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Dynamic Behavior of Machine Foundations on layered sandy soil under Seismic Loadings

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ABSTRACT

In this paper, a dynamic investigation is done for strip, rectangular and square machine foundation at the top surface of two-layer dry sand with various states (i.e., loose on medium sand and dense on medium sand). The dynamic investigation is performed numerically using finite element programming, PLAXIS 3D. The soil is expected as a versatile totally plastic material that complies with the Mohr-Coulomb yield criterion. A harmonic load is applied at the base with an amplitude of 6 kPa at a frequency of (2 and 6) Hz, and seismic is applied with acceleration – time input of earthquake hit Halabjah city north of Iraq. A parametric study is done to evaluate the influence of changing L/B ratio (Length=12,6,3 m and width=3 m), type of sand, and frequency of the machine for soil with two layers (dense and medium sand) and (loose and medium sand). It was noticed that the displacement decreases when the foundation is strip, and has the highest values when the foundation is square. At the same time, the maximum vertical stress of the foundation (L/B = 4 and L/B = 1) appears to be (1262) kPa and (1255) kPa, respectively, due to increasing the foundation mass as a result of increasing its dimensions. Then again, the displacement increases by 20% for vertical displacement when decreasing the relative density. In addition, it has been noticed that there is a decrease in displacement when the frequency value changes from (2 to 6) Hz.

Keywords: seismic load, sandy soil, machine foundation, and Reciprocating Machines Modeling.

السلوك الديناميكي لأساسات ماكينة على طبقات من الترب الرملية تحت الأحمال الزلزالية

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الخلاصة

في هذا البحث ، تم وضع تحليل ديناميكي لأساس الماكينة الشريطي والمستطيل والمربع على السطح العلوي لرمل جاف يتكون من طبقتين بحالات مختلفة على سبيل المثال (مفكك على رمل متوسط وكثيف على رمل متوسط). حيث تم إجراء التحليل الديناميكي عدديًا باستخدام برنامج العناصر المحدودة *PLAXIS 3D*. يُفترض أن التربة مادة بلاستيكية مرنة تمامًا تخضع بسلوكها لمعيار *Mohr-Coulomb*. يتم تطبيق الحمل التوافقي في الأساس بسعة 6 كيلو باسكال بتردد (2 و 6) هرتز ويتم تطبيق الحمل الزلزالي متمثلا بزلزال حلبجة شمال العراق. تم إجراء دراسة بارامترية لتقييم تأثير تغيير نسبة طول الاساس الى عرضه(*B=3 m* , *L=12,6,3 m*), نوع الرمل وقيمة تردد الماكينة للتربة ذات طبقتين (رمل كثيف ومتوسط) و (رمل مفكك ومتوسط). استنتج أن الإزاحة تقل عندما يقترب شكل الأساس من الشريطي، وتكون أعلى قيمه لها عندما يكون الأساس مربع. بينما وجد ان الإجهاد الرأسي للأساس الشريطي اعلى عند مقارنته بالأساس المربع حيث أن قيم الإجهاد القصوى هي (1262) كيلو باسكال و (1255) كيلو باسكال على التوالي بسبب زيادة كتلة الأساس نتيجة زيادة أبعاده. ثم مرة اخرى, يزداد منحنى الإزاحة بنسبة 20٪ بالنسبة للإزاحة الرأسية عند تقليل الكثافة النسبية. بالإضافة إلى ذلك ، لوحظ انخفاض الازاحة بنسبة 5٪ عندما تتغير قيمة التردد من (2 إلى 6) هرتز.

الكلمات الرئيسية: الحمل الزلزالي ، التربة الرملية ، أساس الماكينة و نمذجة الآلات الترددية.

1. INTRODUCTION

The analysis and design of the machine foundation require more consideration since it involves not only the static loads but also the dynamic loads caused by the machine's working. The fundamental objective in designing a machine foundation is to confine the movement amplitude, which will endanger the satisfactory action of the machine. Various techniques have been created throughout the years to calculate the dynamic reaction of soil-foundation systems. The way to deal with such issuing is to register the matrix of dynamic impedance functions, which relate consistent state force and displacement at the foundation soil system.

1.1 Research Background:

The machine foundations should be designed so that the dynamic forces of machines are transmitted to the soil through the foundation so that all kinds of harmful effects are eliminated **(Piyush K. Bhandari, Ayan Sengupta 2014**). The presentation is focused on the parameters that have been studied in this research. The most important parameters that were illustrated are relative density, embedded depth, frequency of the machine, and behavior of sandy soil under the effect of dynamic loads. The arrangements are acquired by utilizing a three-dimensional finite element method by calculating the values of total stress and displacement under a combination of a dynamic and a seismic load.

1.2 Research Signification:

Exhibited to dynamic loads, which depends on the speed of the machine and natural frequency of the foundation and the level of stress that cause dynamic strains as well as the type of the soil. The soil response under dynamic loads is different from that of static loads because it is of significant importance for the stability of structures. Thus, a vibration analysis becomes necessary; therefore, the complete knowledge of the load-transfer mechanism from the machine to the foundation and the complete knowledge of excitation forces and associated frequencies are necessary for correctly evaluating machine performance.

1.3 Literature Review:

(KAREAM et al., 2020) conducted experimental work to study the effect of the machine's circular foundation on the variation of surface settlement, vertical displacement, and stress with a number of cycles. Six laboratory model footings were prepared on medium and dense dry sand separately. A circular steel model of (150 mm) diameter was used to represent the footing. The models were tested under a dynamic load amplitude of 0.25 ton and frequencies of 0.5, 1, and 2 Hz. It was found that the rate of increase in settlement decreased remarkably when increasing the frequency for both types of sand.

(Hadi and Al-Helo, 2015) carried out a dynamic analysis of strip machine foundation to evaluate the dependency of machine foundation on the modular ratio of soil layers of two-layer saturated sand with different states. The dynamic analysis is performed numerically by using finite element software, PLAXIS 2D. A harmonic load is applied at the foundation with an amplitude of 25 kPa at a frequency of 5 Hz. It was concluded that the displacement decreased remarkably when E1is duplicated 2-4 times E2. The pore water pressure increases remarkably when E1 is increased to about five times E2, then the effect decreases.

(Al-Azawi et al., 2006) carried out a dynamic analysis of machine foundations under vertical excitations. The effect of embedment and foundation geometry was taken into account. The effect of embedment upon vertical forced vibration of a rigid footing was investigated theoretically. It was found that the embedment of foundations has a significant effect on the dynamic response. It causes an increase in the dynamic stiffness and damping coefficients and leads to an increase in the resonant frequency and to decrease in the dynamic response of the foundation. A convergence in results was evident when the depth ratio was about 0.50.

(Boumekik et al., 2010) presented laboratory tests for estimating the dynamic stress of the soil by a "vibrating foundation prototype for three specific points of the foundation-soil interface zone". A significant increase in the relative density of the medium dense sand was observed because of the particles’ retightening in the central zone level, which increases their compactness.

(Abd Al-Kaream, 2013) conducted experimental work to study the effect of vertical vibration of a machine on the response of saturated sand prepared at three relative densities (35, 60, and 80%). The type of dynamic load was cyclic with amplitudes of 0.4, 0.6, and 0.8 kN and frequencies of 0.16, 0.5, 1.0, and 2.0 Hz. It was found that the excess pore water pressure increases with increasing load amplitude, frequency, and relative density.

1.4 Research Gap:

Most research focused on the dynamic load due to earthquakes and offshore waves. However, very few studies were available about the effect of machine vibration on the performance of machine foundations with earthquakes and the soil underneath. Nowadays, the development in the industry has introduced huge machines that greatly influence the foundation's performance and the soil underneath, producing another type of vibration load. All machine foundations, irrespective of the size and type, should be regarded as engineering problems, and their designs should be based on sound engineering practices.

1.5 Research Objective:

The main objective of this study is the evaluation of the behavior of the machine foundation under earthquake excitation by numerical analysis through the three-dimension finite element method with **PLAXIS 3D MANUAL (2020).** Studying the influences of dynamic loading variables (loading frequency, amplitudes) and relative density of machine foundation. Investigating the impacts of parameters on the strain, amplitude displacement, and stresses within soils at various dimensions for foundations on sand. Study the effect of the earthquake on the properties mentioned above compared to the effect of machine vibration.

1.6 Type of Machines:

Fig. 1 shows the types of machines according to frequency **(Srinivasulu and Vaidyanathan, 1990)**

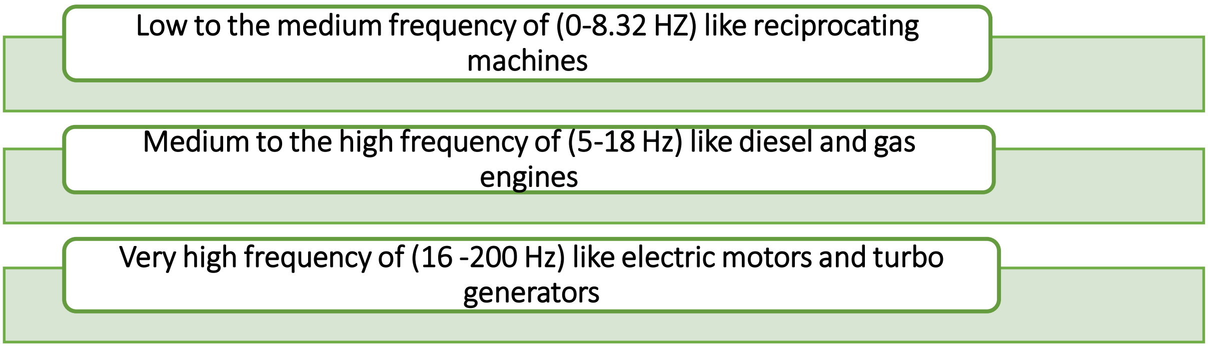

Figure 1. Types of the machine according to the operating frequency

2. ANALYSIS METHODS:

There are many analysis methods, but the finite element method (FEM) is the most commonly accepted analysis tool for solving engineering problems. It is used to solve simple and complex physical problems.

