Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 2 Volume 28 February 2022

Civil and Architectural Engineering

Numerical analysis of a concrete foundation under a combination of a dynamic and a seismic load

Abduljabbar A. Allawi
Bachelor`s
Al-Salam College
Baghdad, Iraq
jabbaradel95@gmail.com

Qassun S. Mohammed
Prof. Dr.
Al-Nahrain University
Baghdad, Iraq
qassun.almohammed@eng.nahrainuniv.edu.iq

ABSTRACT

Improving in assembling technology has provided machines of higher evaluation with better resistances and managed behavior. This machinery led to remarkably higher dynamic forces and therefore higher stresses. In this paper, a dynamic investigation of rectangular machine diesel and gas engines foundation at the top surface of one-layer dry sand with various states (i.e., loose, medium and dense) was carried out. The dynamic investigation is performed numerically by utilizing limited component programming, PLAXIS 3D. The soil is accepted as flexible totally plastic material submits to Mohr-Coulomb yield basis. A harmonic load is applied at the foundation with amplitude of 10 kPa at a frequency of (10, 15 and 20) HZ and seismic load is applied with acceleration – time input of earthquake hit Halabjah city north of Iraq. A parametric statement is completed to evaluate the effect of changing the relative density, embedded depth and frequency of the machine. It has been noticed that the relative density plays an important role in the resistance of settlement, as it increases the resistance of the soil to the applied loads because the dense soil is stiffer**.** While total stress and displacement of different relative density decrease at the time when increasing the foundations' embedding, the ratio was (15%) at the depths (Df=0 and Df=2). In addition, it has been noticed that there decrease of displacement when the frequency value changes from (10 to 20) Hz.

Keywords: seismic load, sandy soil, machine foundation, Machine Diesel and Gas Engines Modeling.

---

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.02.02

Article received: 6 /10/ 2021
Article accepted:7 /11/2021
Article published:1/2/2022

التحليل العددي لأساس خرساني تحت مزيج من الحمل الديناميكي والزلزالي

عبدالجبار عادل علاوي
بكلوريوس
كلية السلام الجامعة

قاسيون سعد الدين محمد
استاذ دكتور
جامعة النهرين

الخلاصة

أدى التحسن في تكنولوجيا التجميع إلى تزويد آلات ذات تصنيفات أعلى بمقاومة أفضل وسلوك متحكم فيه. تؤدي هذه الآلات إلى قوى ديناميكية أعلى وبالتالي ضغوط أعلى. في هذا البحث ، تم وضع تحليل ديناميكي لأساس محركات الديزل والغاز المستطيل على السطح العلوي لطبقة واحدة من الرمل الجاف بحالات مختلفة (على سبيل المثال ، مفكك ، متوسط ، كثيف). يتم إجراء الإثارة الرأسية التوافقية والأفقية. ويتم إجراء التحليل الديناميكي عدديًا باستخدام برنامج العناصر المحدودة *PLAXIS 3D*. يُفترض أن التربة مادة بلاستيكية مرنة تمامًا تخضع لمعيار إنتاج *Mohr-Coulomb*. حيث يتم تطبيق الحمل التوافقي في الأساس بسعة 10 كيلو باسكال وبتردد (10 و 15 و 20) هرتز و تطبيق الحمل الزلزالي متمثلا بزلزال حلبجة. تم إجراء دراسة بارامترية لتقييم تأثير تغيير الكثافة النسبية وعمق التضمين وتردد الالة. وقد لوحظ أن الكثافة النسبية تلعب دورًا مهمًا في مقاومة التربة للاحمال المطبقة لأن كثافة التربة أكثر صلابة. كما نلاحظ نقصان كل من الإجهاد الكلي والإزاحة الكلية للرمل المفكك والمتوسط والكثيف في وقت زيادة عمق التضمين ، وكانت النسبة (15٪) عند الأعماق (*Df = 0* و *Df = 2*). بالإضافة إلى ذلك ، لوحظ انخفاض في الازاحة عند تغيير قيمة التردد من (10 إلى 20) هرتز.

الكلمات الرئيسية: الحمل الزلزالي ، التربة الرملية ، أساس الآلة ، نمذجة محركات الديزل والغاز.

