Al-Rafidain Engineering Journal (AREJ) Vol.30, No.2, September 2025, pp. 163-175

Assessing the Dynamic Behavior of Step Footing Placed on the Surface of Sandy Soil

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Received: May 30th, 2025 Received in revised form: July 25th, 2025 Accepted: August 25th, 2025

ABSTRACT

Numerous factors, including soil type, moisture content, foundation type, and excitation intensity, have impacted how soil responds to excitation forces. An accumulation of underlining soil deformation caused by the machine's vibration may exceed the limit. An experimental investigation was conducted to evaluate the effect of machine-induced vibrations on four prototype footings positioned at the soil's surface. Among the four footing models, three were designed with stepped areas, while one had a uniform rectangular section. The stepped footings were constructed with varying bottom-to-top area ratios (A_2/A_1) of 1.0, 1.2, 1.5, and 2. Three operating frequencies (10, 40, and 70 Hz) were applied to each of the four footings. The soil used was sand with a medium relative density of 50%. Dynamic response data include vertical amplitudes (displacement, velocity, and acceleration), settlement, and pressures at various depths. Despite different in magnitudes, it was found that the stepped footings significantly reduced the machine-foundation system's pressure, settlement, and amplitude movements. For instance, the stepped footing with area ratio of (A2/A1=2.0) displayed the lowest dynamic response. The pressure decreased by an average of 14.5% when the area ration changes from (A2/A1=1.0) (A2/A1=2.0), while the total settlement, amplitude displacement and acceleration were reduced by about 30%, 42% and 54%, respectively. Further, compared to a uniform footing, stepped footing is more cost-effective with high-performance.

Keywords:
Machine foundation; Step footings; Sandy soil; Amplitudes

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1. INTRODUCTION

Current developments in technology in the mining, cement, and grinding mill industries necessitate the creation of a machine foundation system with high performance, availability, and precision. These structures have complicated geometry and multiple loads in addition to being sensitive [1]. In addition to avoiding resonance, the primary objective of machine foundation design is to minimize and restrict vibration amplitudes to remain within a reasonable range [2]. The stiffness of the foundation and underlying soil have impact factors on the behavior of machine foundation, whereas the mass of block foundations plays a major role [3].

Using the MATHCAD application, Fattah et al. [4] investigated the issues with machine foundations when the block footings were subjected to a vertical vibration. As the machine operating frequency, soil density, shear modulus, Poisson ratio, and damping ratio increased, it was found that the maximum displacement significantly decreased. According to Van Koten et al. [5], the soil on each side of shallow and deep foundations substantially enhanced damping and effectively decreased displacement amplitude. Hussein et al. [6] demonstrated experimentally that when the machine was placed on the surface, the amplitude displacement and pressure increased under the machine foundation.

The impact of several parameters on the vibration modes' response of a rectangular foundation situated on sandy soil was examined by Abdul Kaream et al. [7]. It employed a variety of vibration modes, including pitching load amplitude, frequency, rocking, and vertical. It was found that changing the vibration mode have a little effect on the final strain under the same frequency and displacement in the Z-direction, while the Y-direction displacement amplitude is larger under the rocking mode and the X-direction displacement amplitude is higher under the pitching mode with the same frequency. A 3D finite element method was used to examine the vibration transmission properties of the footings [8]. It was examined how the loading intensity impacted a number of characteristics, including the damping coefficient, soil stiffness, and natural frequency. In addition, the impact of footing shape on the elastic uniform compression coefficient, shear modulus, and dynamic shear strain was suitably assessed. It was revealed that the system response is greatly influenced by the shape of the foundations. When the reciprocating machine's frequency fluctuates without causing any detrimental effects, it is possible to maintain the foundation's size and frequency constant [9].

Experiments were carried out on circular and rectangular machine footing types resting on clay soil under varying saturation levels of 60% and 100%. The experiment's findings demonstrated that increasing the saturation level has the effect of lowering the foundation's amplitude displacement to about 60%. Significant impact on displacement inside the soil results from a change in saturation level [10]. On the surface, the dry soil showed a 33% acceleration over the saturated one, and the pressure beneath the footing dropped by 40%, whereas the saturated soil settled 150% more than the dry soil [11]. The geometry of the machine foundation relative to the slab and column dimensions was studied by Ahmed et al. [12] using numerical analysis. It was found that the natural frequency and the displacement amplitude were controlled by geometry. As the dimensions of the column increased, the natural frequency increased and the displacement decreased. Through experimental investigated, Fattah et al. [13] found that the amplitude of the displacement of the rectangular machine-footing placed on dry sand was higher than that in saturated case. The settlement decreased with increasing density, saturated and embedment, while increased with frequency level. On the contrary, the slab properties showed a slight effect on the dynamic response of the foundation system. The behavior of three different kinds of machine foundations set on sandy soil at various frequency levels was examined empirically by Alhasso and Qasim [14]. The foundational shapes were strip, square, and rectangular. It was found that a decrease in displacement was correlated with an increase in the foundation's length to width ratio.

This study experimentally investigates the dynamic response of four model footings with uniform and stepped sections to compare their performance and identify the configuration with the lowest response under dynamic machine loading.

2. INDEX PROPERTIES OF SOIL

According to the Unified Soil Classification System (USCS), the sandy soil used in the current study is classified as poorly graded sand (SP). The soil sample underwent a number of index and physical testing in accordance with ASTM [15] procedures. Fig. 1 displays the soil's grain size gradation, and Table 1 lists the characteristics of the sand used in the current study.

Table 1 Index test properties of sand

Properties	Value	Sspecification
Specific gravity (G_s)	2.65	ASTM D 854
Coefficient of uniform (C_u)	5.15	ASTM D 422
Coefficient of curvature (C_C)	0.285	ASTM D 422
Soil classification (USCS)	SP	ASTM D 2487
Maximum void ratio (e_{max})	0.536	………
Minimum void ratio (e_{min})	0.295	………
Max dry unit weight (kN/m^3)	20	ASTM D 4253
Min dry unit weight (kN/m^3)	17.0	ASTM D 4253
Field dry unit weight (kN/m^3)	18.4	--------
Angle of internal friction (φ^o) for (Dr) =50%	36°	ASTM D3080

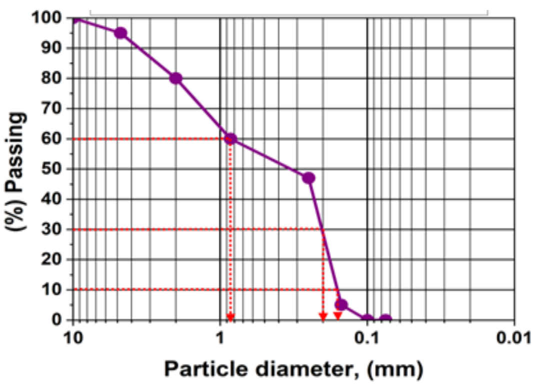


Fig. 1 Grain size gradation curve of the sand

3. METHODOLOGY

3.1 Experimental Setup

A steel box of 1400 x 1200 mm, 800 mm in height, and 6 mm in plate thickness made up the experimental model. In order to accommodate the boundary effects of physical models subject to dynamic loading, these dimensions were chosen (see Fig. 2a).