- The Linear Elastic Spring Method
- The Elastic Half-Space Analogs Theory
- The Impedance Function Method
- Lumped Mass-Parameters System Method
- Finite Element Method

3. MATERIALS AND METHODS:

The material's properties are categorized into five phases:

1. Soil properties: The soil used in this parametric review is sandy soil with various states (i.e., loose, medium, and dense). The soil store is accepted to obey the advanced Mohr-Coulomb yield, with boundaries carried on from **(Hadi and Al-Helo, 2015)** aside from the dilatancy boundary. The influence of dilatancy is considered in the current review. The dilatancy of sand depends upon both the density and the friction angle. It is reasonable in PLAXIS to utilize of cohesion c > 0.2 kPa for cohesionless sands and dilatancy angle ψ = Ø − 30 for the soils with Ø > 30, and ψ = 0 for the soils with Ø < 30 **(Brinkgreve et al., 2013).** Because of this, the amount of cohesion is accepted to be equivalent to 1 kPa to avoid inconveniences, and the dilatancy angle is expected as (ψ = Ø – 30) **(Mohammed Y Fattah et al., 2015)**.

2. Foundation properties: The concrete foundations are accepted as a linear elastic material with boundaries displayed in **Table (1).** The heaviness of the machine relies on its kind proposed by **(Mohammed Y Fattah et al., 2014).** The proportion between the weight of the foundation and the weight of the machine is around taken as 2.16.

3. Sinusoidal excitation: The most common problem involving dynamic loading is that of foundation for machinery:

$$f(t) = \alpha \sin \omega t$$

where:
α = maximum amplitude of dynamic force,
ω = 2πf with f = operating frequency,
t = time.

Typical operating frequencies range from (3 Hz) for large reciprocating air compressors to about (200 Hz) for turbines and high-speed rotary compressors. Therefore, the frequencies (2 and 6 Hz) were used according to what was referred to in paragraph 1.6, taking into account these values are within the range of the reciprocating machine. The value of amplitude 6 kPa while the frequency is about 2 Hz. **Fig. 2** shows the definition of a harmonic multiplier **PLAXIS 3D MANUAL, (2020).**

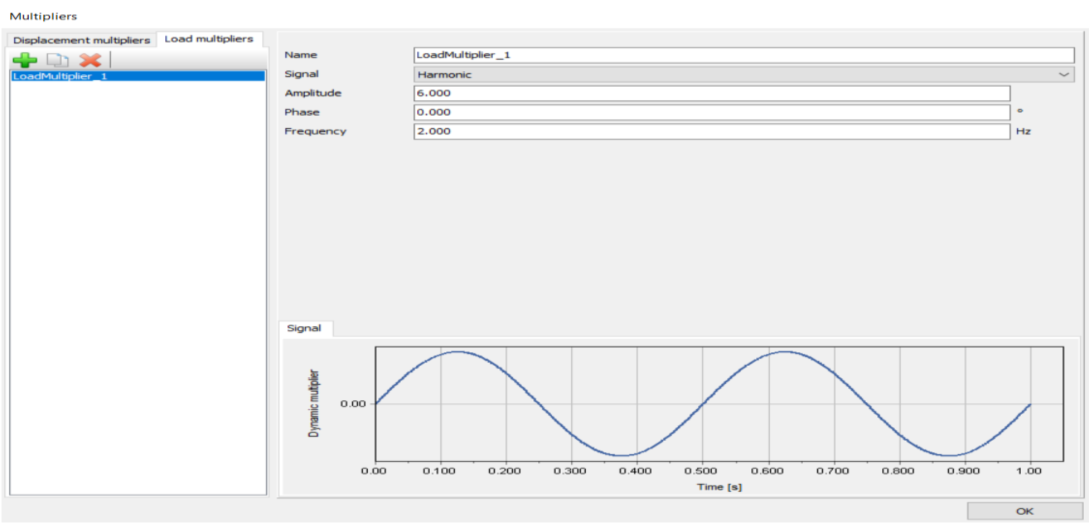

Figure 2. Definition of a harmonic multiplier

4. Seismic Load: Acceleration-time records for (Halabjah), The greatest earthquake that Iraq in Halabjah city at the Iraq – Iran border in November 2017, with a magnitude of 7.3 this earthquake is used for applying dynamic prescribed displacement of the bottom surface of the model. The acceleration/time records were input (m/s2) during (180) seconds. **Fig. 3** shows acceleration – time input of the earthquake.

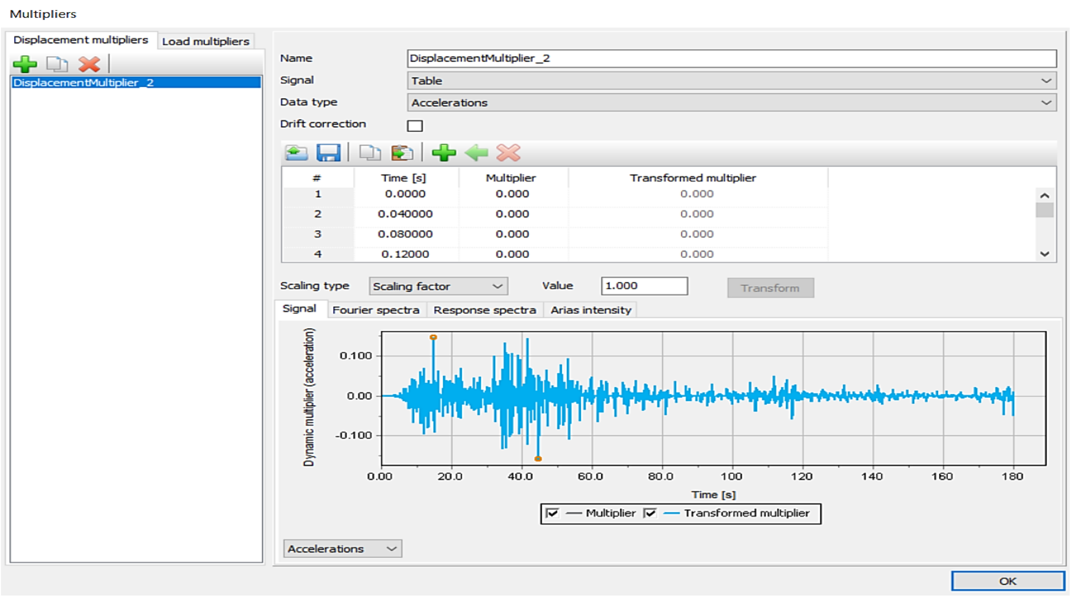

Figure 3. Acceleration – time input of earthquake hit Halabjah in November 2017 during 180 seconds recorded by The Iraqi Seismological Network (ISN)

5. Performing Calculation: Fig. 4 shows the calculations performed that have been divided into the following phases:

- The initial Phase is pure soil.
- The first phase is generated to calculate structure elements using plastic calculation type.
- Second phase is generated to calculate the vibration of machine foundation in Z direction using dynamic calculation
- The third phase calculates the stresses for the model earthquake in the X direction using the dynamic calculation method by switch-on the Z and Y fixed.