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 the design of 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 the soil-foundation system. 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 such 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:

The soil response under dynamic loads is different from that of static loads because it is of significant importance for the stability of structures. 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. 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 a must for the correct evaluation of 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 several 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 dynamic load amplitude of 0.25 ton and different 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 a decrease in the dynamic response of the foundation. A convergence in results was obvious 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 of amplitudes 0.4, 0.6, and 0.8 kN and with 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 of the researches focused on the dynamic load due to earthquakes and offshore waves. However, very little information was 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 have a significant influence on the performance of the foundation and the soil underneath, producing is another type of vibration load. All machine foundations, irrespective of the size and type of machine, should be regarded as engineering problems, and their designs should be based on sound engineering practices.

1.5 Research Objective:

This study's main objective is to evaluate the behavior of the machine foundation under earthquake excitation by numerical analysis through the three-dimension finite element method with **PLAXIS 3D MANUAL (2020).** Also, studying the influences of dynamic loading variables (loading frequency, amplitudes) and relative density of machine foundation. Then, investigate the influences of parameters on the strain, amplitude displacement, and stresses in soils at various embedded depths for foundations on sand. Study the effect of the earthquake on the mentioned above properties compared to the effect of machine vibration.

1.6 Type of Machines:

According to frequency: **(Srinivasulu and Vaidyanathan, 1990)**

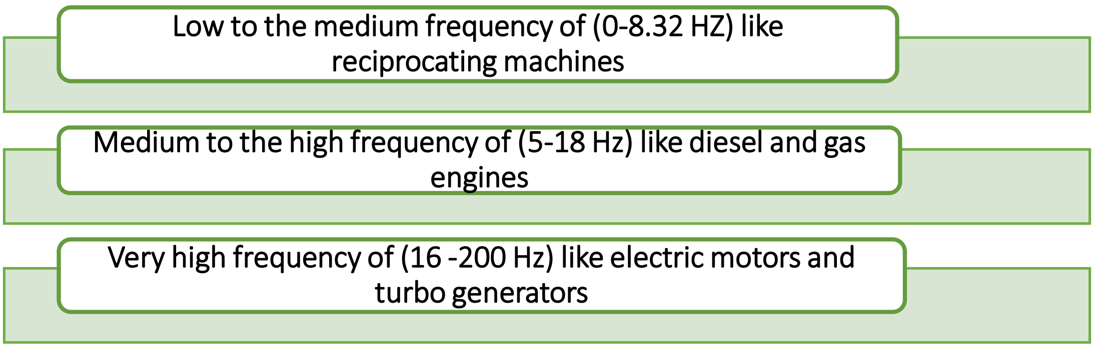

Figure 1. Types of the machine according to the operating frequency.

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 materials properties are categorized into four 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 equivalent to 1 kPa to keep away from inconveniences, and the amount of the dilatancy angle is expected as (ψ = Ø – 30).

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

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 = $2\pi f$ 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. The amplitude value is 10 kPa while the frequency is about 10 Hz. Fig. 2 shows the definition of a harmonic multiplier PLAXIS 3D MANUAL (2020). Therefore, the frequencies (10, 15, 20 Hz) were used according to what was referred to in paragraph 1.6, taking into account these values are within the range of the diesel machine**.**