The sand was passed through sieve #10 and retained on sieve #100. Layers of sand, each 100 mm thick, were placed in the test box to guarantee the uniformity of the soil density. As shown in Fig. 2b, the layers were manually compacted using a steel tamper to meet the requirements for sandy soil (relative density = 50%). To verify the desired density, a sand cone was used to control the density. In order to measure the machine vibration impacts (distributed pressure, settlement, and vertical amplitudes) of the machine-foundation system, the experiment model was designed and built with accessories and sensors installed. To absorb any vibration waves, compressed cork was applied to the box area's inner walls.

(a) The box model

(b) Compacted the soil as layers

Fig. 2 Text box model

The machine-foundation-soil system is depicted in Fig. 3. Four screws hold the electric vibration rotary machine which creates excitement in the foundation to the top of the surface footing. The machine is 80 × 200 mm in size, weighs 49 N, and has a maximum frequency of 6000 rpm. Its forcing vibration amplitude is 10 kN.

Fig. 3 Machine-foundation-soil system

3.2 The steel model footings

Four prototype footing models have been chosen with a different ratio of the bottom section area (A2) to the top section area (A1). The footings models are identical in weight (277 N), and their dimensions are as follows:

1. The area ratio A2/A1 =1.0: The uniform model footing has a same top area (A1) and a bottom area (A2) of (240× 140) mm, as shown in Fig. 4a.
2. The area ratio A2/A1 = 1.2: The step model footing has a top area (A1) of (240×140) mm and a bottom area (A2) of (260× 160) mm, as shown in Fig. 4b.
3. The area ratio A2/A1 = 1.5: The step model footing has a top area (A1) of (240×140) mm and a bottom area (A2) of (320× 160) mm, as shown in Fig. 4c.
4. The area ratio A2/A1 = 2.0: The step model footing has a top area (A1) of (240×140) mm and a bottom area (A2) of (360×185) mm, as shown in Fig. 4d.

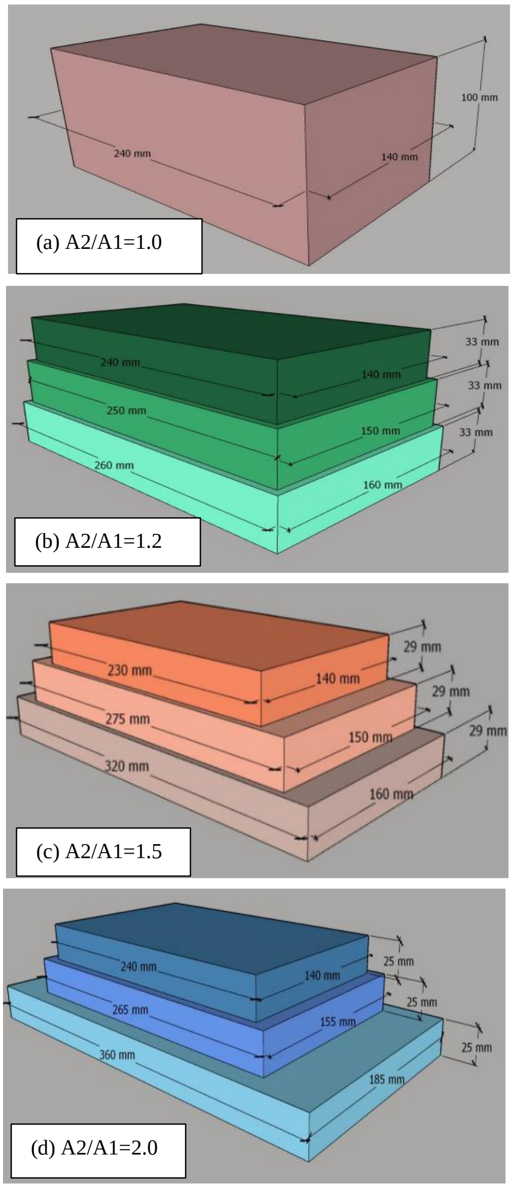


Fig. 4 Types and shapes of footings

3.3 Model instrumentations

As seen in Fig. 5, several kinds of sensors were positioned in the soil at different points.

1- The pressure sensors: due to the deep distribution of pressures in the soil under dynamic load, the pressure monitored at four depths within the soil medium were distrbuted as follows:
  - The (P1) was placed below the center of the footing at a depth of B/2 (where B represents width of footing), which designate as (0, 0.5B).
  - The (P2) was placed below the center of the footing at a depth of 1.0B which designate as of (0, 1.0B).
  - The (P3) was placed below the center of the footing at a depth of 2.0B, which designate as (0, 2.0B).
  - The (P4) was placed at a depth of 1.0B and at distance 1.0B from the center of the footing, which designate as (1.0B, 1.0B).
2- The vertical dynamic vibration sensor: To measure the vertical amplitudes of displacement, velocity, and acceleration under the dynamic load, a 1g accelerometer type was positioned at top the footings.
3- Linear Variable Differential Transformer sensor (LVDT): To measure the total settlement of the machine-foundation-soil system under dynamic loading, an LVDT was positioned atop the footing.

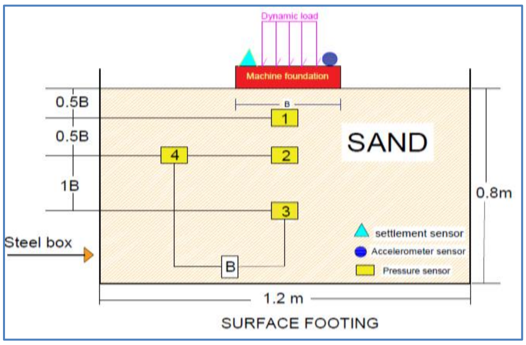


Fig. 5 Schematic view of sensors distribution in the model

3.4 Research Methodology

The dynamic response behavior of four different footing types having the same weight (277 N) was examined in this study. The three footings of the stepped section having area ratios of (bottom area / top area) expressed as (A2/A1) equal to (1.2, 1.5, and 2.0) while the fourth one is a uniform rectangle (as reference). The machine fixed on the footings and rested on dry sand was excited to cause vertical vibration in these footings.