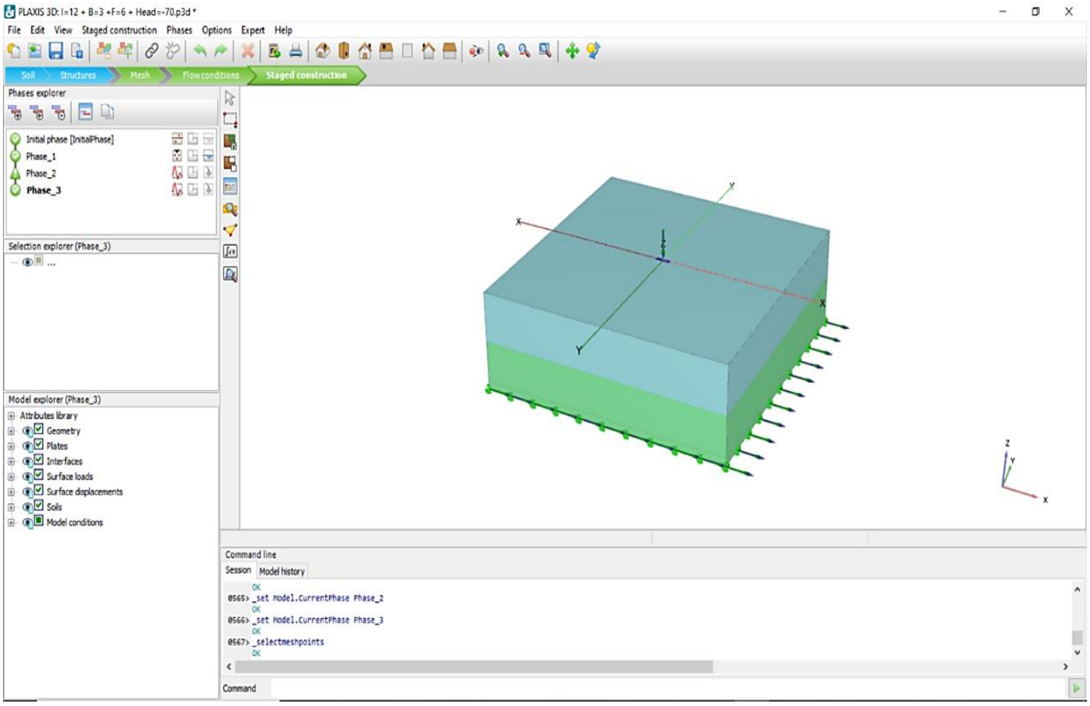

Figure 4: Stage of construction

Table (1): Parameters used for the numerical calculation

Parameters	Foundation	Dense sand	Medium sand	Loose sand
Modulus of elasticity, E (MPa)	20,000	55	40	28
Shear modulus, G (MPa)	8,700	21	15	10.4
Depth (m)	1.5	35	35	35
Unsaturated unite weight (kN/m^3)	24	19	17	16
saturated unite weight (kN/m^3)	-	21	19	18
Cohesion, (c) (kPa)	-	1	1	1
Friction angle, (ϕ)	-	34	32	30
Dilation angel, (Ψ)	-	4	2	0
Poisson`s ratio, (υ)	0.15	0.3	0.32	0.34
Relative Density, (Dr) %	-	75	60	40

4. NUMERICAL MODEL

4.1 Validation Model:

The verification is performed to check the accuracy of the PLAXIS by comparison with numerical and experimental studies to use it in analyzing Dynamic Behavior of Machine Foundations under

Seismic Loadings excitation. Two cases were examined; **the first** examined the reliability of soil shear strength parameters using a suitable laboratory model. **The second model** is free vibration and earthquake analysis of a building.

4.1.1 The Reliability of Soil Shear Strength Using a Suitable Laboratory Model:

The experimental work includes subjecting the laboratory model to a series of tests to investigate the conduct of soil subjected to dynamic loading and the shear strength after several cycles. Footings of four shapes, circular with a diameter (of 150 mm), rectangular with dimensions of (300x100 mm), and made of (20 mm) thick steel plates, were used. The test results revealed that Young's modulus of the steel used was 37.26 and 140.00 GPa for secant and tangent modulus, respectively. In addition, the unit weight of the steel used was about 77.6 kN/m^3 **(Abdul-Kaream, 2020).**

4.1.2 Free Vibration and Earthquake Analysis:

This example demonstrates the natural frequency of a long five-story building when subjected to free vibration and earthquake loading. The building consists of 5 floors and a basement. It is 10 m wide and 17 m high, including the basement. The total height from the ground level is 5 x 3 m, and the basement is 2 m deep. A value of 5 $kNm^2$is taken as the weight of the floors and the walls. The building is constructed on a clay layer of 15 m depth underlayer by a deep sand layer. In the model, 25 m of the sand layer will be considered **PLAXIS 3D MANUAL, (2020).**

4.2 Computational Model:

This exploration does a dynamic limited component analysis of strip, rectangular and square foundations under seismic load. A length=12,6,3 m and width=3 m dimensions foundation with 1.5m thickness is placed on the top surface for soil with two layers (dense and medium sand) and (loose and medium sand) **(Nour,2020).** The investigation is performed numerically utilizing the finite element programming, PLAXIS 3D. The limits of the soil are taken as (80 m) wide and (70 m) far away from the foundation to limit the boundary influence. Mohr-Coulomb model is selected for soil modeling. It is a bilinear model defined by five input parameters: the elasticity modulus (E), the Poisson's ratio (υ), the angle of internal friction (ϕ′), the cohesion (c'), and the dilatancy angle (ψ ′) **(Alzabeebee, 2021).** The elastic parameters control the settlement before reaching failure, while the shear strength parameters (ϕ′ and c') control the failure conditions. Finally, the dilatancy angle (ψ ′) controls the irreversible volume change due to shearing for, assuming damping ratios (ƺ=5%, α=0.6 and β=0.00018) from chart in plaxis according the frequency of machine **(Hadi and Al-Helo, 2015).** To investigate the total stress and displacement under machine foundation, the soil is thought to be dry. The limit conditions and other illustrate subtleties considered for the foundation are displayed in **Fig. 5A.** Due to the large model's geometry, the coarse mesh was selected. The mesh was refined at the bottom foundation for better accuracy as shown in **Fig. 5B.** Absolute fixities (ux = uy = uz = 0) are applied at the foundation of the model, fixities (ux = uy = 0) are applied at the drastic vertical limits and fixities (uy =uz = 0) are applied the seismic load. To avoid reflection in seismic waves PLAXIS put viscous option in the boundary conditions, viscous option applied on the model in Xmax,min and Ymax,min and None for boundary Zmax,min **PLAXIS 3D MANUAL, (2020).** It ought to be noticed that in this investigation, a vertical vibration is applied and the all-out displacement are estimated at the top main point of the foundation. Notice here that all cases are examined for duration of (120 sec), to representation of the machine in the first phase for 40 seconds and then combined with the earthquake for 80 seconds.

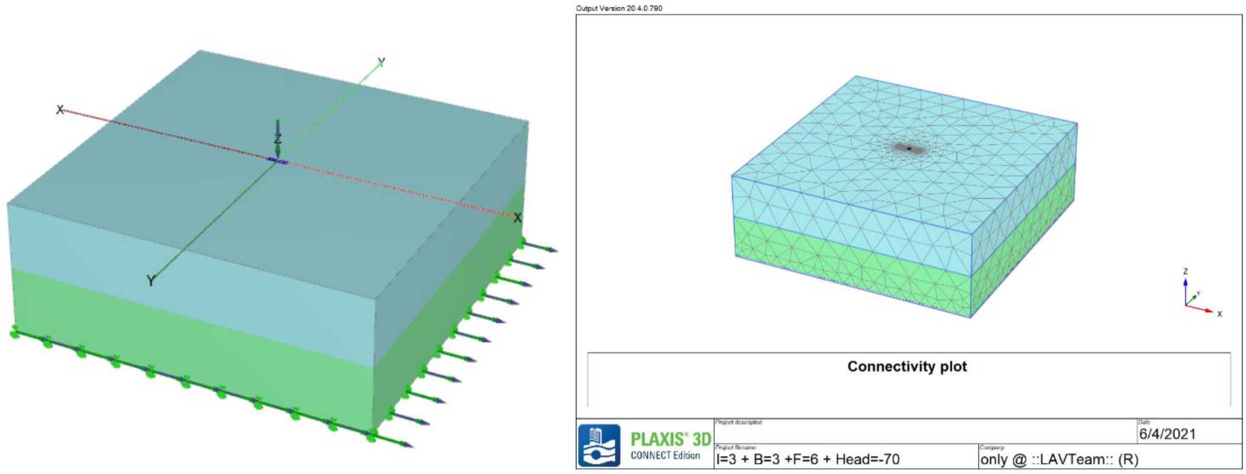

Figure 5. (A)The numerical modeling of reciprocating machines and (B) Mesh generation modeling of square footing when (f=6 HZ)

5. RESULTS AND DISCUSSIONS

5.1 Results of Validation Test:

5.1.1 Results of Laboratory Model:

The numerical analysis of the selected case (the reliability of soil shear strength parameters) using PLAXIS 3D 2013 involved investigation of the strain that occurred due to vibration of the machine with different the shapes of foundation by comparing the results of the numerical analysis with the experimental work, it appeared that the difference between the strain for the L/B ratio 3 is 10%, as shown in the **Fig. 6A.**

5.1.2 Results of Free Vibration and Earthquake Analysis:

In the results of the numerical analysis of settlement with time by using PLAXSIS, one point was studied; the point (0,1.5,15). By comparing the results of numerical analysis with the tutorial manual model, a clear comparison in the precipitation results appeared, as shown in **Fig. 6B.**