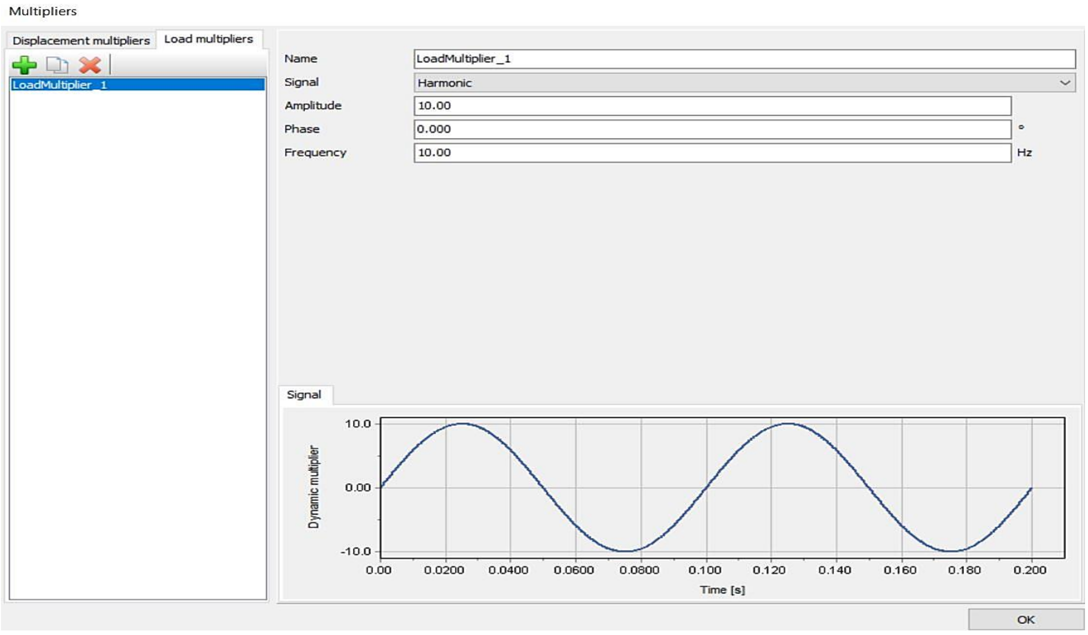

Figure 2. Definition of a harmonic multiplier.

4. Seismic Load: Acceleration-time records for (Halabjah). The greatest earthquake in Iraq was 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 the acceleration – time input of the earthquake.

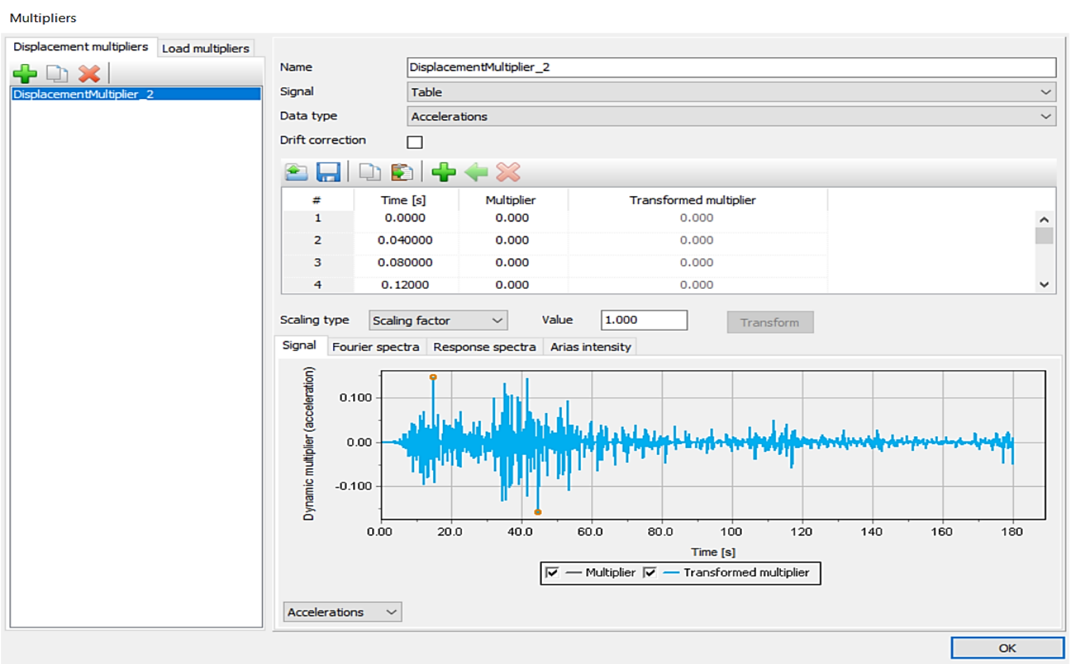

Figure 3. Acceleration – time input of earthquake hit Halabjah in November 2017 during 180 seconds recorded by The Iraqi Seismological Network (ISN).

Table 1. Parameters used for the numerical calculation.

