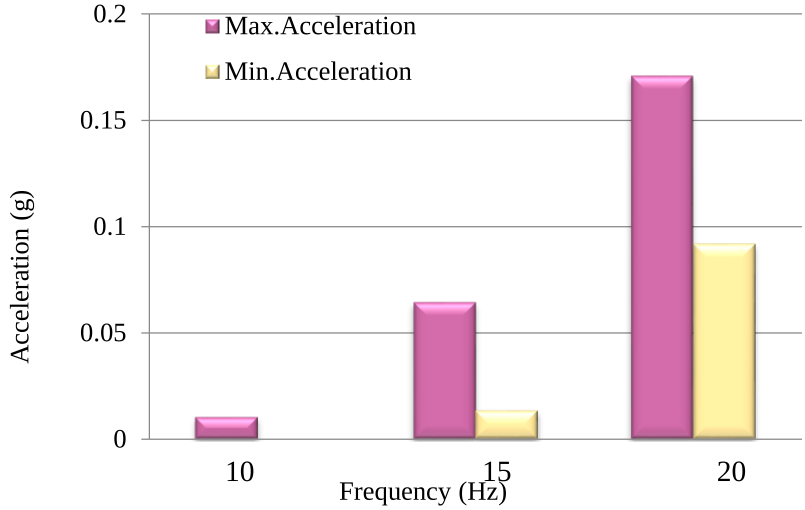
Figure 9. The acceleration versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for dry condition



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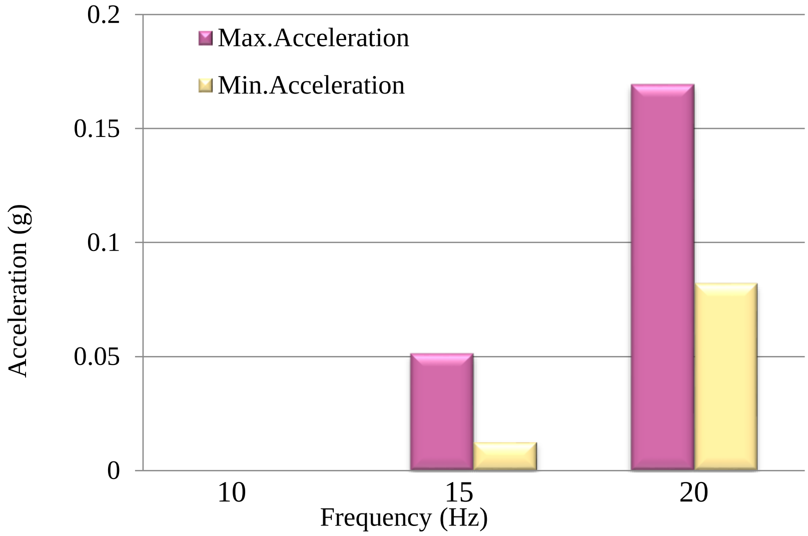

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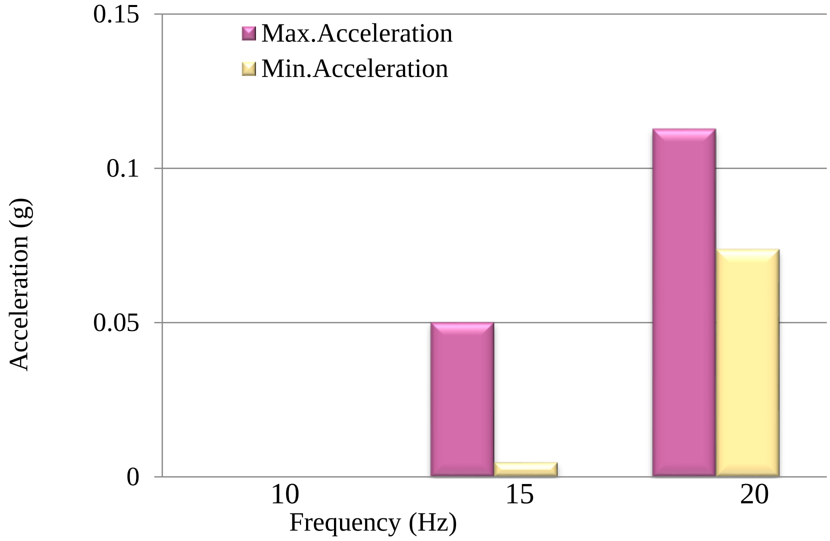
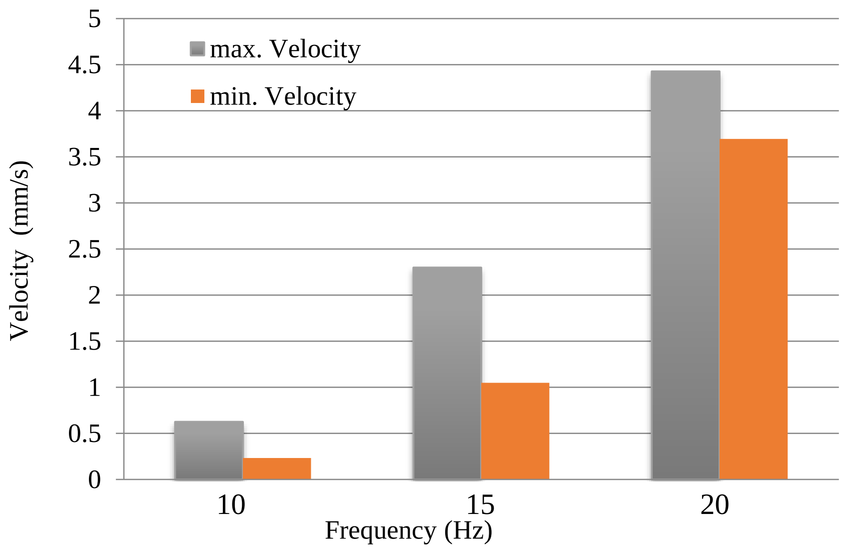