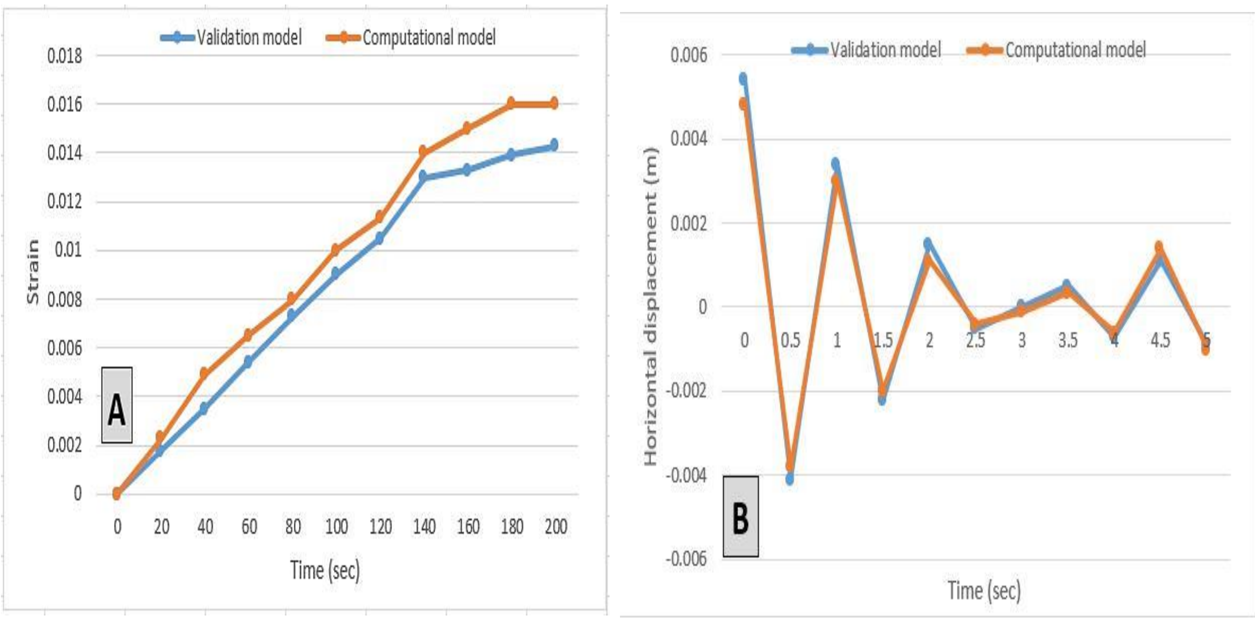

Figure 6. Strain with time for (A) rectangular footing and (B) point (0,1.5,15) on the sand of Dr=50%

5.2 Results of Computational Model

5.2.1 Influence of the Shape of Foundation

Displacement in Z and X directions:

The vertical and horizontal vibration applied are estimated at the top centric point, and the illustrated Figures show the reading of the displacement versus the time of different shapes of footing using soil with two layers (dense and medium sand) and (loose and medium sand) with operating frequency (6 HZ). It has been noticed that the vertical displacement decreases by 10% when the foundation shape is strip, and its highest values are when the foundation is square. These outcomes are viable to the discoveries of **(Tutunchian et al., 2011),** who found that the settlement of the foundation increases with the decrease in the ratio between the length to the width of the foundation. In addition, the highest displacement caused by the machine's vibration was 0.07 mm Fig. 8, while the highest displacement caused by the earthquake was 10 mm Fig. 7 in which the displacement ratio is 99%. Then again, vertical displacement increases by 20% when the relative density decreases, **Fig. 9**. These results are suitable with the revelations of **(Al-Ameri, 2014),** who found that the surface displacement for the footing on sands decreases when the relative density is increased. On the other hand, the effect of the foundation shape (L/B ratio) on the horizontal displacement is more signification than it is in the vertical displacement. However, there is a difference in the behavior after the (100sec), as shown in **Fig. 11.** In general, the curves follow the same trend, in which there is a sharp increase in the rate of displacement after applied the earthquake at (40sec).

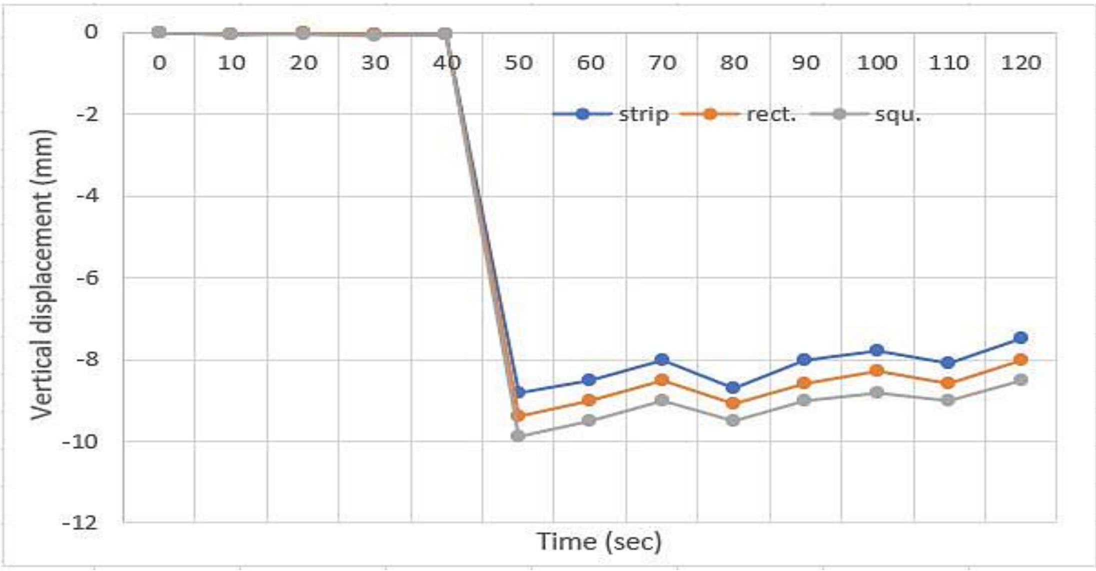

Figure 7. Total vertical displacement with a time of (dense and medium sand) when (f=6Hz)

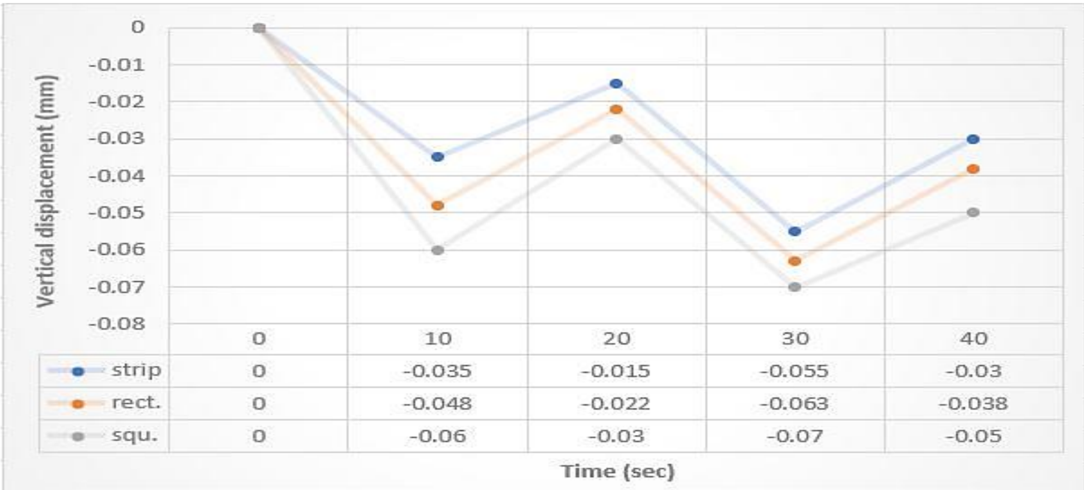

Figure 8. Total vertical displacement of the machine with a time of (dense and medium sand) when (f=6Hz)

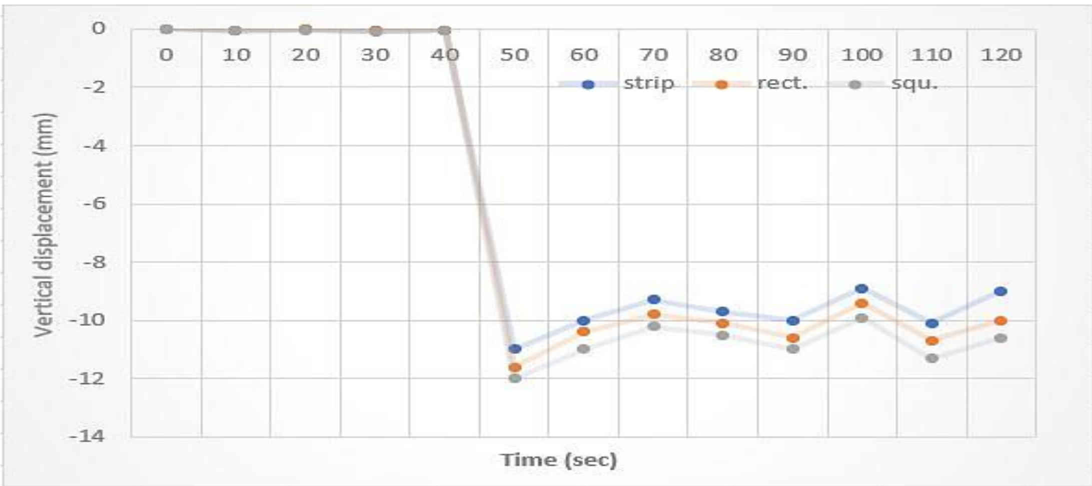

Figure 9. Total vertical displacement with a time of (loose and medium sand) when (f=6Hz)