Parameters	foundation	Dense sand	Medium sand	Loose sand
Modulus of elasticity, (E) (MPa)	20,000	65	40	28
Shear modulus, (G) (MPa)	8,700	21	15	10.4
Depth (m)	2	70	70	70
Unsaturated unit weight (kN/m^3)	24	19	17	16
Cohesion, (c) (kPa)	-	1	1	1
Friction angle, (ϕ)	-	38	34	30
Dilation angle, (Ψ)	-	8	4	0
Poisson`s ratio, (υ)	0.15	0.3	0.32	0.34
Relative Density, (Dr) %	-	80	60	40

4. NUMERICAL MODEL

4.1 Validation Model:

The verification was 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** was with 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 included subjecting the laboratory model to a series of tests to investigate the conduct of soil subjected to dynamic loading and the shear strength after a number of cycles. Footings of four shapes, circular with a diameter (150 mm), rectangular with dimensions of (300x100 mm), 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:

Dynamic limited component analysis of rectangular foundation under seismic load is done in this exploration. A length=20 m and width=4 m dimension foundation with 2 m thickness is placed on the top surface of the soil with one layer (dense, medium, and loose 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, assuming damping ratios (ɛ=5%, α=4.2 and β=0.0005) from the chart in **PLAXIS** according to the frequency of machine **(Hadi and Al-Helo, 2015).** The limit conditions and other illustrate subtleties considered for the foundation are displayed in **Fig. 4.** 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. 5.** 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, viscous option in the boundary conditions was introduced, viscous option was applied on the model in Xmax,min and Ymax,min and None for boundary Zmax,min **PLAXIS 3D MANUAL, (2020).** It should be noticed that all cases are examined for the duration (120 sec), to represent the machine in the second phase for 40 seconds and then combined with the earthquake for 80 seconds.

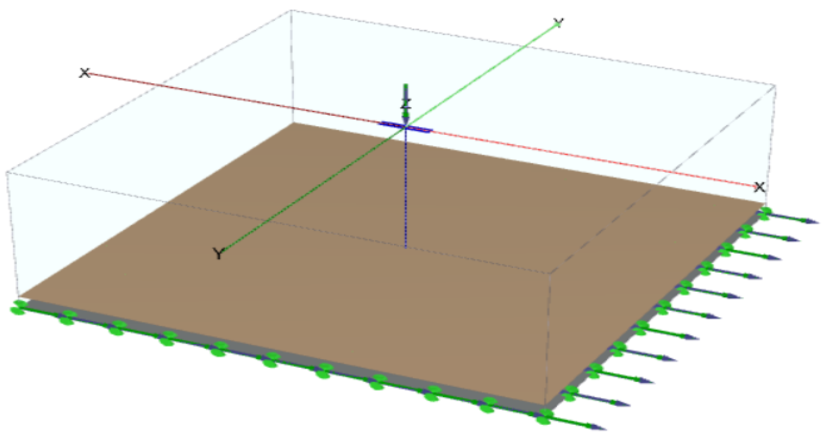

Figure 4. The numerical modeling of machine diesel and gas engines modelling.

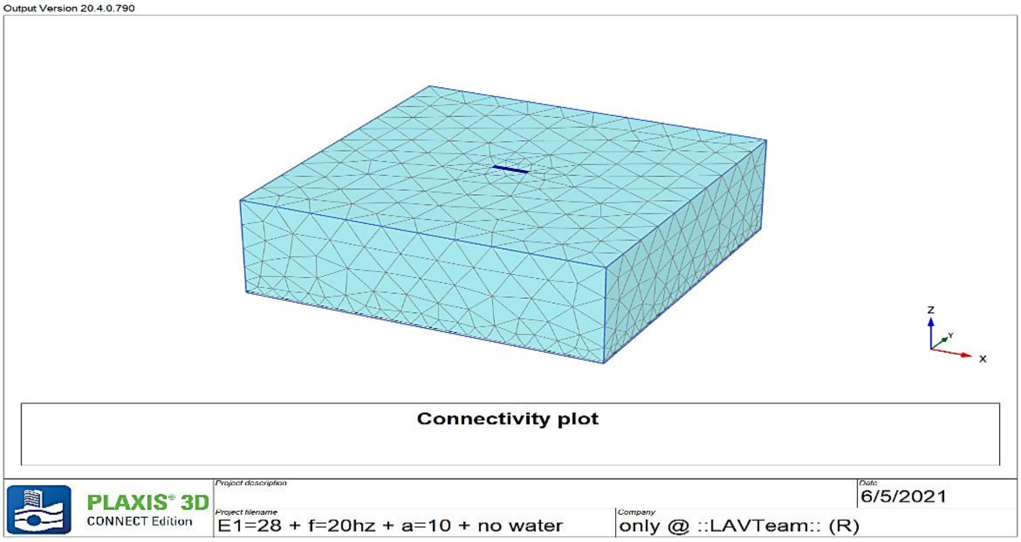

Figure 5. Mesh Generation Modelling of loose sand when (f=20 HZ).