(c)

Figure 10. The acceleration versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for soaked condition

3.1.3. Velocity

In Figures 11 and 12, the maximum and minimum velocity versus frequency is plotted for both dry and soaked sandy soil. It is obvious that when the frequency increases for both dry and soaked conditions of soil, the velocity increases. At the spacing (S = 0.5B) the maximum velocity reaches the highest value at the frequency of 20 Hz. In both dry and soaked soil conditions, the velocity increases if the frequency is increased from 10 Hz to 15 Hz. Due to the effect of water as a wave damper, it was found that in soaked conditions, the velocity value of the three frequencies (10, 15, and 20) Hz is less than in the dry state. The magnitude of the velocity decreases when the spacing increases from (S = 0.5B) to (S = B). This is attributed to the vibrations that are transmitted away from the source of vibration (the foundation of the machine) to the pile foundation. In other words, when the distance increases, velocity decreases, and the energy of the vibrations decreases as it travels through the soil. The maximum velocity in the dry state increased by three times from 10 Hz to 15 Hz at a spacing of 2b and increased by eight times in value at 20 Hz. The value is doubled from 10 Hz to 15 Hz or 20 Hz for the minimum velocity. The value of velocity is lower in the soaked than it is in the dry condition. When the frequency increased from 10Hz to 15Hz, the maximum velocity increases a little. When the frequency increased from 15Hz to 20Hz, the velocity is doubled as the frequency increases from 10 to 15Hz. When comparing the magnitude of velocity at (S = B) and (S = 2B) for both cases, the value of velocity decreased in this case (soaked and dry state) as shown in Figures 9 and 10. Lambe and Whitman (1979) have observed that the velocity at frequency of 20 Hz can be the most hazardous, since its maximum value is 4.43 mm/s, a case which is regarded to be disturbing and harmful for humans. The allowed velocity has been taken is 2.5 mm/s, while the frequency at 15 Hz has a max velocity of 2.3 mm/s, which can be noticeable and dangerous. When operating within the permitted limits and at a frequency of 10 Hz, its maximum velocity is 0.6 mm/s slightly noticeable (Lambe and Whitman, 1979). [15]



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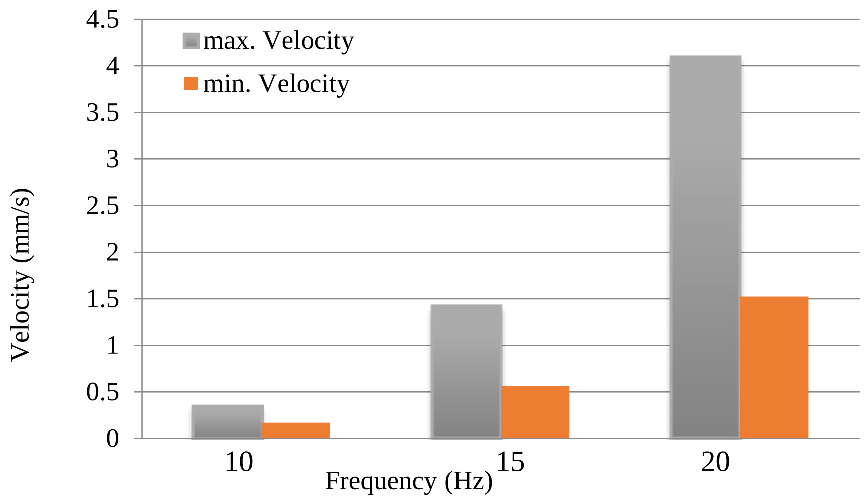

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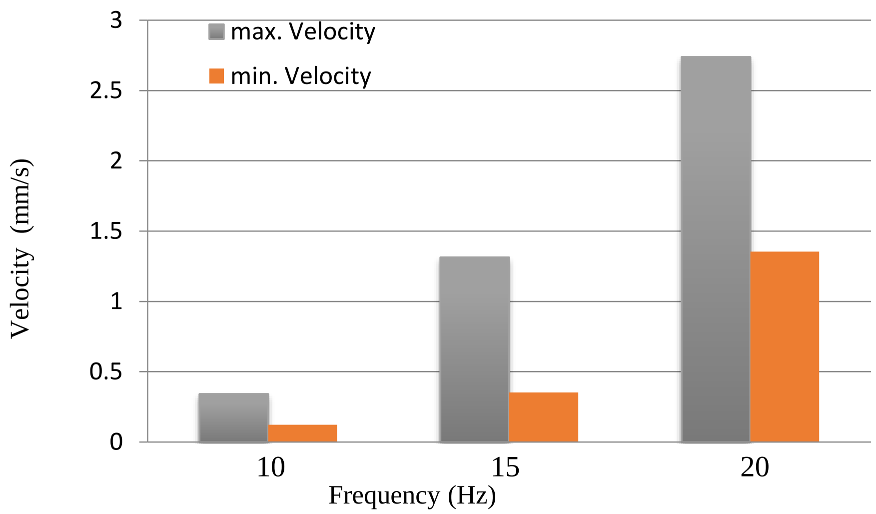