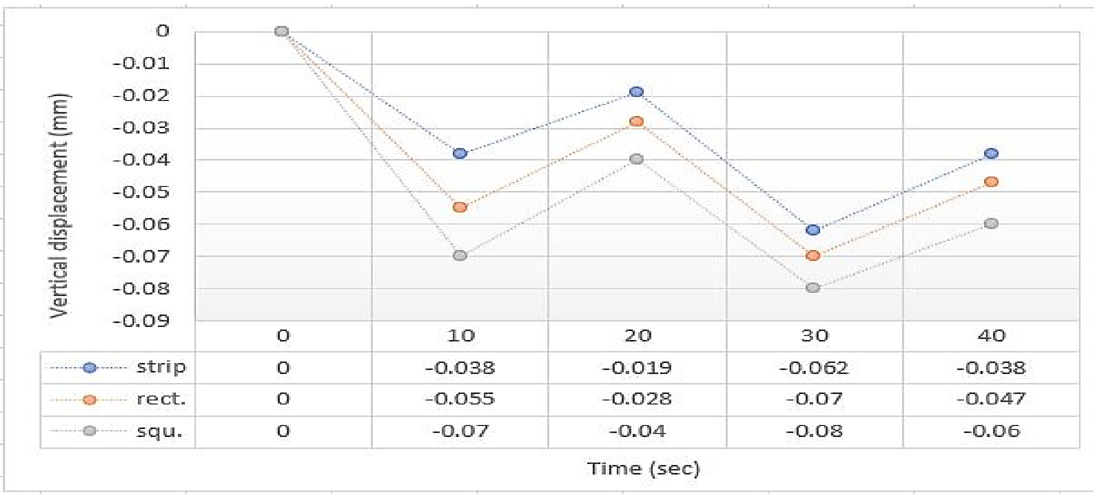

Figure 10. Total vertical displacement of the machine with a time of (loose and medium sand) when (f=6Hz)

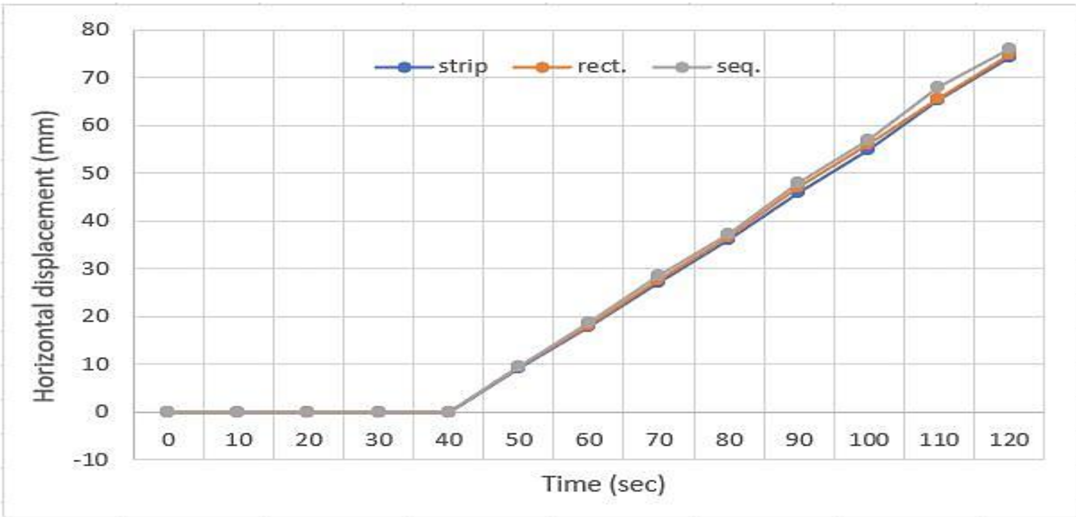

Figure 11. Total horizontal displacement with a time of (dense and medium sand) when (f=6) HZ

Total stress in Z and X directions:

From **Fig. 12-14**, it can be observed that for a given shape of footing, the stress improves with the increase in the mass ratio. This agrees with the finding of **(Nagaraj and Ullagaddi, 2010).** The vertical stress is inversely proportional to the area. Still, despite the fact that the large area in relation to the foundation (L/B = 4) compared to the foundation (L/B = 1), for a cross-section, the maximum stress values appear to be (1262) kPa and (1255) kPa respectively **Fig. 13** and **Fig. 14** and this is due to the increase the foundation mass as a result of increasing its dimensions, which in turn increases the applied stress **(Chandrakaran et al., 2007).** On the other hand, it can be seen in the **Fig. 15** and **Fig. 16** that the horizontal stresses in the foundation (L/B=4) equals (580) kPa and the foundation (L/B=2) equals (584) kPa; the reason for this is due to the increase in the stress value resulting from the small square foundation area in relation to the rectangle. Finally, **Fig 12 and 17** show the vertical and horizontal stress applied measured at the top central point.

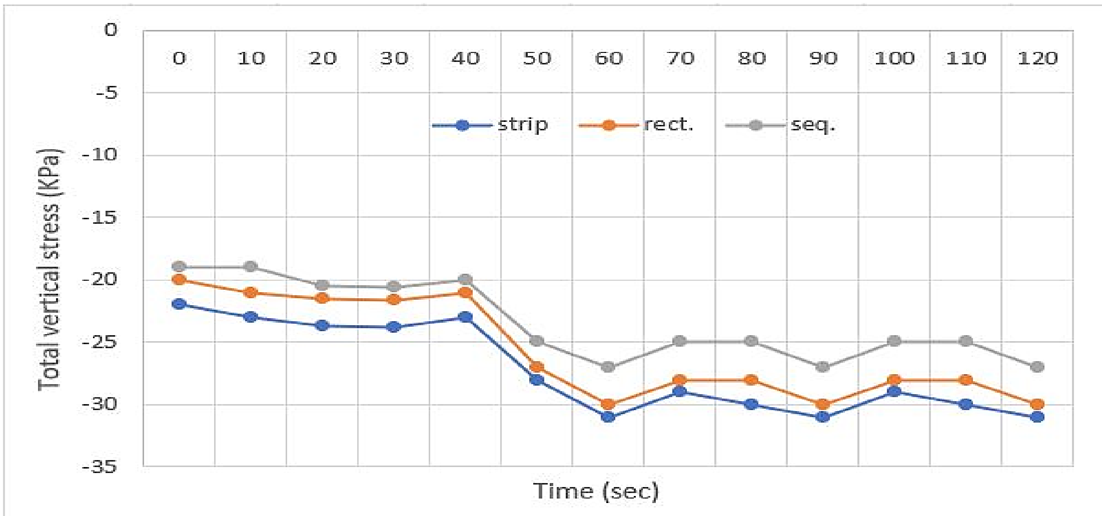

Figure 12. Total vertical stress with time for different L/B ratios when (f=6) Hz

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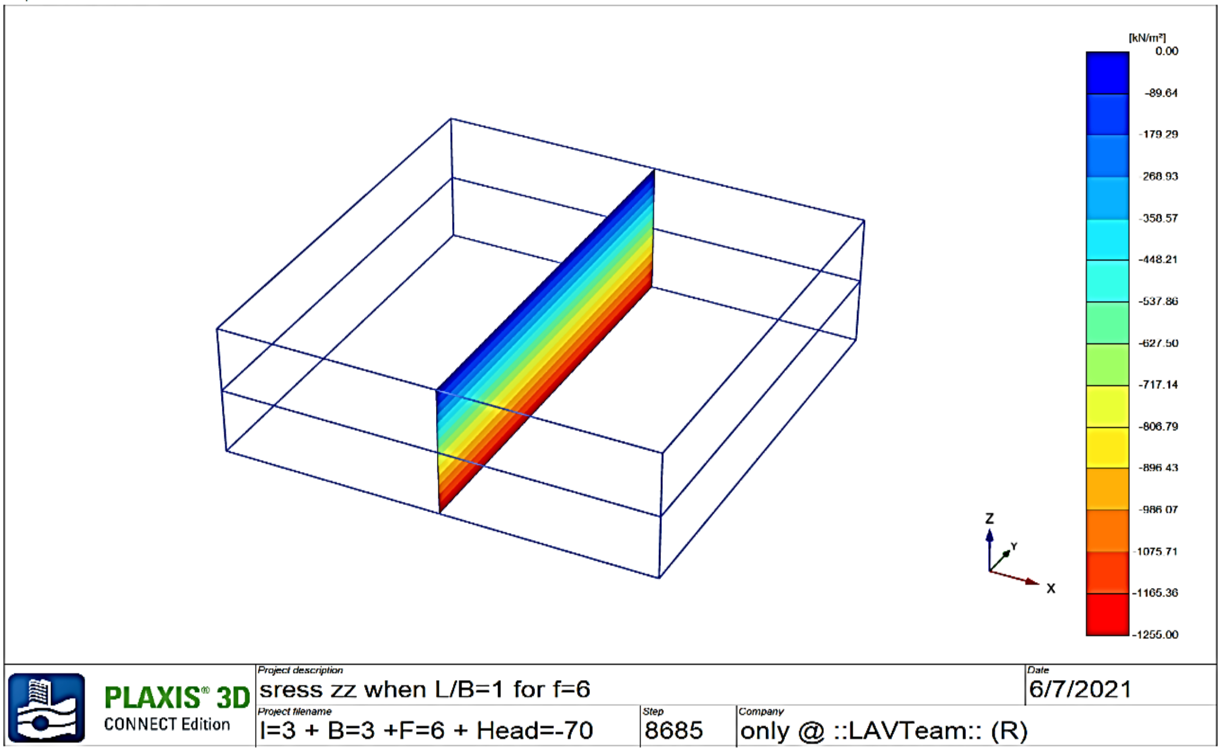