The footings were exposed to three frequencies (10, 40, and 70 Hz), which correspond to low, medium, and high speed, respectively, as defined by Bhatia [16]. The tests continued for 900 seconds. According to the design requirements (w_o/w_n < 0.5 or w_n/w_o >2), the selected frequencies are away from the resonance frequency [16]. The sensors were positioned at designated locations and connected to the data acquisition system shown in Fig. 6 to control and monitor the test operation in accordance with the scheme shown in Fig. 5. Lastly, the measured data includes the vertical amplitudes of displacement, velocity, and acceleration as well as the distributed pressure and total settlement.

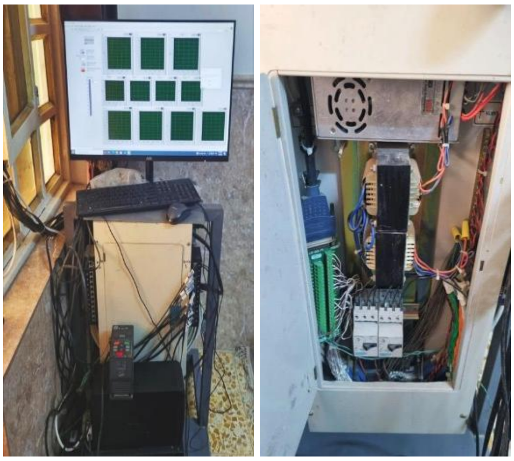


Fig. 6 Programmable logic controller (data acquisition)

4. RESULTS AND DISCUSSIONS

4.1 Effect of Footing Area Ratio on Pressure Distribution

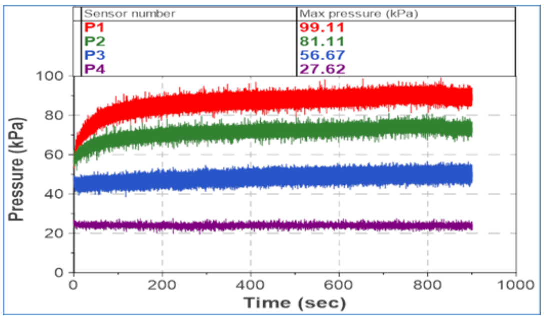
At various depths in the soil beneath the footing, the maximum pressure readings were recorded. Three frequencies (10, 40, and 70 Hz) were applied to the footing with different area ratios (A2/A1).

Table (2) shows that, compared to the low and medium frequencies (10 and 40 Hz), the largest pressures have been noticed with the high-speed frequency (70 Hz).

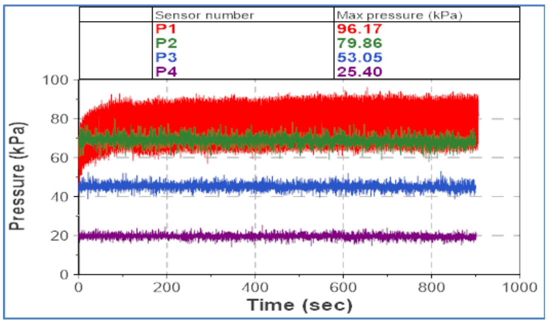
For instance, Fig. 7 displays the pressure distribution beneath the footing across the 900-second stimulation period at a frequency of 70 Hz. Table (2) shows that, compared to the low and medium frequencies (10 and 40 Hz), the largest pressures have been noticed with the high-speed frequency (70 Hz). The variation of the pressure becomes almost constant over time as non-uniformity of footing increases, i.e. the area ratio (A2/A1) increases. Furthermore, it can be shown that as the area ratio (A2/A1) increases, the footing becomes less sensitive to machine vibration, indicating a decrease in the machine-footing system's dynamic responsiveness. The sensor (P1) recorded the highest pressures at depth 0.5B of order 99.1 kPa. Abdul Kream et al. [17] reported a similar conclusion.

In addition, the maximum pressure decreases as the area ratio increases. Quantitavely, for the footing of the area ratio (A2/A1) of 1.0, 1.2, 1.5, and 2.0, the pressure values are 99.11, 96.17, 87.17, and 84.64 kPa, respectively.

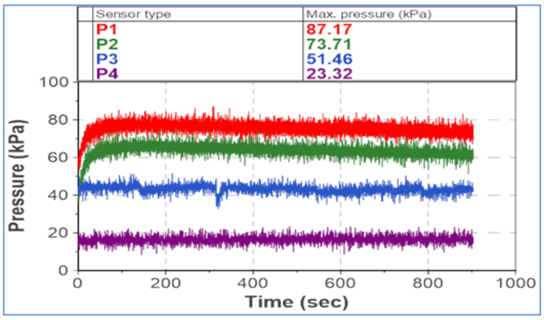
An increase in the footing area ratio under dynamic loading results in a wider distribution and dispersion of pressure beneath the footing. This indicates that as the area ratio increases, the foundation's dynamic reaction diminishes, reducing its susceptibility to external excitation.



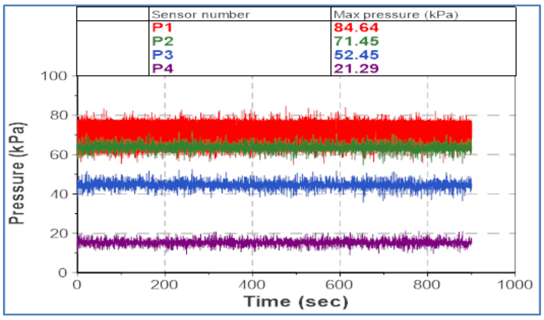
a. Footing (A2/A1 = 1.0)



b. Footing (A2/A1 = 1.2)



c. Footing (A2/A1 =1.5)



d. Footing (A2/A1 =2.0)

Fig. 7 Variations of pressure with time under frequency (70) Hz

Figure 8 along with Table 2 reveals that, at a frequency of 10 Hz, the maximum pressure recorded at 0.5B under footings has been obviously decreasing by 5.1%, 10%, and 14% when the ratio (A2/A1) is increased from 1.0 to 1.2, 1.5, and 2.0 accordingly. For frequency 40 Hz, the pressure decreased by 4%, 8%, and 14%; for frequency 70 Hz, pressure decreases by 3%, 12%, and 15%. Fattah et al. [18] found that although the pressure decreased with depth, it was 10% more at the footing's corner.

In general, it can be concluded based on the pressure results that the maximum effective area ratio is 1.5 for high frequency, after which the effect is small.