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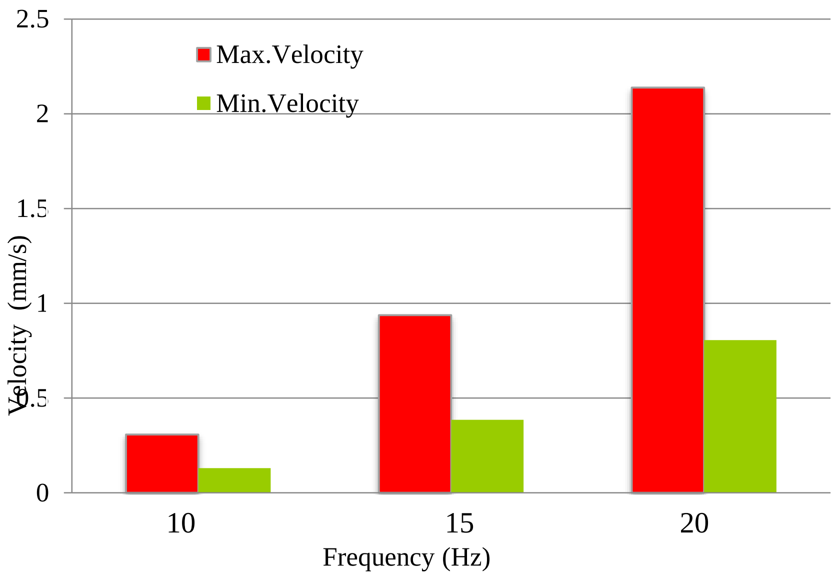
Figure 11. The velocity versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for dry condition.



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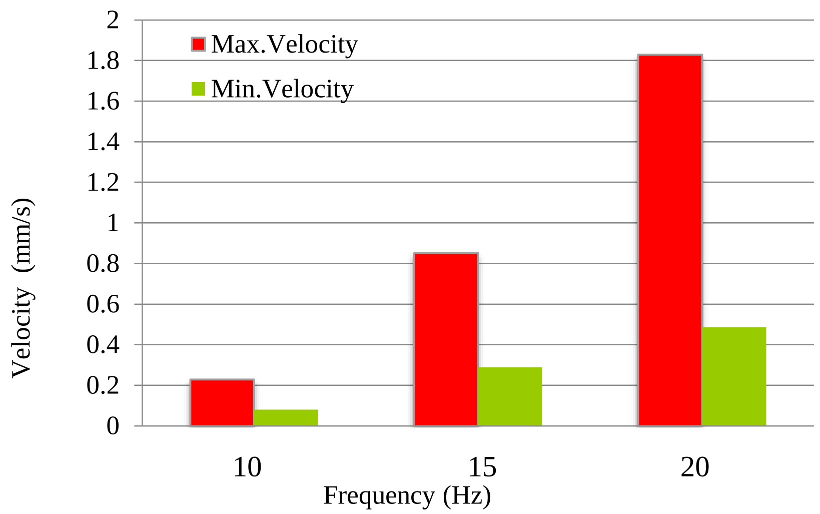

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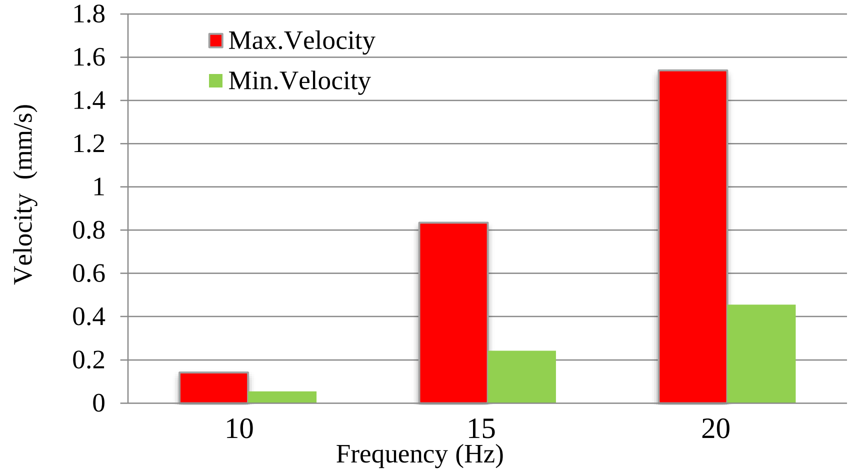


Figure 12. The velocity versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for soaked condition