Figure 13. Total vertical stress a cross-section when (L/B=1) for (f=6) HZ

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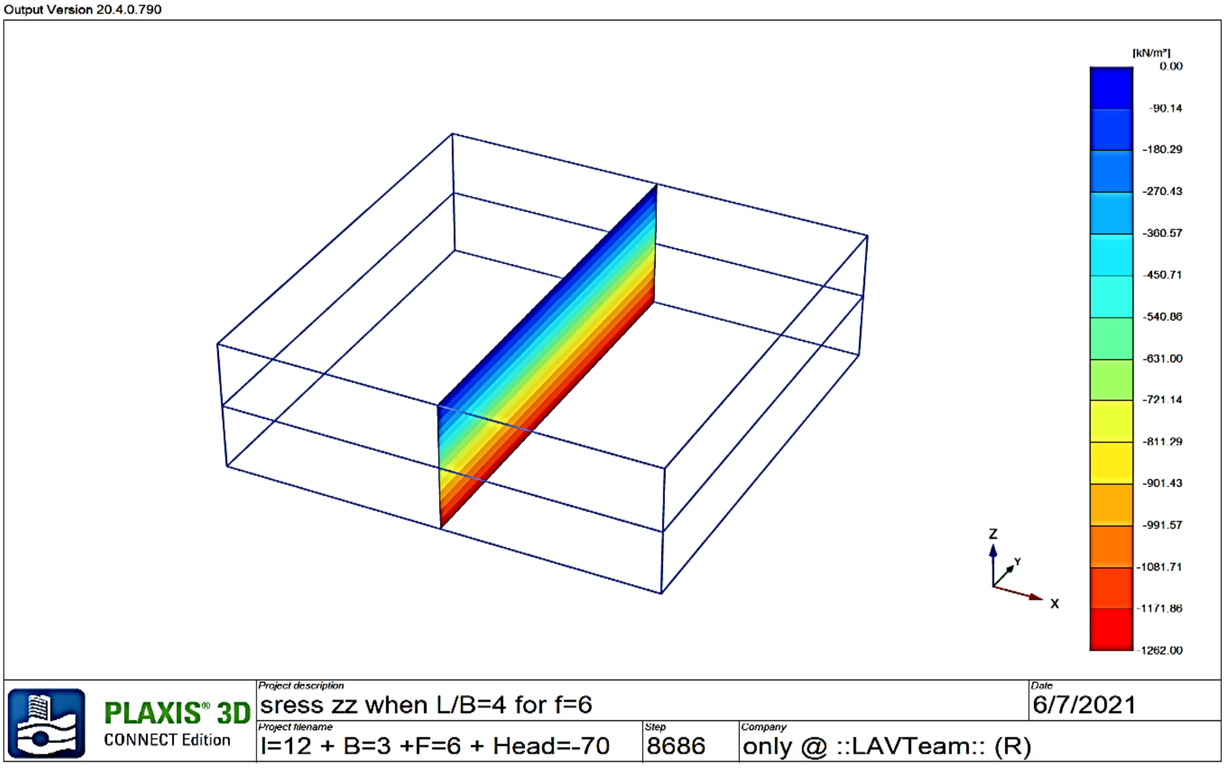