Table 2 Maximum pressure (kPa) measured below the footings at different locations after 900 seconds

Frequency level	**Locations (B=width of footing)**	**Maximum pressure (kPa)**			
		Footing area Ratio (A2/A1)			
		1.0	1.2	1.5	2.0
10 Hz	0.5 B	71.0	67.4	64.0	61.0
	1 B	63.3	59.6	57.0	50.0
	2 B	42.8	37.6	33.5	32.0
	(1B, 1B)	19.4	17.8	15.7	14.5
40 Hz	0.5 B	87.0	83.2	80.0	75.0
	1 B	74.0	70.0	68.5	61.0
	2 B	53.0	49.6	44.0	43.5
	(1B, 1B)	25.5	24.3	21.4	19.5
70 Hz	0.5 B	99.1	96.2	87.2	84.6
	1 B	81.1	79.9	73.7	71.5
	2 B	56.7	53.1	51.5	52.5
	(1B, 1B)	27.6	25.4	23.3	21.3

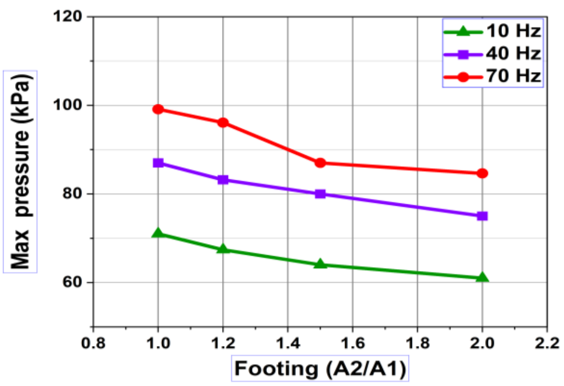
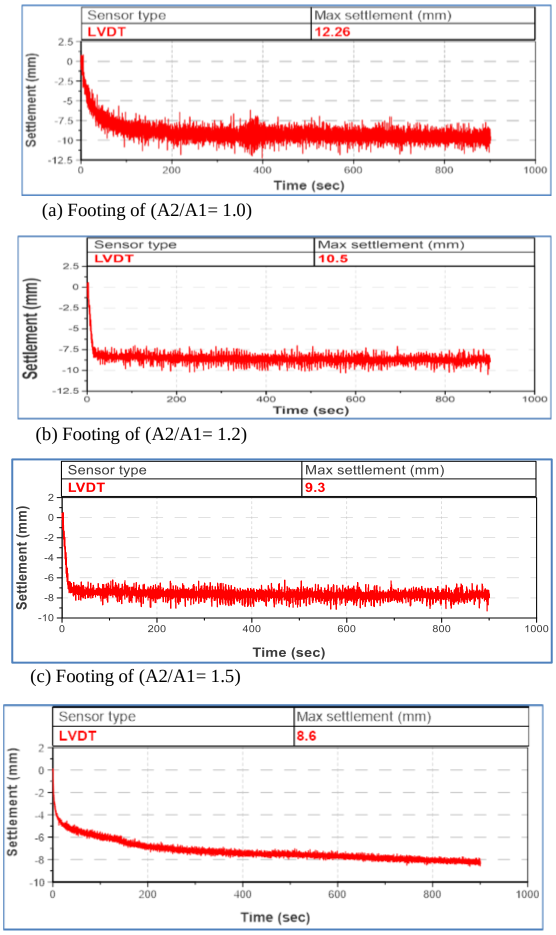


Fig. 8 Relationship between maximum pressures and area ratio of footing at depth 0.5B under 70Hz

4.2 Effect of Footing Area Ratio on Settlement

The settlement-time responses realtion for the four footing types is displayed in Fig. 9. It is obvious that following a substantial increase in the settlement during the early stages of machine operation, the settlement almost remains unchanged. By increasing the footings' area ratios, one can observe a notable drop in settlement values. An increase in the contact area between the base of the stepped footings and the surrounding soil particles is the cause of the decrease in settlement.

Except for the behavior of the footings with area ratio (A2/A1=2.0), the footings generally showed a similar tendency with regard to the settlement-time relationship. After 200 cycles, the footing with the area ratio (A2/A1=1.0) steadied. In the meantime, next 10, 20, and 400 cycles, respectively, the stable conditions of footings with (A2/A1 = 1.2, 1.5, and 2.0) are merged.



(a) Footing of (A2/A1= 1.0)

(b) Footing of (A2/A1= 1.2)

(c) Footing of (A2/A1= 1.5)

(d) Footing of (A2/A1= 2.0)

Fig. 9 Variations of settlement with time under frequency 70Hz

The settlement values drop significantly when (A2/A1) increases from 1.0 to 1.2, 1.5, and 2.0 by 22.5%, 31%, and 31% for 10 Hz, respectively, as displayed in Fig. 10 and Table 3. Furthermore, it is observed that the values of settlement decrease by 13%, 26%, and 27% for the frequency of 40 Hz as (A2/A1) increases. The comparable settlement reductions under 70 Hz are 14%, 24%, and 30%. This indicates that the effect of the base area ratio on the settlement decreases with increasing frequencies. Additionally, the settlement increases as the frequency level rises, which is consistent with the findings of Fattah et al. [13].

Footing area ratio (A2/A1)	Maximum settlement (mm)		
	Frequency		
	10 Hz	40 Hz	70 Hz
1.0	8.0	10.0	12.3
1.2	6.2	8.7	10.5
1.5	5.5	7.4	9.3
2.0	5.5	7.3	8.6

Table 3 Maximum settlement of the footings at different frequency after 900 second

Additionally, it is obvious from Fig. 10 that as (A2/A1) increases above 1.5, the settlement almost remains unchanged particularly for low frequency. This gives limits on the extent to which the increase in the base area of the footing affects settelement.

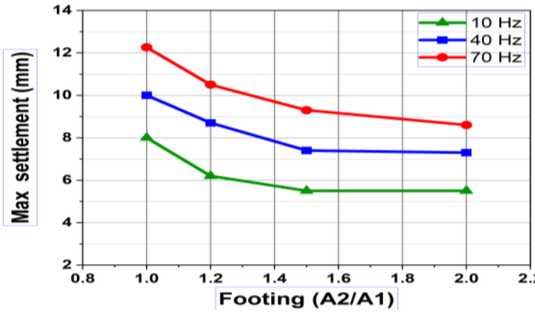


Fig. 10 Relationship of max settlement and area ratios footings under 70 Hz

4.3 Effect of Footing Area Ratio on Vertical Displacement, Velocity, and Acceleration

Over a period of 900 seconds, three variables were recorded: the maximum amplitudes of acceleration, velocity, and displacement caused by excitation. Reviewing Figs.11 to 14 under 70 Hz, it is clear that converting from a uniform rectangular footing to stepped footings reduces the maximum vertical amplitude (displacement, velocity, and acceleration), and that these increase as the footing area ratio (A2/A1) increases. This is belonged to the spreading dynamic loads across a greater area, the stepped footings provide greater stability than the rectangular footing. Further, the soil-footing interaction leads to more stability and step footing can provide more restrain against lateral movement under the dynamic loads such in case of machine vibration.