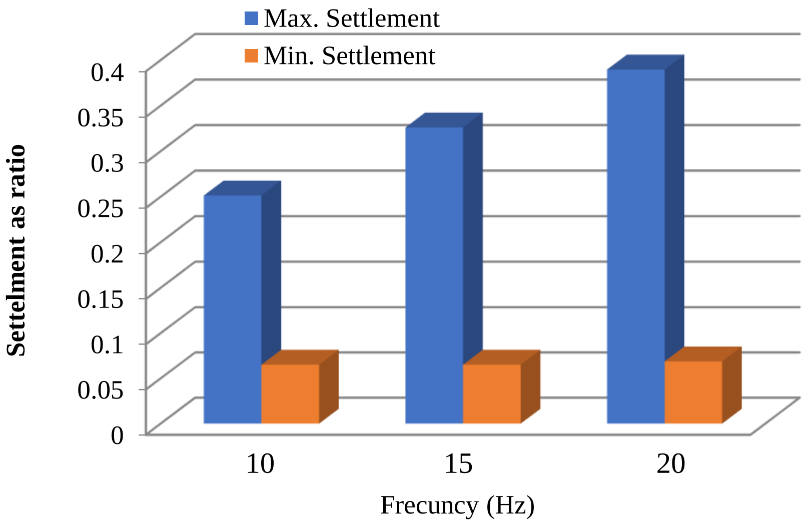
3.1.4. Settlement

Figures 13 and 14 show the pile foundation settlement of the maximum and minimum versus frequency. At (0.5B) the settlement increases in both the dry and soaked states of soil with the frequency increases from 10 Hz to 15 Hz, which is a slight increase as compared to the 20 Hz frequency. This case is considered to be the most dangerous in both conditions (dry and soaked), The settlement value produced by the settlement from the frequency at 10 Hz, is lower than that from the frequency at15 Hz, which is the lowest when compared to the settlement from the 20 Hz frequency. So, the eventual settlement of the foundation increases with the amplitude of the dynamic force. At this point, an increase in soil permeability, which causes a decrease in density, is regarded to be the main cause of the settlement that occurs. It can be said that the compromise of 20 Hz is up to 61% of the allowable value of settlement ratio which is considered to be dangerous, 15 Hz is up to 48% Hz, 10 Hz up to 31% Hz. The latter is considered to be the safest of the (15 and 20) Hz frequencies. [16-19].

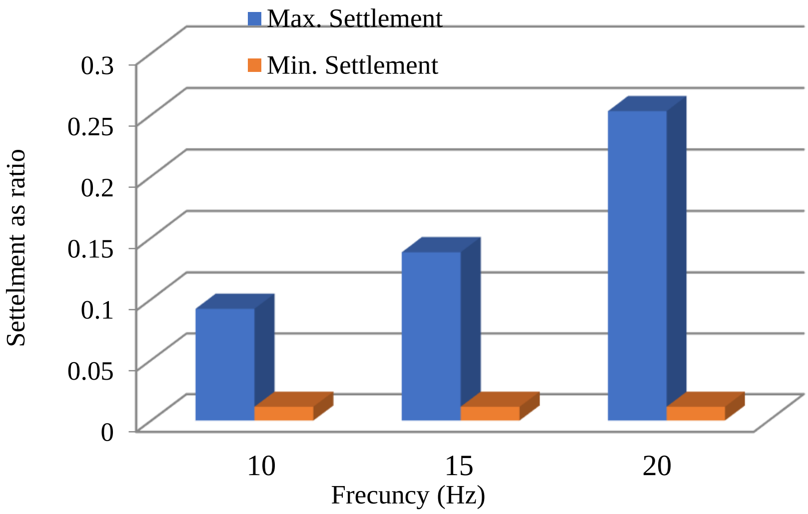
It is noticeable that the settlement results were presented more easily when dividing the settlement values in millimetres by the diameter of the pile (0.8) to extract the percentage of precipitation and dividing the result by (10) %

of the pile diameter of (0.1) as a failure criterion equal to (1), as shown in the equation below:

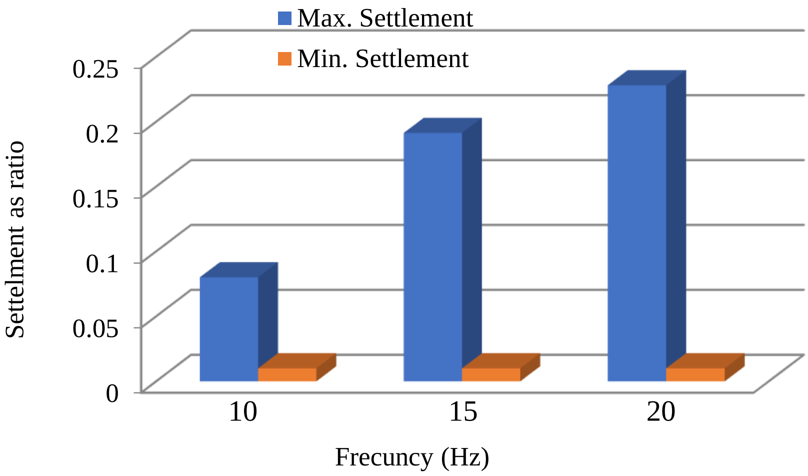
$$\text{settlement asRatio} = \frac{\text{settlement reading (mm)/ failure criteria(10\%Diameter of pile)}}{\text{0.1 failure criteria}} \quad (2)$$



(a)



(b)



(c)

Figure 13. The Settlement versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for dry condition