5. RESULTS AND DISCUSSION

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 the occurred due to vibration of machine with different the shape 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 are 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). A clear comparison in the precipitation results is done by comparing the results of numerical analysis with the tutorial manual model, as shown in **Fig. 6B.**

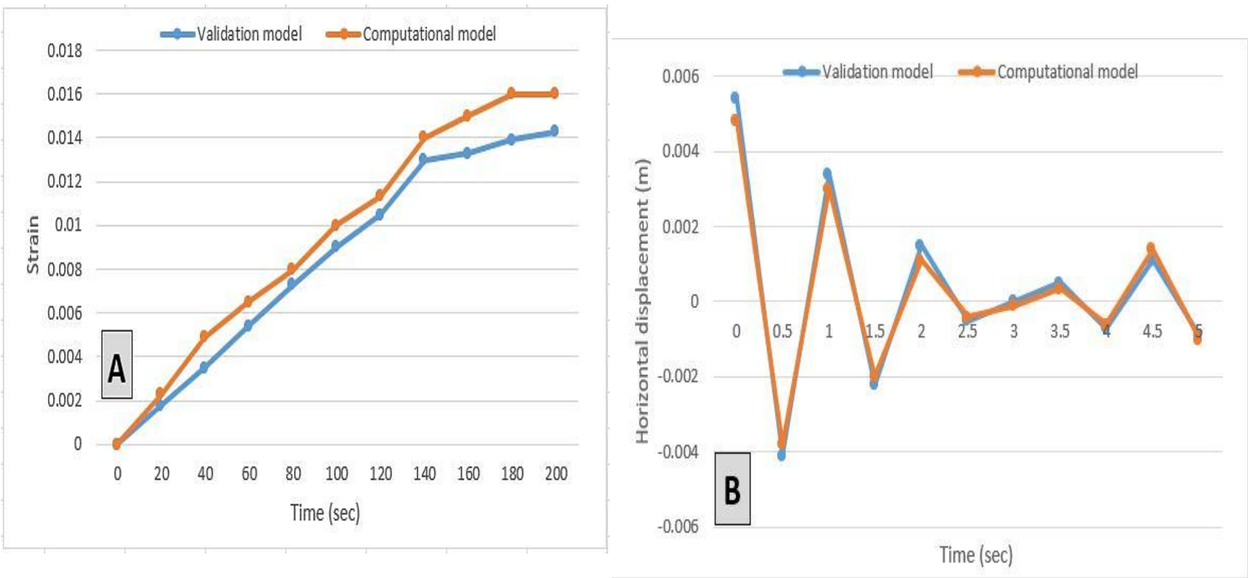

Figure 6. Strain with time for (A) rectangular footing and (B) point (0,1.5,15) on the sand of Dr=50%.

5.2 Results of analytical model:

5.2.1 Influence of the Relative Density

Displacement in Z and X-direction:

The vertical and horizontal vibration applied are estimated at the top main point. The illustrated **Fig. 7** and **Fig. 8** show the displacement reading versus the time of different relative density using soil with one layer (dense, medium, and loose sand) with operating frequency (20HZ). It has been noticed that the relative density plays an important role in the resistance of settlement, as it increases the resistance of the soil to the applied loads **(Al-Ameri, 2014),** so that the comparison shows that the value of vertical displacement decreases about 50% when increasing the value of the relative density by 80% as the dense soil is stiffer **(Mitchell and Soga, 2005)**. The results presented a clear effect of the earthquake on the displacement compared with the effect of machine vibrations. The vertical displacement is enlarged by about 99% when an earthquake is influencing the machine foundation (Dr=40%). On the other hand, it was also being noticed from **Fig. 8** that the horizontal displacement of loose sand is more (10-16) % when compared to medium and dense sand. The reason for this is due to an increase in the characteristics of dense and medium sand and a decrease in voids.