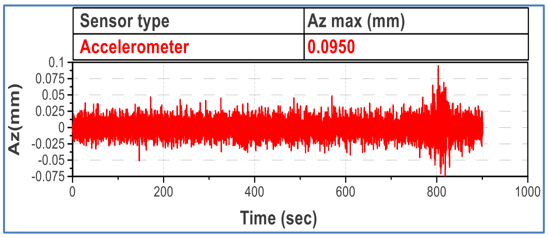
Table 4 shows that when the ratio (A2/A1) changes from 1.0 to 1.2, 1.5, and 2.0, respectively, the maximum displacement amplitude under frequency 10 Hz drops by 40%, 50%, and 60%. In parallel, the displacement drops by 25%, 25%, and 44% at a frequency of 40 Hz, whereas at a frequency of 70 Hz, the changes are 16%, 21%, and 32%. Increases in the area of contact footing with the soil caused this impact by allowing for greater dynamic load distribution, which in turn decreased displacement. Because of interlocking that providing between the ground and the footing through friction resistance and because of additional loading of soil over the steps.

Table 4 Maximum vertical amplitudes (displacement, velocity, and acceleration)

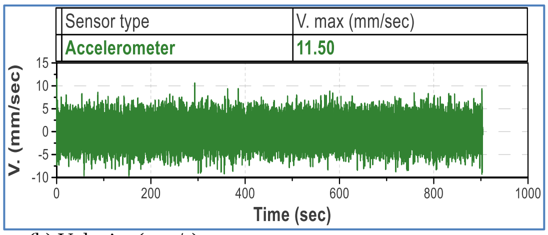
Frequency level	Maximum Amplitudes after 900 sec	Footing area Ratio (A1/A2)			
		1.0	1.2	1.5	2.0
10 Hz	Max. displacement (mm)	0.05	0.03	0.025	0.02
	Max velocity (mm/sec)	7.70	6.50	5.60	5.10
	Max. Acceleration (mm/sec^2)	0.06	0.04	0.03	0.02
40 Hz	Max. displacement (mm)	0.08	0.06	0.06	0.045
	Max velocity (mm/sec)	10.9	9.60	7.40	6.50
	Max. Acceleration (mm/sec^2)	0.07	0.05	0.04	0.03
70 Hz	Max. displacement (mm)	0.095	0.08	0.075	0.065
	Max velocity (mm/sec)	11.50	11.2	7.50	7.00
	Max. Acceleration (mm/sec^2)	0.086	0.07	0.065	0.05

Similar trending amplitudes of maximum vertical velocity decreases by (16%, 27%, and 34%,); (, 12%, 32% and 40%); (3%, 35%, and 39%), respectively for 10, 40, and 70 Hz, when the uniform footing (A2/A1 = 1.0) is changed to stepped footing that approaches to (A2/A1=2.0).

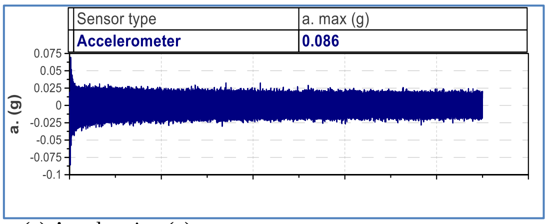
When changing from uniform footing to non-uniform footings between the three ratios (1.2, 1.5, and 2.0), the maximum acceleration declines by increasing the ratio (A2/A1) by (33%, 50%, and 67%); (29%, 29%, and 57%); (19%, 24%, and 42%), respectively, for the three operating frequencies (10, 40, and 70 Hz).



(a) Displacement (mm)

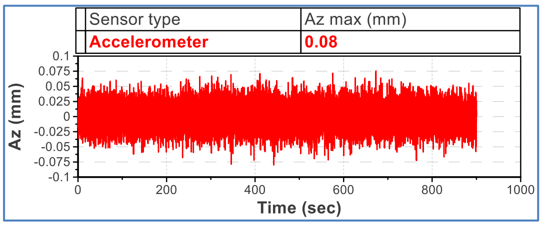


(b) Velocity (mm/s)

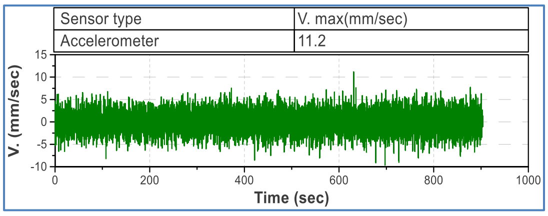


(c) Acceleration (g)

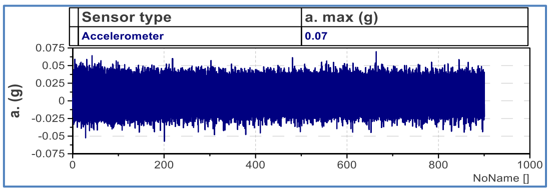
Fig. 11 Variations of amplitudes (displacement, velocity, and acceleration) with time for footing (A2/A1=1.0)



(a) Displacement (mm)

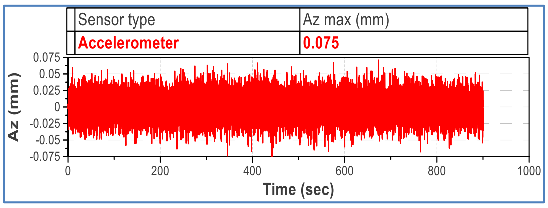


(b) Velocity (mm/s)

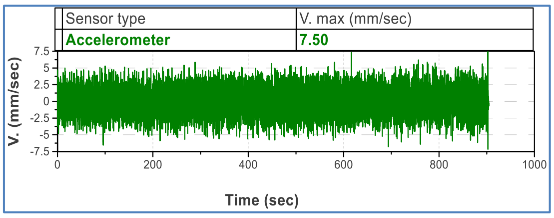


(c) Acceleration (g)

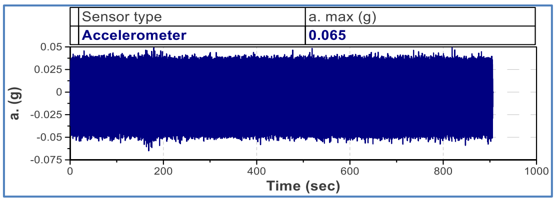
Fig. 12 Variations of amplitudes (displacement, velocity, and acceleration) with time for footing (A2/A1=1.2) under 70 Hz



(a) Displacement (mm)