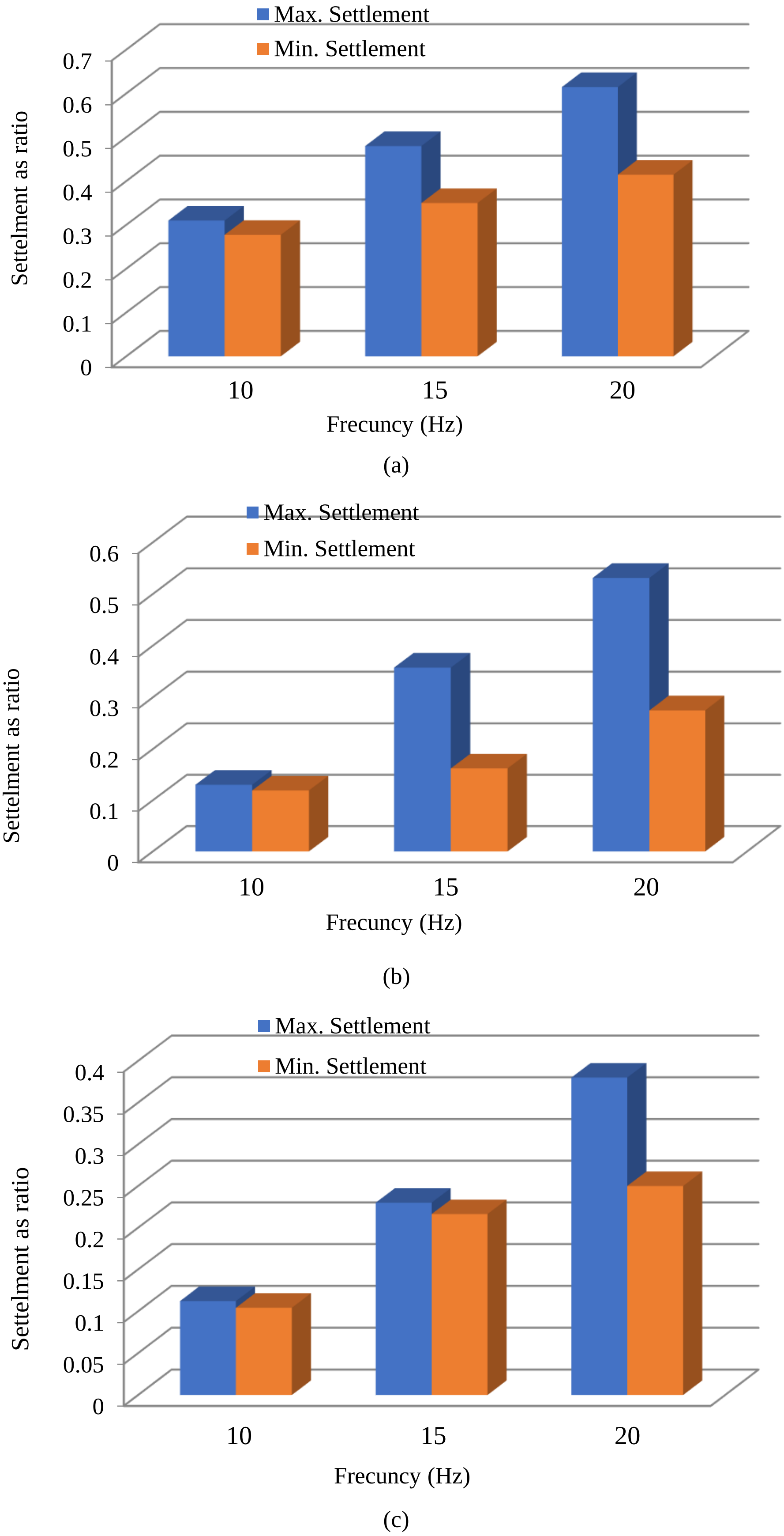


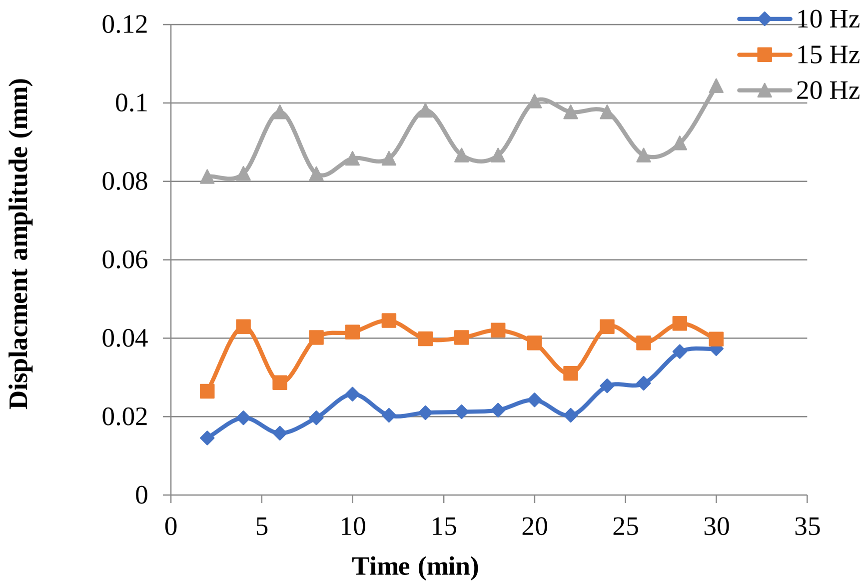
Figure 14. The Settlement versus frequency for different spacing (s), a at S = 0.5B, b at S = 1B, c at S = 2B) for soaked condition