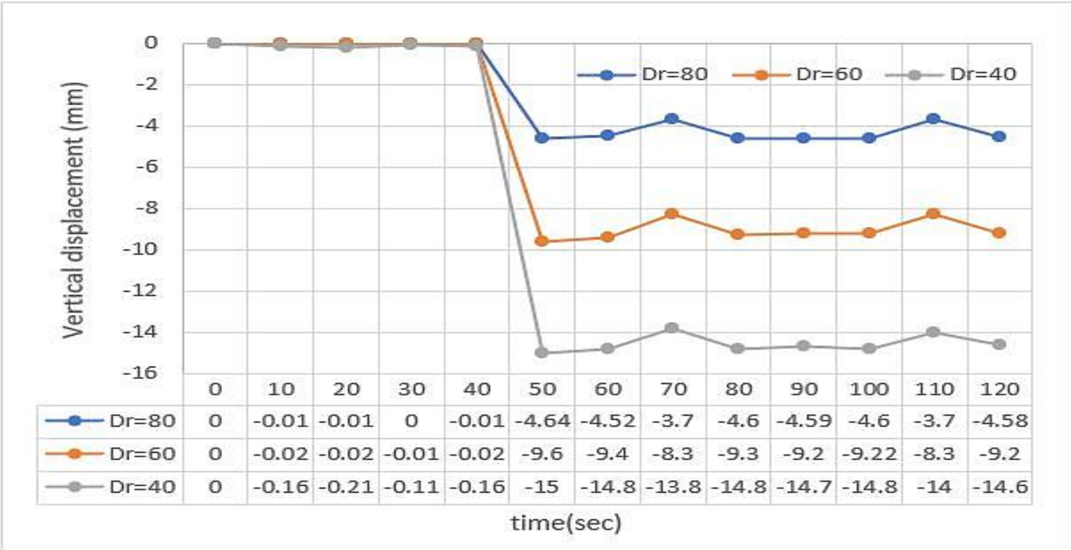

Figure 7. Total vertical displacement with time for different relative density when (f=20) Hz.

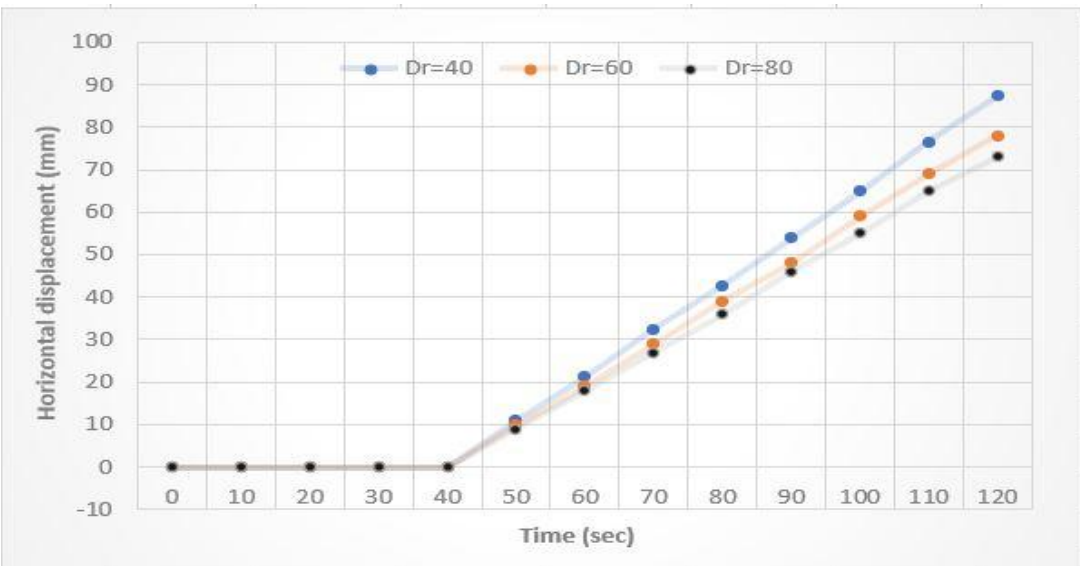

Figure 8. Total horizontal displacement with time for different relative density when (f=20) Hz.