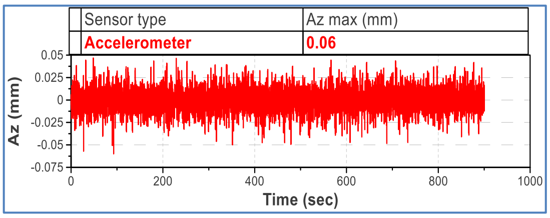


(b) Velocity (mm/s)

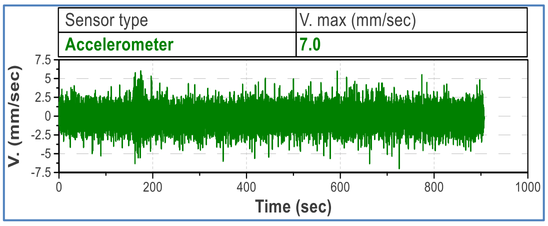


(c) Acceleration (g)

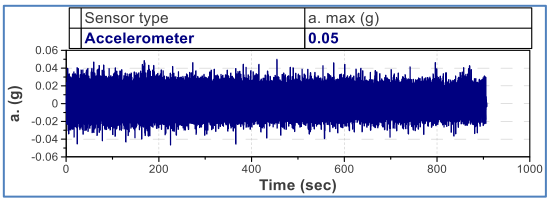
Fig. 13 Variations of amplitudes (displacement, velocity, and acceleration) with time for footing (A2/A1=1.5) under 70 Hz



(a) Displacement (mm)



(b) Velocity (mm/s)



(c) Acceleration (g)

Fig. 14 Variations of amplitudes (displacement, velocity, and acceleration) with time for footing (A2/A1=2.0) under 70 Hz

It is evident from Fig. 15 that the footing of ratio 1.2 yielded the largest rate of the displacement amplitude decrease. However, as Fig. 16 illustrates, the maximum rate of decrease in amplitude velocity was attained at the footing ratio of 1.5. The amplitude acceleration decreased at almost the same rate as (A2/A1) increased as shown in Fig. 17; nevertheless, the biggest drop was seen at (A2/A1) = 1.2.

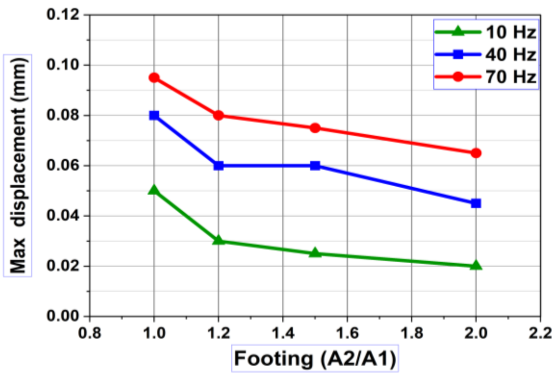


Fig. 15 Relation of maximum displacement and area ratios footings

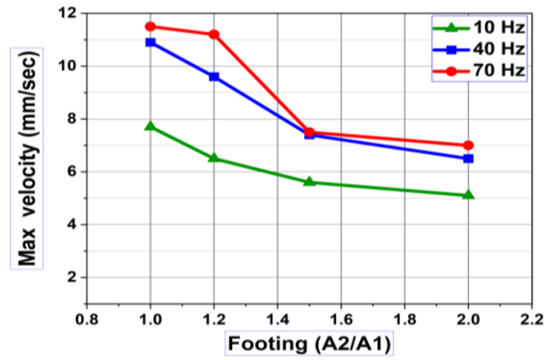


Fig. 16 Relation of maximum velocity and area ratios footings

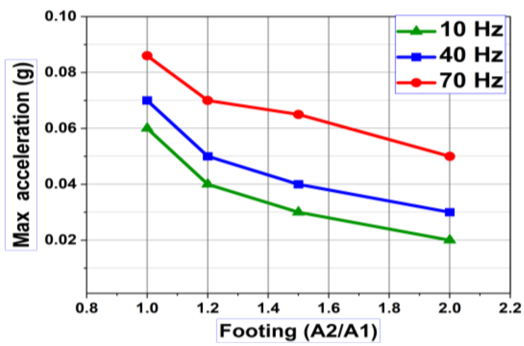


Fig. 17 Relation of maximum acceleration and area ratios footings

The results showed that displacement, velocity, and acceleration diminish as the area of the foundation's lower base increases, as is usual in the field of knowledge. However, the degree of frequency level determines the ratio of (A2/A1) at which the rate of the effect will reduces. Although it was 1.2 for the displacement and 1.5 for the velocity, but the influence of the area ratio persisted for acceleration after the ratio of 2.0.

4.4 Numerical Analysis

4.4.1 General

The experimental tests were simulated using the 3D-Plaxis program, a finite element based. The model is a surface machine-footing system placed on 50% relative density sandy soil. Machine frequencies of 10, 40, and 70 Hz have been applied to the stepped footing with area ratios (A2/A1) of 1.0, 1.2, 1.5, and 2.0.

4.4.2 Numerical simulation

The typical finite element model is shown in Fig. 18. To reduce the calculation time, a quarter of the model has a dimension of 60cm×50cm with a height of 80cm has been taken in the analysis. The amplitude dynamic load of 10 kN applied on the top surface of footing. Specific free-field boundary conditions were proposed at the side of the model, while a compliant boundary used at the base of the model [19].

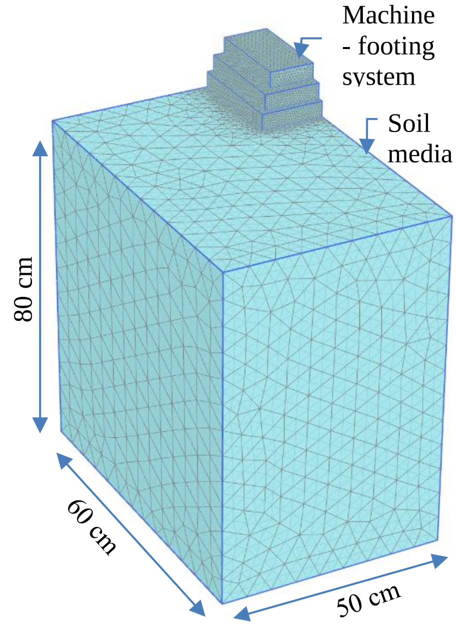


Fig. 18 Finite element modeling

4.4.3 Impact of footing area ratio on maximum pressure

The variation in maximum pressure over time caused by the machine's excitation for various area ratios (A2/A1) at frequencies of 10, 40, and 70 Hz is depicted in Fig. 19. It is obvious that the pressure decreased as (A2/A1) increased. This drop in pressure is a result of the footing's bottom area expanding, which increased the pressure distribution in the soil media. In the meantime, as the machine's frequency rises, so does the pressure. As presented in Table 5, the experimental and numerical results show good agreement, highlighting the influence of the footing area ratio on maximum pressure