3.2 Curve method

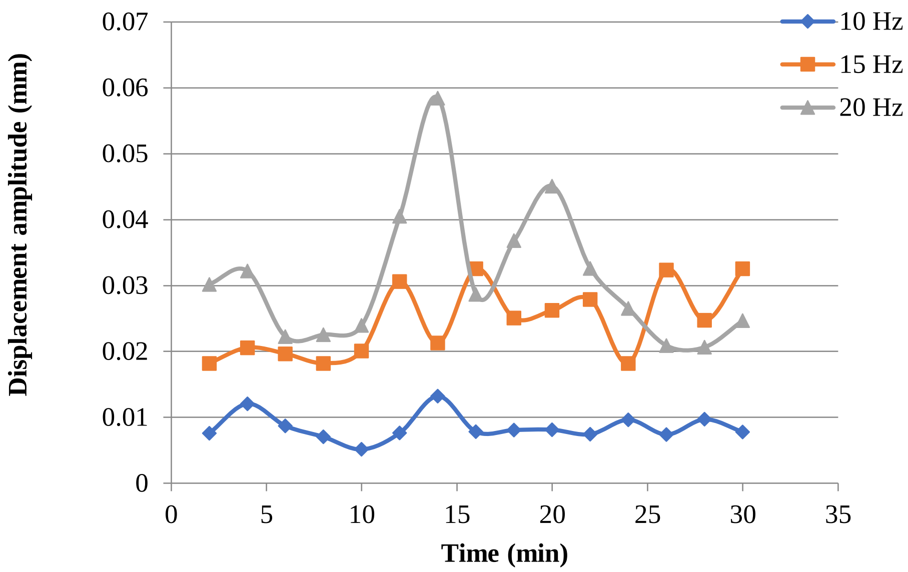
The connection between displacement amplitude, acceleration, velocity, settlement, and time were presented below:

3.2.1 Displacement amplitude

Figure 15 (a and b) shows the relationship between displacement amplitude with time for three frequencies (10, 15 and 20) Hz in both immersed and dry conditions for a distance of (0.5B). In figure 15 (a), we notice that the 20 Hz frequency seemed to be fluctuated, then increased towards the end of the test. As for the 15 Hz frequency, it fluctuated and increased towards the end of the test. The amplitude curve at 10 Hz shows less fluctuation than the 15 and 20 Hz curve and approached to the curve of 15 Hz at the end of the test. The author believes that in terms of displacement for 20 Hz, it is considered to be more dangerous than 10 and 15 Hz due to the severe fluctuation and high peak value. Figure 15 (b) shows the relationship between amplitude and time for the three frequencies regarding soaked sandy soil, and the exciting footing here is at the distance of (0.5B). As shown in figure 15 (b), the 10 Hz time curve has the least fluctuation during the test time. The 15 Hz frequency shows a fluctuation of more than 10 Hz and increases slightly at the end of the test and the 20 Hz frequency has the most fluctuation during the test period and reaches its highest value at the minute of (14) then becomes less at the frequency curve of 15 Hz in the last minutes of the test. In other words, the author sees that, according to the large fluctuation, the frequency of 20 is more dangerous than the frequency of 10 Hz and 15 Hz, and this leads to a significant increase with the increase in frequency, and its value is less than that in the dry soil.



(a)

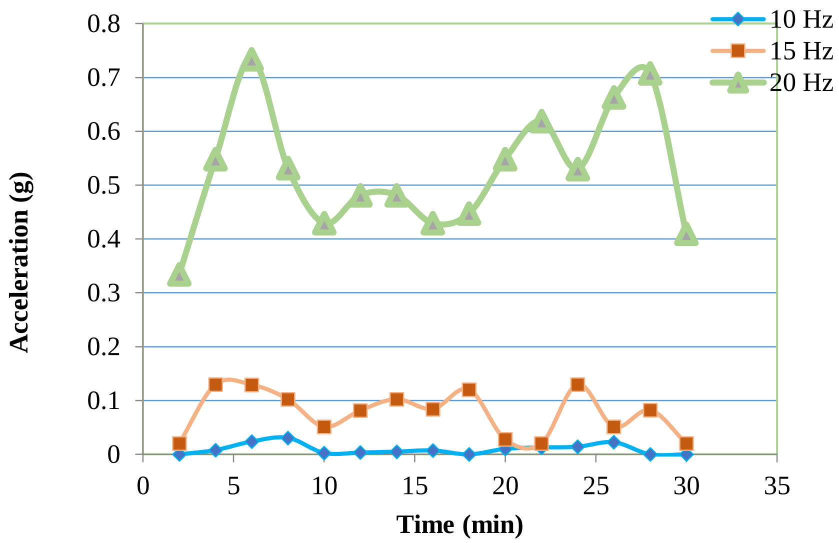


(b)

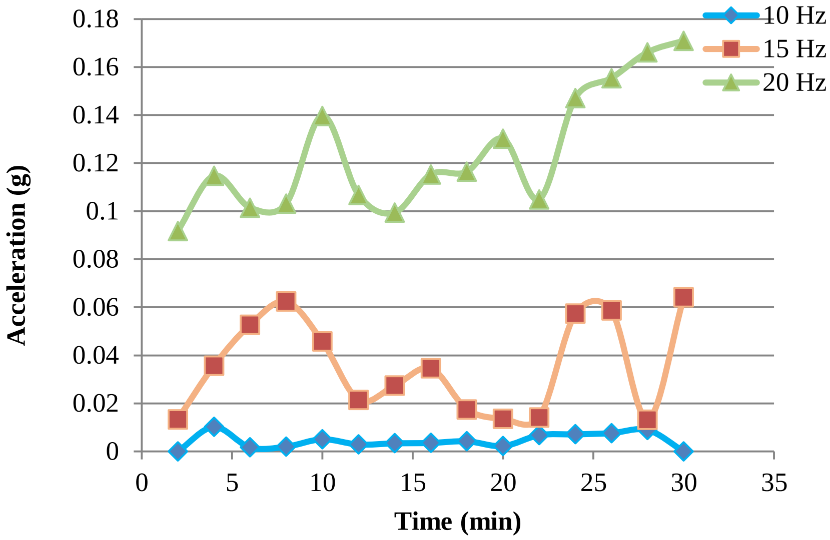
Figure 15. The displacement amplitude versus frequency for different spacing (s), a at S = 0.5B for a: dry soil, b: soaked soil