Total stress in Z and X-direction:

The numerical analysis shows the relationship between the total dynamic stress and the time in **Fig. 9 to Fig. 11.** It was noticed that the total dynamic stress in the dense sand was less than that of loose sand. These results confirm the findings of **(Boumekik et al., 2010).** Thus, the rise in the thickness of medium-dense sand due to the inhibition of particles at the level of the central region creates an increase in their density. On account of dense sand, the high axial pressure will have the direction to be moved to the corners because of the underlying confinement. In addition, **Fig. 9** shows horizontal stress applied is measured at the top central point. It is clear that the behavior of the horizontal stress is slightly turbulent, as it records its highest value over a certain range of penetration when the soil is loose (550kPa) compared to dense sand (380kPa) that has a higher relative density and modulus of elasticity that led to disperse the generated stress, unlike loose soil that is easy to penetrate. On the other hand, from **Fig. 12** and **Fig. 13,** which describe the vertical stress, it was be noticed that there is a relationship between the applied stresses and relative density, which can be taken into account that in dense soils and due to their properties, an increase in the applied loads occurs. Hence, the value of the stress increases with the stability of the area when compared with loose. In contrast, the highest value of stress in dense soils was (1,333) kPa, while in loose soils, it was about (1,121) kPa.

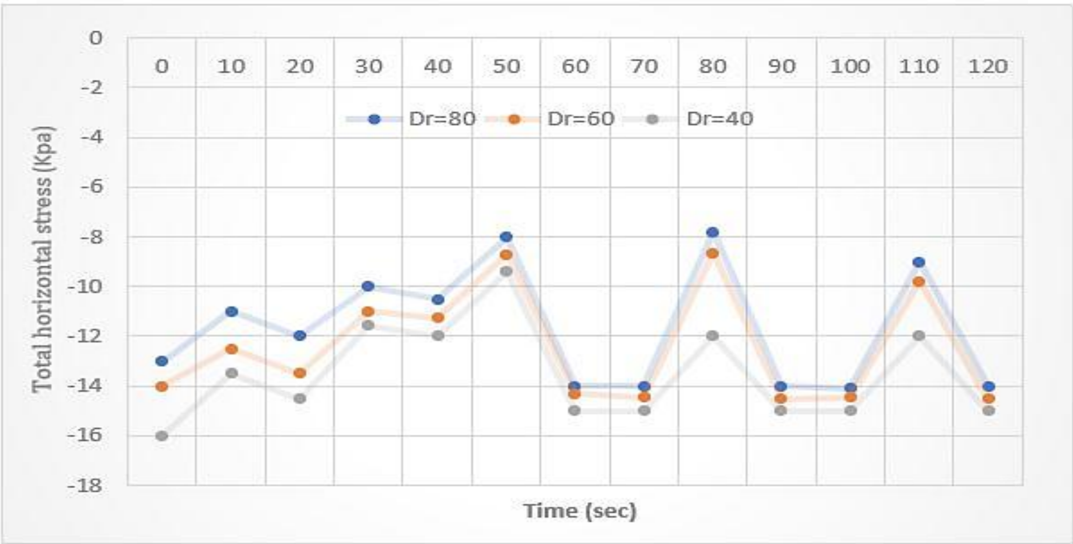

Figure 9. Total horizontal stress with time for different relative density when (f=20) Hz.