Table 5 Maximum pressure (kPa) measured below the footings at 0.5B after 900 seconds

Frequency level	**Test type**	***Maximum pressure (kPa)***			
		Footing area Ratio (A2/A1)			
		1.0	1.2	1.5	2.0
10 Hz	Experimental	71.0	67.4	64.0	61.0
	Numerical	72.5	67.0	63.7	61.2
40 Hz	Experimental	87.0	83.2	80.0	75.0
	Numerical	85.3	80.0	79.5	74.0
70 Hz	Experimental	99.1	96.2	87.2	84.6
	Numerical	99.0	94.4	87.0	82.1

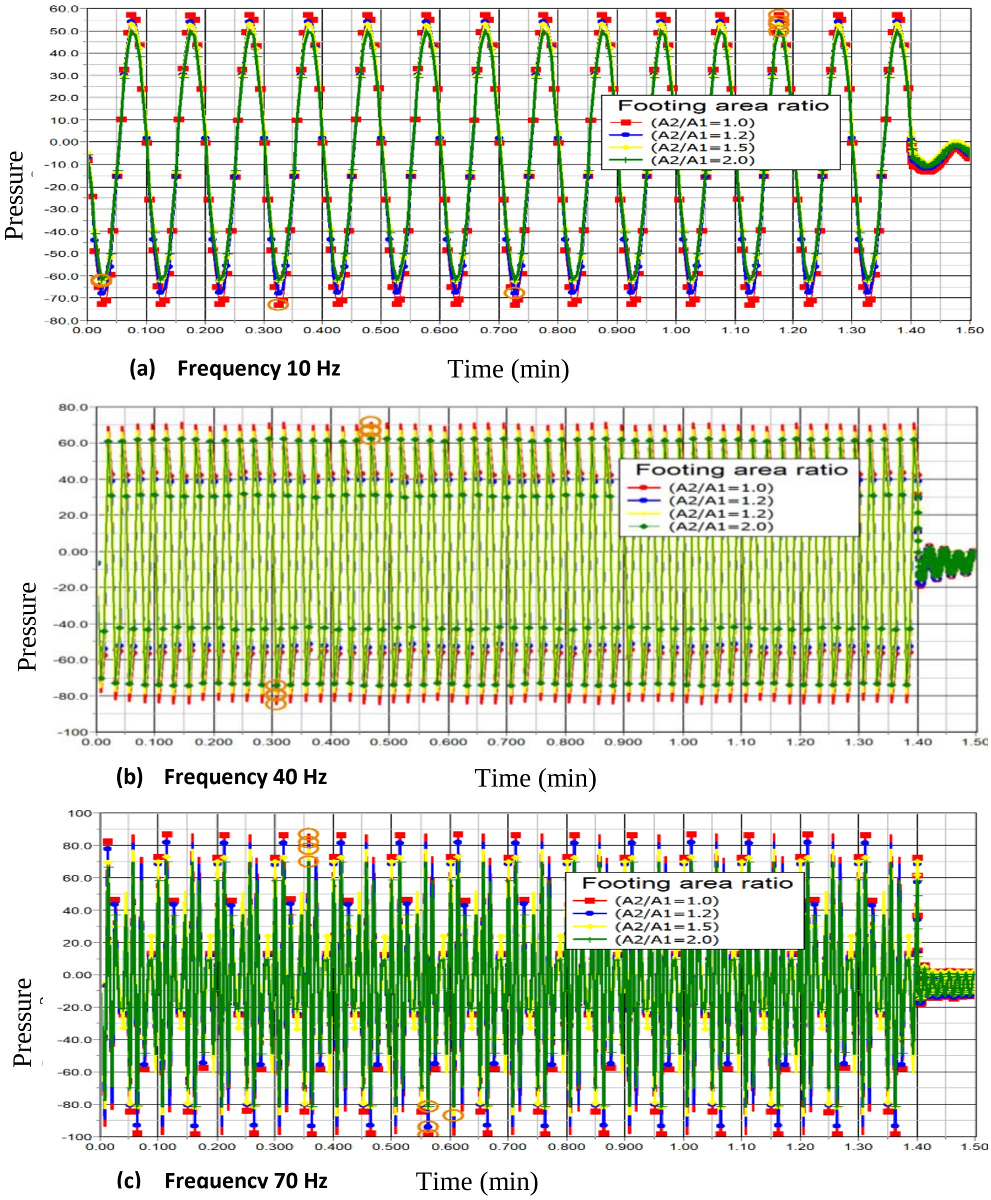


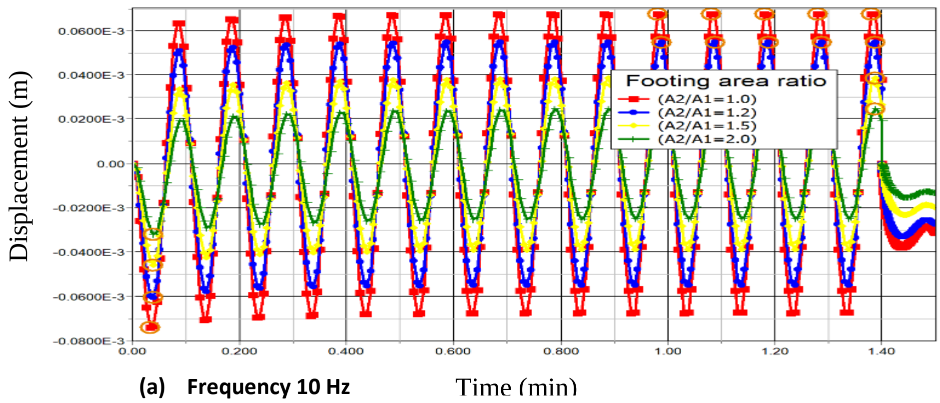
Fig.19 Variations of pressure with time at depth 0.5B