3.2.2. The acceleration

Figure 16 (a and b) shows the relationship between the accelerations and time for the three frequencies (10, 15 and 20) Hz in both soaked and dry soil for the distance of (0.5B). In figure 16 (a), we notice that acceleration corresponding to 20 Hz oscillates over time and decreases at the end of the test. The acceleration curves for 10 and 15 Hz appeared to be close together with little fluctuation for most of the testing time. Both curves almost converge and drop little difference between them, in contrast to the 20 Hz curve. In figure (16.b), it can be seen that the acceleration curve at the frequency of 10 Hz is the least oscillating and decreases at the end of the test. The 15 Hz curve is more volatile and increases towards the end of the test. As for the frequency of 20 Hz, it is the most volatile, and from the minute of (24) it tends to increase linearly until the end of the test.



(a)

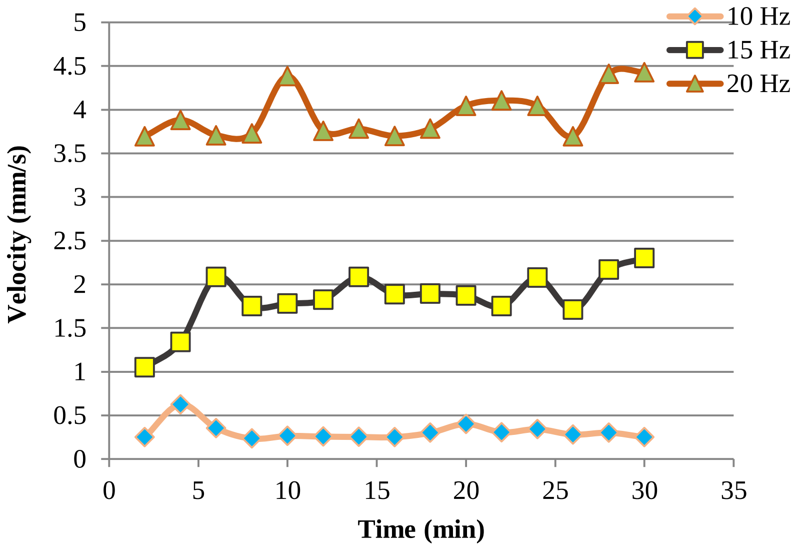


(b)

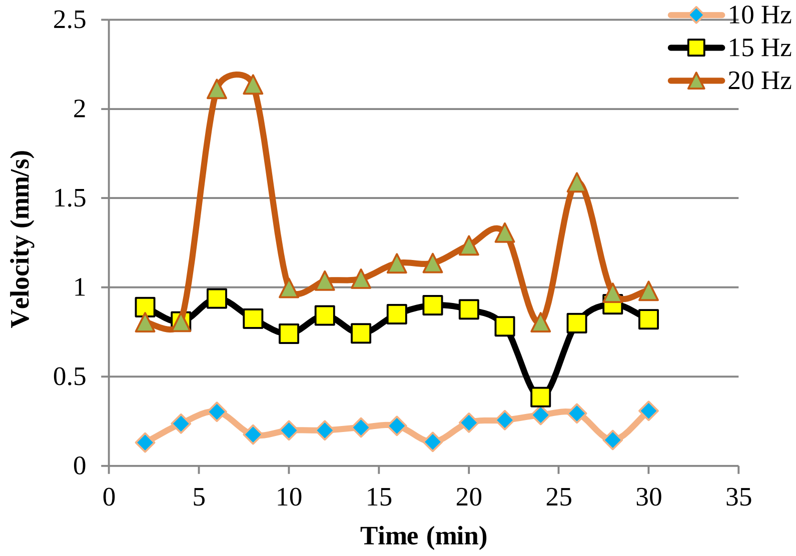
Figure 16. The acceleration versus frequency for different spacing (s), a at S = 0.5B for (a): dry soil, (b): soaked soil.

3.2.3. The velocity

Figure 17 (a and b) plots the velocity over time in dry and soaked sandy soil. It is noticeable that in Figure 17 (a) that the velocity curve at 10 Hz shows a slight fluctuation and decreases at the end of the test. Similarly, the frequency of 15Hz shows a little fluctuation during testing and increases eventually. While the frequency of 20 Hz shows a lot of fluctuation during testing. Figure 17 (b) shows the relationship between velocity versus time measured for the same frequencies (10, 15 and 20 Hz) regarding soaked condition of soil. It is clear from the curves that the velocity increases with increasing frequency. Moreover, the velocity curve at 10 Hz remains nearly constant with a slight fluctuation. The frequency curve of 15 Hz begins with a slight fluctuation and continues until the 24th minute in which a fall occurs, then returns to the previous position and continues until the end of the test. While the frequency curve of 20 Hz appears below the frequency of 15 Hz in the first minutes of the test, it intersects with the frequency of 15 Hz at the minutes of 4 and 28, respectively from beginning until the middle of the test, then the 20 Hz curve begins to increase until the end of the test.