Figure 14. Total vertical stress a cross-section when (L/B=4) for (f=6) HZ

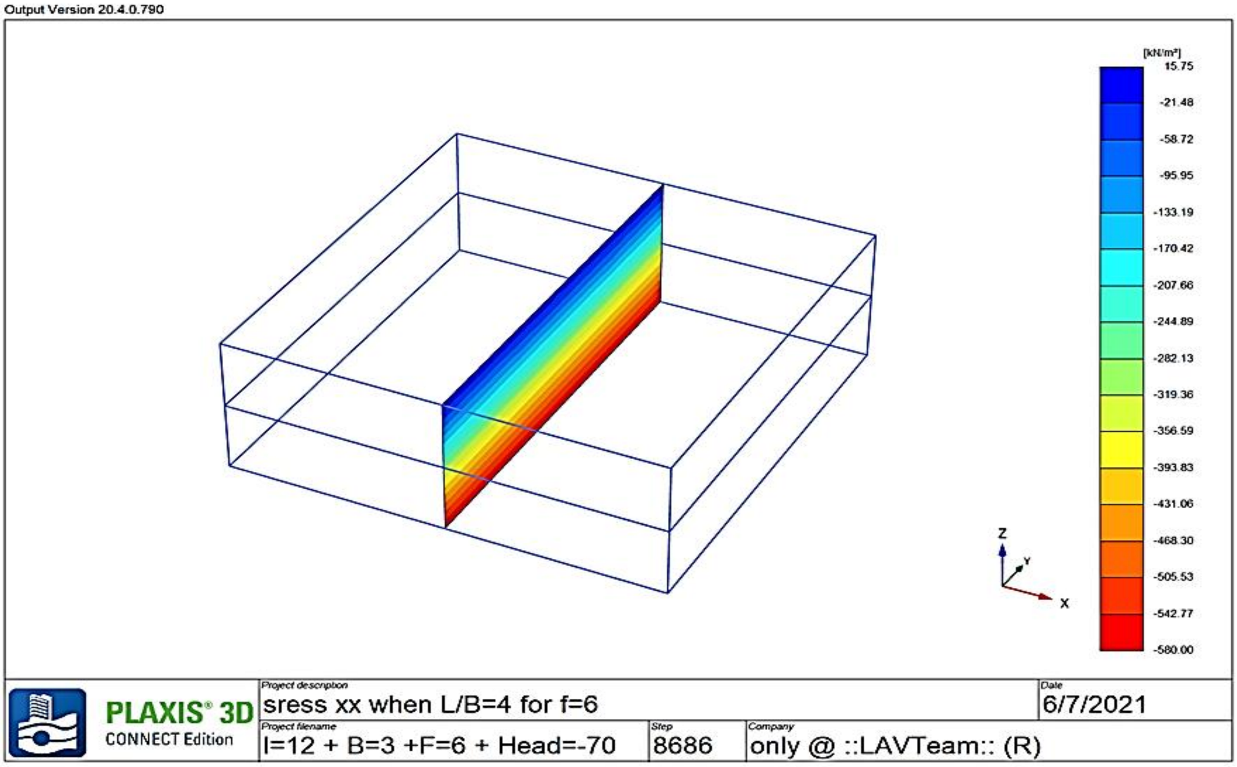


Figure 15. Total horizontal stress a cross-section when (L/B=4) for (f=6) HZ

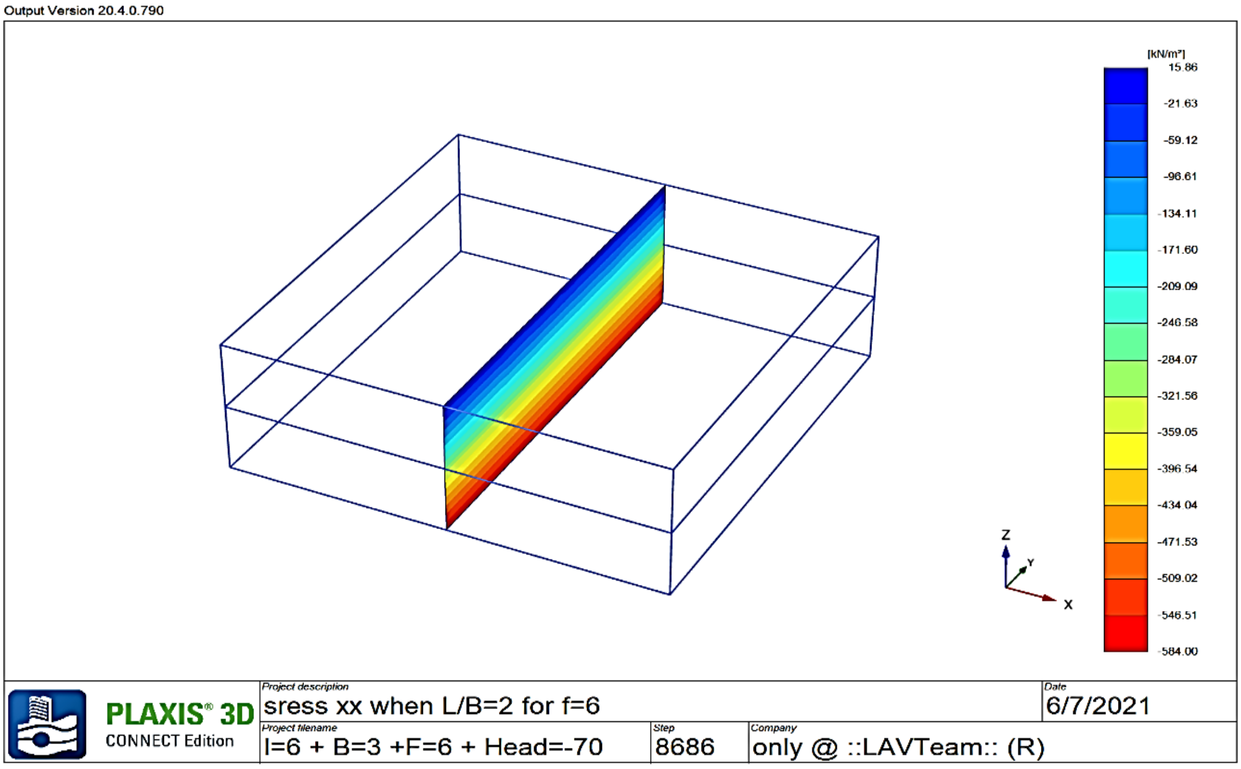


Figure 16. Total horizontal stress a cross-section when (L/B=2) for (f=6) HZ

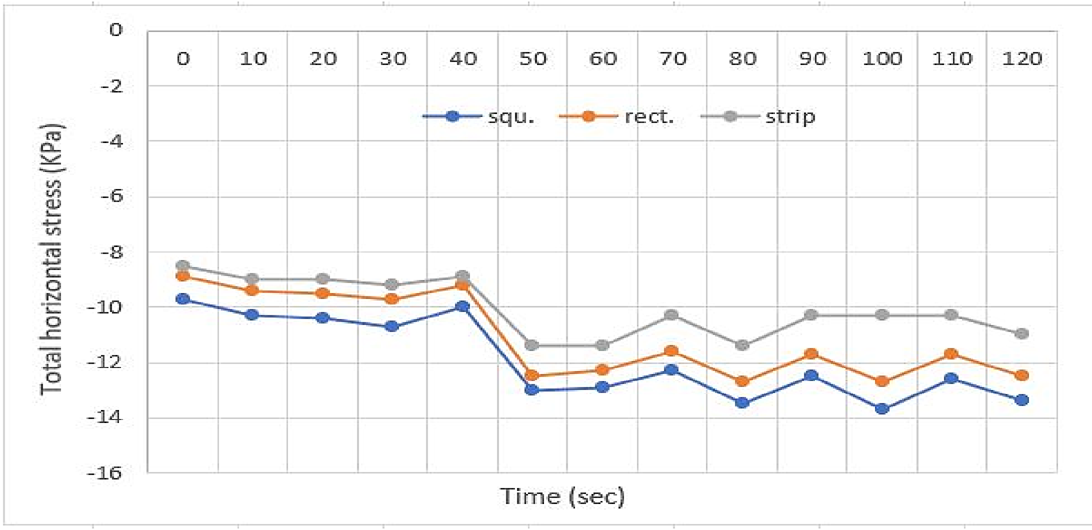


Figure 17. Total horizontal stress with time for different L/B ratios when (f=6) Hz

5.2.2 Influence of the Relative Density

Displacement in X direction:

To study the influence of the relative density in the sandy soil of three shape footing (L/B=4, L/B=2, and L/B=1). **Fig. 18** and **Fig. 19** show that relative density plays an important role in the resistance of settlement, as it increases the resistance of the soil to the applied loads **(Mitchell and Soga, 2005).** The displacement gradually increases with time, so the comparison shows that the vertical and horizontal displacements in low relative density are (15-20%) higher than in high relative density because the dense sand is stiffer. These outcomes are viable to the revelations of **(Al-Ameri, 2014),** who found that the settlement for the footing on sands decreases when the relative density is increased.

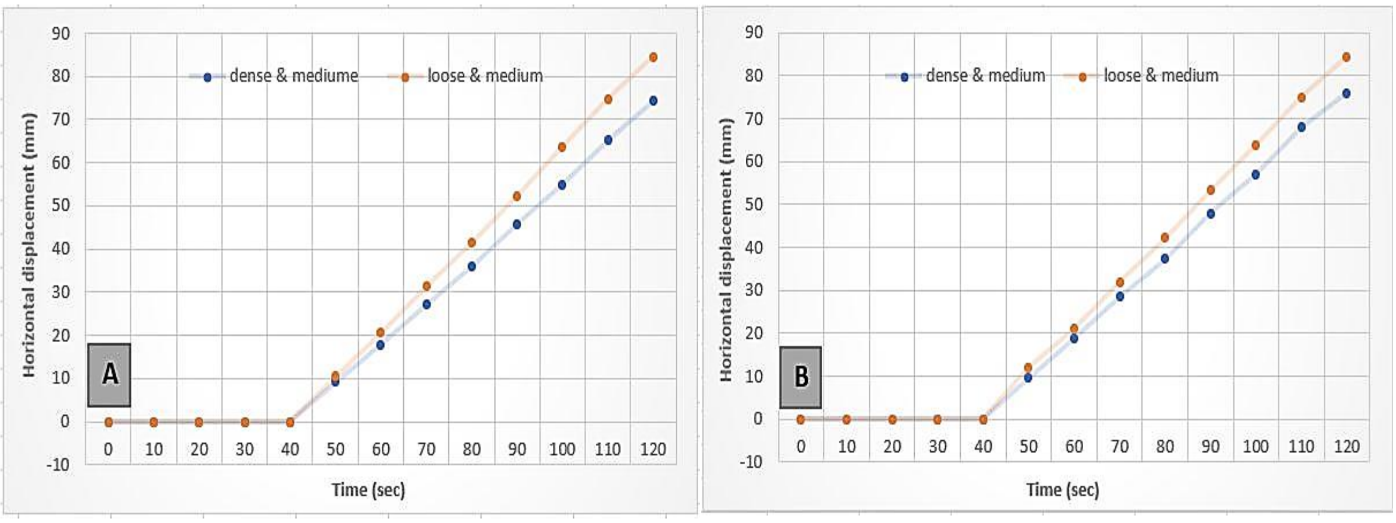


Figure 18. Total horizontal displacement with time for different relative density (A) strip footing and (B) square footing when (f=6) HZ

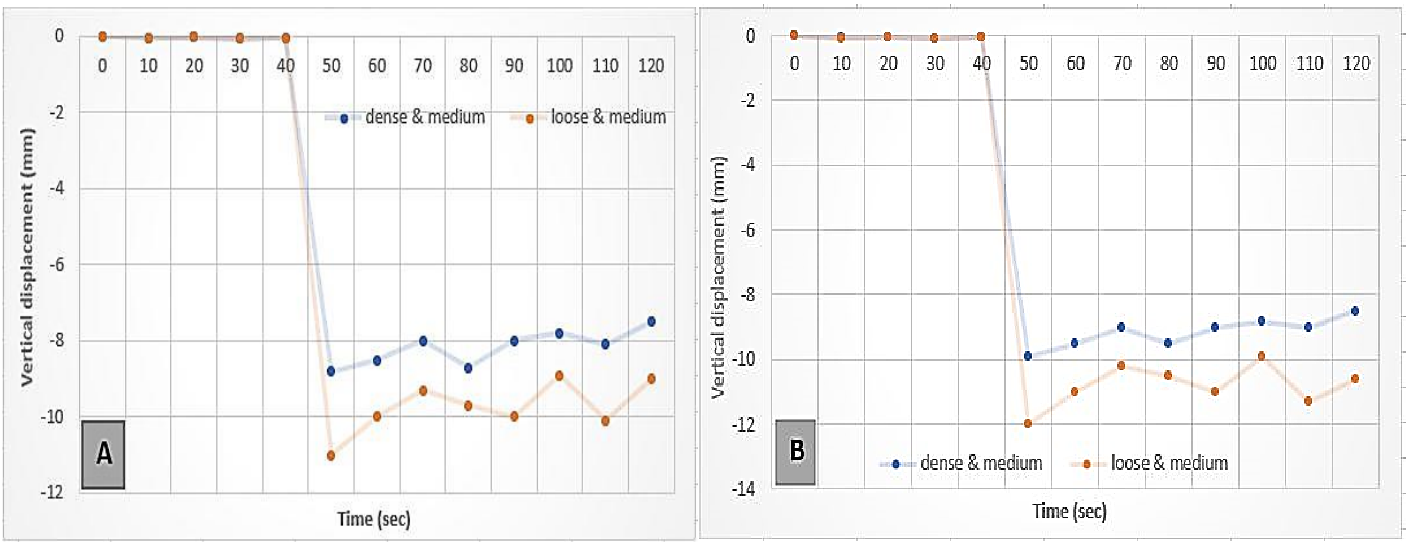
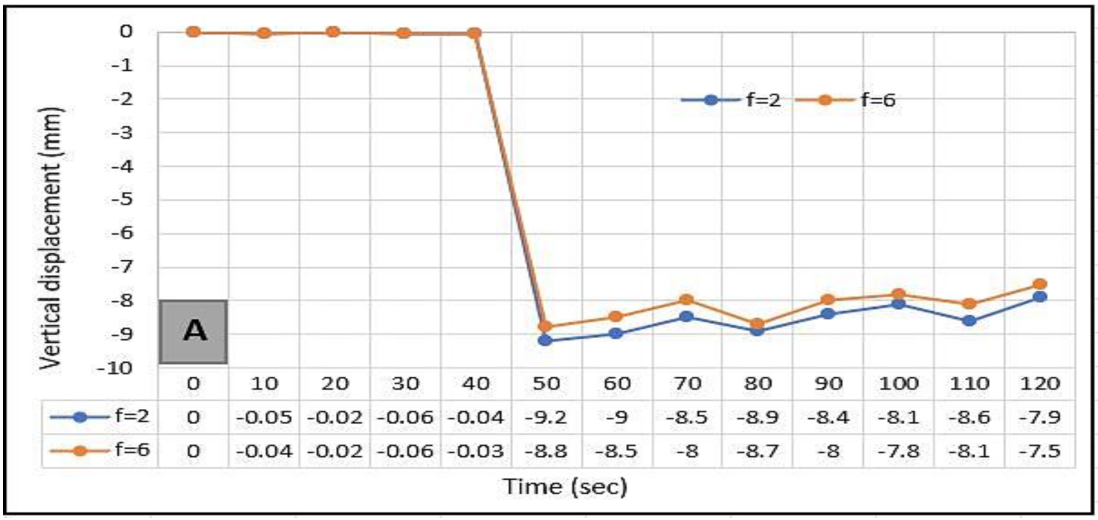