4.4.4 Impact of footing area ratio on displacement amplitude

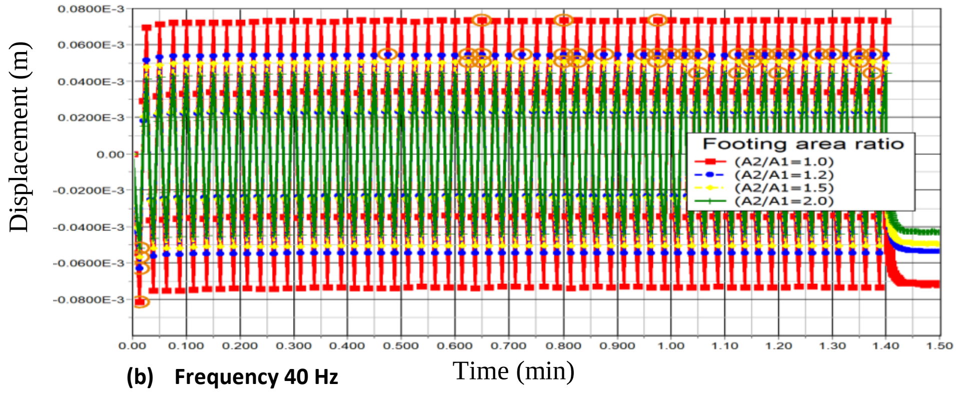
The footing area ratio (A2/A1) impacts the amplitude displacement, as shown in Fig. 20 for frequencies 10, 40, and 70 Hz. The displacement behavior during machine vibration corresponds to the pressure attitude. Once more, when the ratio (A2/A1) rises, that is, as the bottom area of the footing increases the amplitude displacement decreases. Furthermore, the displacement increases as the vibration's intensity increases. Table 6 shows that there is a good agreement between the experimental and numerical results.

Table 6 Maximum amplitude displacement below the footings at 0.5B after 900 seconds

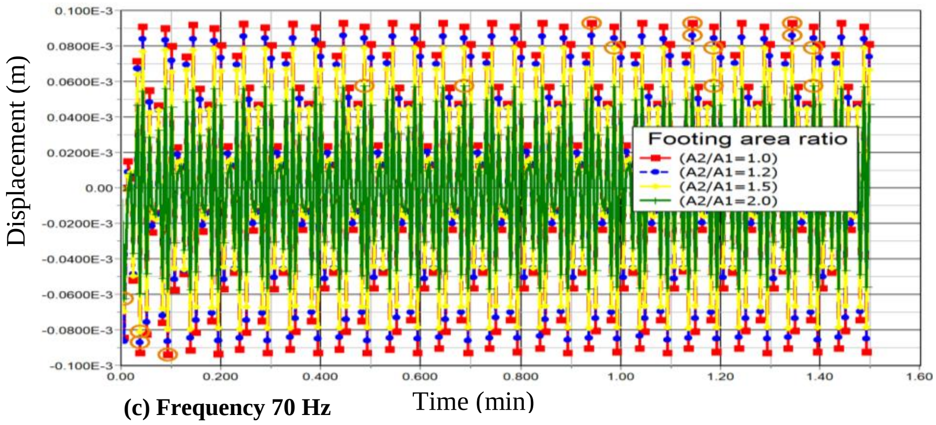
Frequency level	Test type	Maximum displacement (mm)			
		Footing area Ratio (A2/A1)			
		1.0	1.2	1.5	2.0
10 Hz	Experimental	0.070	0.05	0.035	0.025
	Numerical	0.073	0.06	0.040	0.030
40 Hz	Experimental	0.080	0.06	0.060	0.045
	Numerical	0.082	0.07	0.055	0.050
70 Hz	Experimental	0.095	0.08	0.075	0.065
	Numerical	0.095	0.09	0.08	0.065



(a) Frequency 10 Hz



(b) Frequency 40 Hz



(c) Frequency 70 Hz

Fig. 20 Variations of amplitudes displacement with time at depth 0.5B

5. Conclusions

Several conclusions can be made based on experimental and numerical findings conducted on the medium-dense sand:

- As the area ratio (A2/A1) increased from (1.0-1.2), (1.0-1.5), and (1.0-2.0), respectively, the maximum pressures below the footings at depths (0,0.5B) under frequencies 10, 40, and 70 Hz decreased by around 5%, 10%, and 14%.
- The settlement decreases when the footing's area ratio (A2/A1) increased from 1.0 to (1.2, 1.5, and 2.0). Under 10Hz, the reductions are (23%, 31%, and 31%). The corresponding reductions under 40 Hz are (13%, 26%, and 27%), and under 70 Hz are (14%, 24%, and 30%).
- The amplitude displacement decreases by (24%, 29%, and 42%) under frequencies of low-speed frequency, (25%, 25%, and 44%) under medium-speed frequency, and (16%, 21%, 32%) under high-speed frequency, through increase the footing' area ratio from (A2/A1=1.0) to (A2/A1=1.2, 1.5, and 2.0) respectively. Similarly, the velocity and acceleration amplitudes reduce with ratio (A2/A1).
- Regarding the amplitude of the pressure, settlement and velocity, the effective area ratio (A2/A1) is 1.5. Meanwhile, the effective (A2/A1) in case of the amplitude displacement is 1.2. Beyond these area ratios insignificant effect displayed.

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تقييم السلوك الديناميكي لاساس مدرج مستند على سطح تربة رملية

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تاريخ الاستلام:30 مارس 2025 استلم بصيغته المنقحة: 25 يوليو 2025 تاريخ القبول: 25 أغسطس 2025

الملخص

هنالك عدة عوامل منها نوع التربة والرطوبة الطبيعية ونوع الاساس ودرجة الاهتزاز لها تاثير على استجابة التربة لقوى الاهتزاز. ان تراكم التشوه في التربة الناتج عن اهتزاز الماكنة قد يتجاوز الحدود المسموح بها.تم دراسة تاثير اهتزاز الماكنةعلى اربعة انوع من الاسس موضوعة على سطح تربة تجريبيا. ثلاثة انواع من الاسس مدرجة والنوع الرابع هو اساس منتظم الشكل. اخذت نسب مختلفة من مساحة الاساس السفلية (A2) الى المساحة العليا (A1) وهي (A2/A1= 1.0, 1.,2, 1.5 and 2.0). تم اعتماد ارتدادات مختلفة (10,40 and 70 Hz) مسلطة على الاساس. ان تربة الاساس هي رملية ذات كثافة نسبية متوسطة (50%). تم قياس الاستجابة الديناميكية متمثلة بالتشوه والسرعة والتعجيل ، اضافة الى الهبوط والضغط تحت اعماق مختلفة. وجد ان الاساس المدرج يقلل من ضغط اهتزاز الماكنة على التربة وكذلك يقلل من الهبوط والترددات. وكمثال فان الدراسة وجدت ان الاساس بنسبة (A2/A1=2.0) يعطي اقل استجابة للقوة الداينميكية. ان الضغط يقل بنسبة 14.5% عندما يتغير الاساس من منتظم (A2/A1=1.0) الى مدرج (A2/A1=2.0)، بينما الهبوط الكلي وترددات التشوه والتعجيل تقل بنسب 30% و 42% و 54% على التوالي. اضافة الى ذلك فان مقارنة الى الاساس المنتظم فان الاساس المدرج اكثر اقتصاديا مع اداء اعلى.

الكلمات الدالة:

اساس الماكنة، اساس مدرج، تربة رملية، السعة