(a)

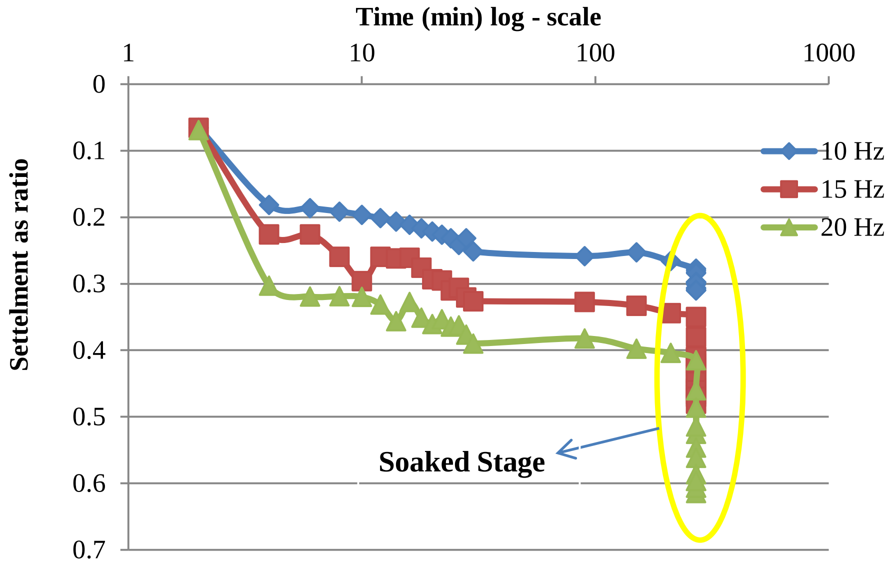


(b)

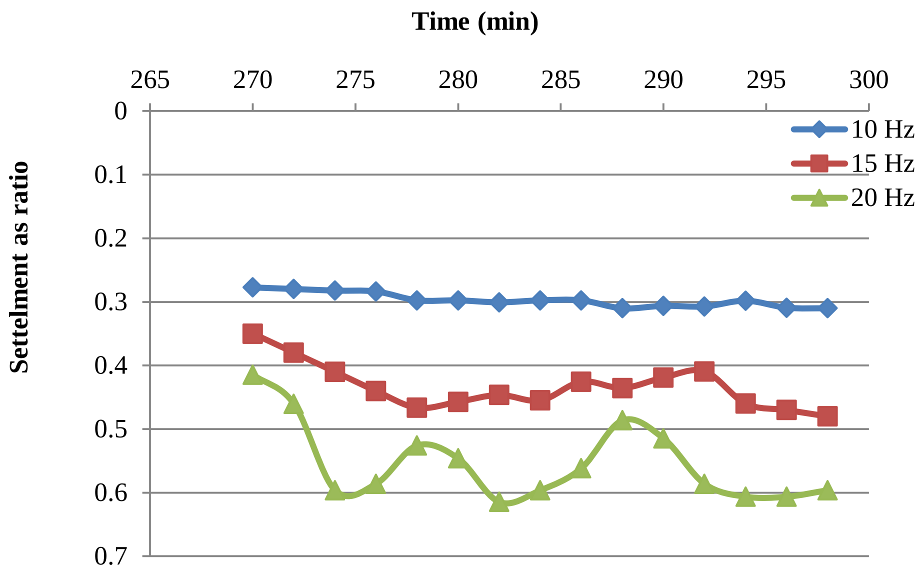
Figure 17. The velocity versus frequency for different spacing (s), a at S = 0.5B for (a): dry soil, (b): soaked soil.

3.2.4. The settlement

Figure 18 show the relationship between settlement against time measured for three frequencies (10, 15, and 20 Hz), on dry and soaked soil conditions; the vibration footing is located here at a distance of (0.5B). As can be seen in the figure (a), the settlement for the 20 Hz curve appears to be the largest in both dry and soaked operating conditions when compared to the settlement for the 15 and 10 Hz curves. However, throughout the testing, the curve at 10 Hz has the lowest settlement, but the curve at 15 Hz has a larger settlement.



(a)



(b)

Figure 18. (a)The Settlement ratio versus time for both states (dry and soaked) at spacing (0.5B). (b). Zooming of soaked soil

4. Conclusions

In this study, a laboratory experiment was conducted to study the dynamic behavior of a foundation of piles as a result of the effect of different frequencies in sandy soil. Based on the results obtained, the following conclusions can be drawn:

1. The values of displacement capacity, velocity, acceleration and settlement decrease with increasing distance between the two foundations (pile foundation and machine foundation) from 0.5B to 2B in the dry and soaked state.
2. The values of displacement, velocity, acceleration and settlement increase with increasing the operating frequency of the vibration source (machine foundation) from 10 Hz to 20 Hz in both dry and soaked states.
3. The most dangerous condition is at the frequency of 20 Hz and the distance is 0.5 B in the dry state. Generally, the dry state is considered to be more dangerous than the soaked state, with the exception of settlement, whose values are higher in the soaked state than those in the dry state.

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