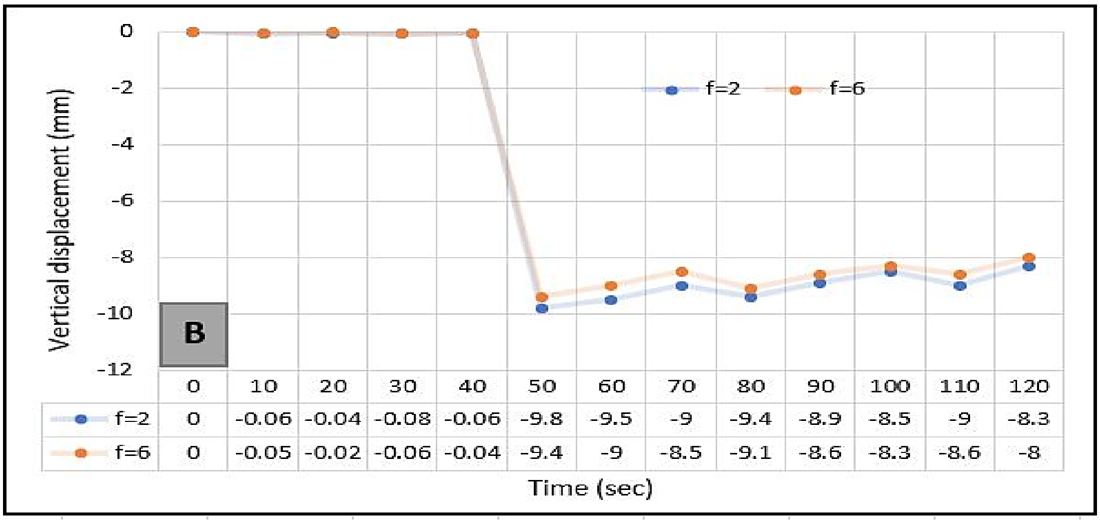
Figure 19. Total vertical displacement with time for different relative density of (A) strip footing and (B) square footing when (f=6) HZ

5.2.3 Influence of the Frequency of Machine

Displacement in Z direction:

It very well may be seen that the magnitude of displacement at the base of the foundation increases gradually with time at an earlier stage (40sec.), after that, these values increment and because of the earthquake became higher by about (99%). In addition, **Fig. 20** shows the effect of changing the frequency amount on the values of vertical displacements for different foundation shapes, where the vertical displacement value increases about 5% when the frequency value is reduced from 6 Hz to 2 Hz. This observation agrees with **(Mohammed Yousif Fattah et al., 2007).**





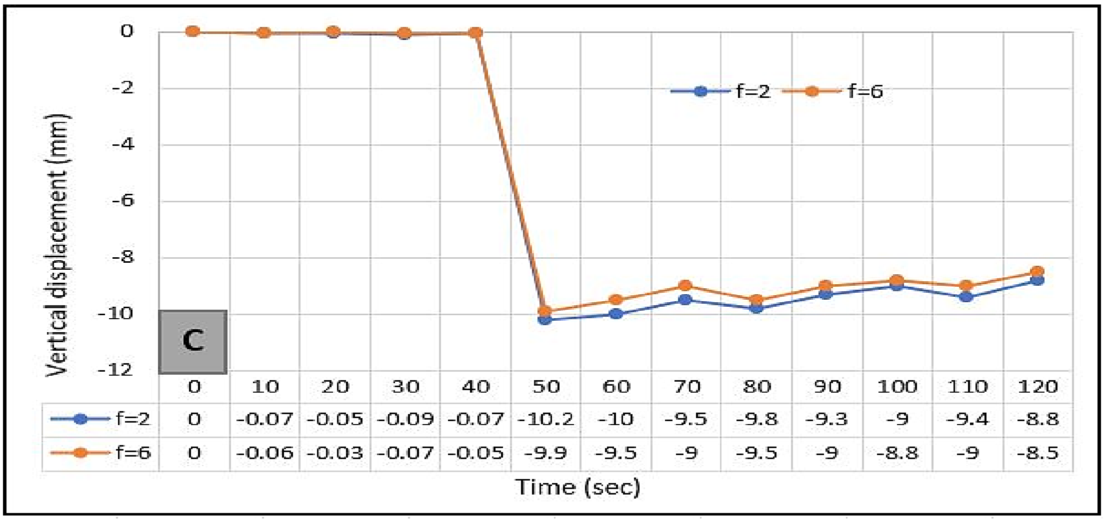


Figure 20. Total vertical displacement with time for different frequencies of (A) strip footing (B) rectangular footing (C) square footing

6. CONCLUSIONS

From the parametric review completed in this paper by using the (FEM) PLAXIS 3D V20 for analysis of machine foundation under seismic load rested on sandy soil with different densities and frequencies for strip, rectangular and square foundation, the following conclusions can be drawn:

i. The three-dimensional analysis using the finite element method can be used to analyze machine foundations under seismic load on dry soil in a successful way.

ii. It has been noticed that the vertical displacements decreased by about 5% when changing the frequency of the machine from 2 to 6 Hz.

iii. By studying the effect of the shape of the foundation on the vertical and horizontal displacements, it was found that when the L/B ratio increases, the vertical displacements decrease by 10%. While the effect of the foundation shape on the horizontal displacement is more signification than it is in the vertical displacement and the value of vertical stress increases in proportions that vary according to the point chosen.

iv. The ratio between displacement caused by the earthquake and displacement caused by the machine's vibration is 99%.

v. The most significant variable influencing the issue of machine foundations is the relative density of the soil. It was discovered that by the exact technique, the greatest horizontal displacement declined by 15 % and 20% for the vertical displacement when the relative density increments as the type of soil is sand

REFERENCES

Abdul-Kaream, K. W., 2020. Effect of Uncertainties of Soil Shear Strength Parameters on the Reliability of Machine Foundations, Ph.D. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

Abd Al-Kaream, K. W., 2013. *The dynamic behavior of machine foundation on saturated sand*, M. Sc. Thesis, Building and Construction Engineering Department, University of Technology, Iraq.

Al-Ameri, A. F. I., 2014. Transient and Steady State Response Analysis of Soil Foundation System Acted upon by Vibration, Ph.D. Thesis, Civil Engineering Department, University of Baghdad, Iraq.

Al-Hasso, N. K. I., 2020. Analysis and Design of machine foundation Using Analytical and Numerical Methods, M.Sc. Thesis, Civil Engineering Department, University of Mosul, Iraq.

Al-Helo, H. K., 2015. Dynamic Behavior of Machine Foundation on Two-Layer Soil System, In Journal of Engineering and Development, Vol. 19, Issue 1.

Al-Taie, A. J., and Albusoda, B. S., 2019. Earthquake Hazard on Iraqi Soil Halabjah Earthquake as a Case Study, *Geodesy and Geodynamics*, *10*(3), 196–204.

Al-Azawi, T. K., Al-Azawi, R. K., and Al-Jaberi, Z. K., 2006. Stiffness and Damping Properties of Embedded Machine Foundations, *Journal of Engineering*, *12*(2).

Boumekik, A., Belhadj-Mostefa, S., and Meribout, F., 2010. Experimental Analysis of the Dynamic Stress Distribution at the Soil Foundation Interface, Asian Journal of Civil Engineering (Building and Housing), 11, No. (5), pp 575-583.

Chandrakaran, S., Vijayan, P. and Ganesan, N., 2007. A Simplified Procedure for Design of Machine Foundations Subjected to Vertical Vibrations, Journal of the Institution of Engineers, India, Civil Engineering Division, 88, No. (5), pp. 3-12.

Fattah, M. Y., Al-Neami, M. A., and Jajjawi, N. H., 2014. Prediction of Liquefaction Potential and Pore Water Pressure Beneath Machine Foundations, Central European Journal of Engineering, 4(3), 226–249.

Fattah, M. Y., Salim, N. M., and Al-Shammary, W. T., 2015. Effect of Embedment Depth on Response of Machine Foundation on Saturated Sand, Arabian Journal for Science and Engineering, 40(11), 3075–3098.

Fattah, M. Y., Al-Mufty, A. A., and Al-Badri, H. T., 2007. Design Charts For Machine Foundations, Journal Of Engineering, 13(4).

Mitchell, J. K., and Soga, K., 2005. Fundamentals of Soil Behavior", Vol. 3, John Wiley and Sons New York.

Nagaraj, T. K., and Ullagaddi, P. B., 2010. Experimental study on load settlement behavior of sand foundations, Indian Geotechnical Conference 2010, GEO Trendz December, 16–18.

Piyush, K. B., and Ayan, S., 2014. Dynamic Analysis of Machine Foundation, Assistant Professor, Dept of Civil Eng., PDVVP COE, Ahmednagar, Maharashtra, India.

PLAXIS 3D Manual (2020), Delft University of Technology & PLAXIS bv, Netherland.

Srinivasulu, P., and Vaidyanathan, G. V., 1990. Machine foundations, McGraw-Hill Publishing Company Limited.

Tutunchian, M. A., Shahnazari, H., Salehzadeh, H., and Asadi, M., 2011. Study on Dynamic Behavior of Shallow Foundations on Liquefiable Sand Using Video Processing Technique, Electronic Journal of Geotechnical Engineering, 16, 945–960.