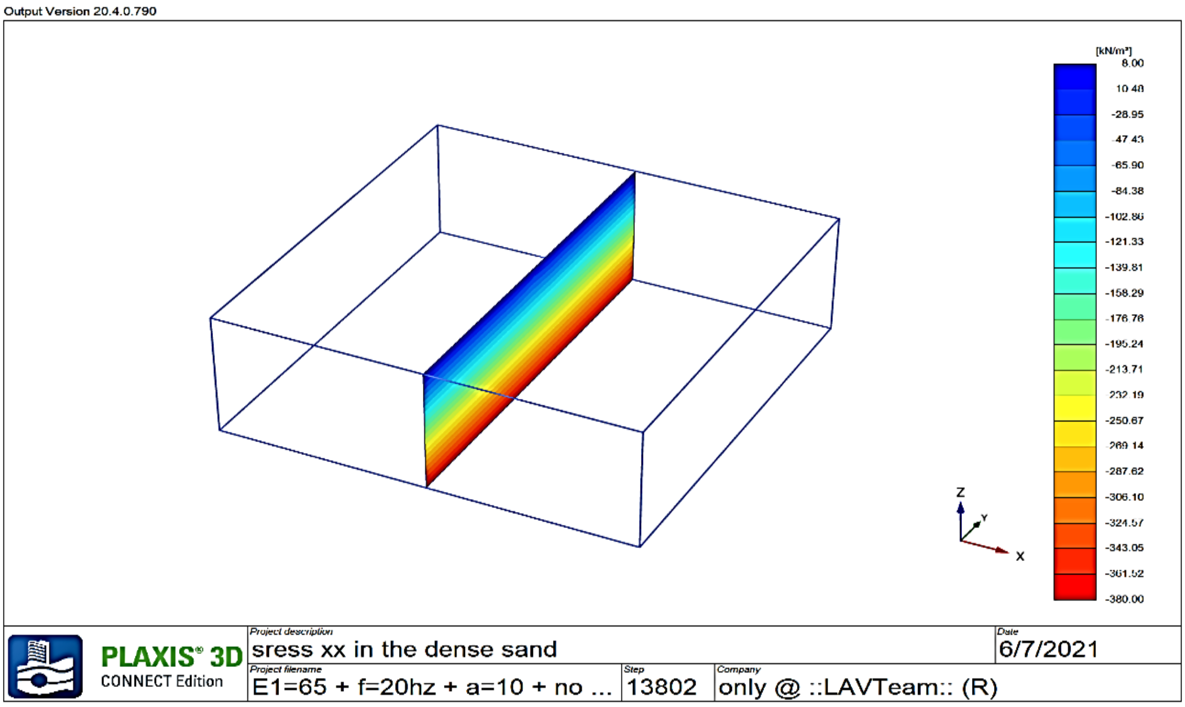

Figure 10. Total horizontal stress across section in the dense sand when (f=20) HZ.

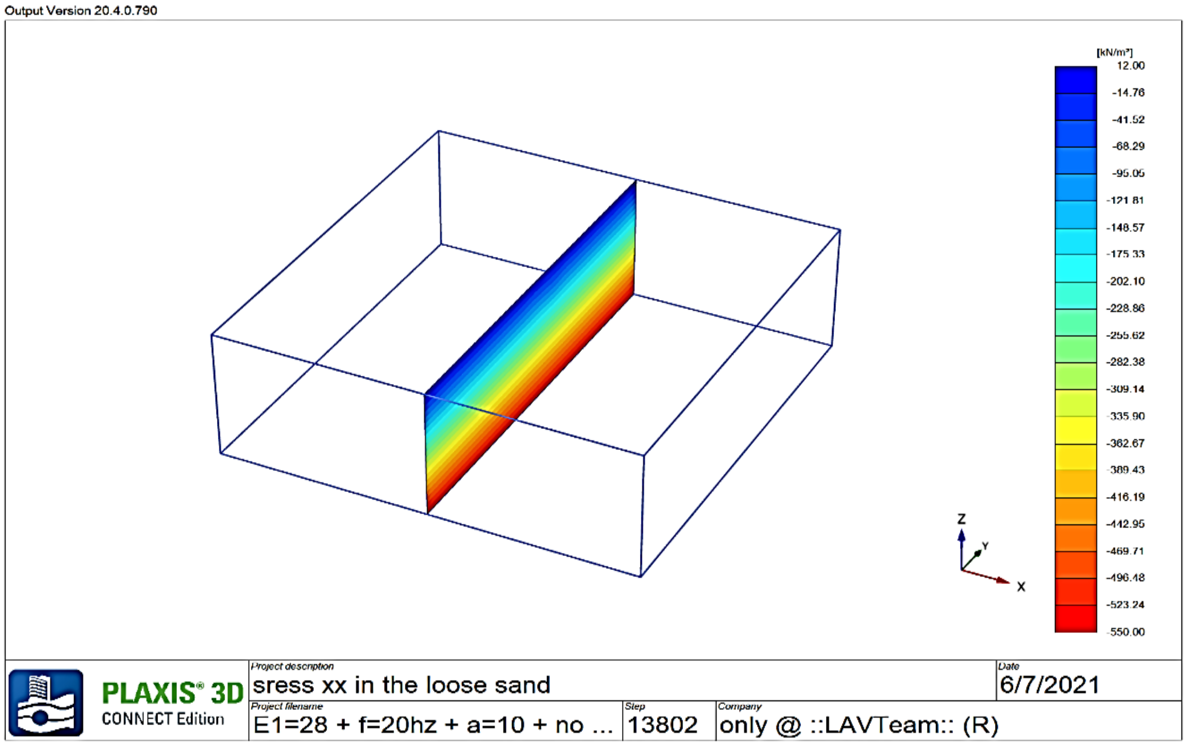

Figure 11. Total horizontal stress across a section in the loose sand when (f=20) HZ.

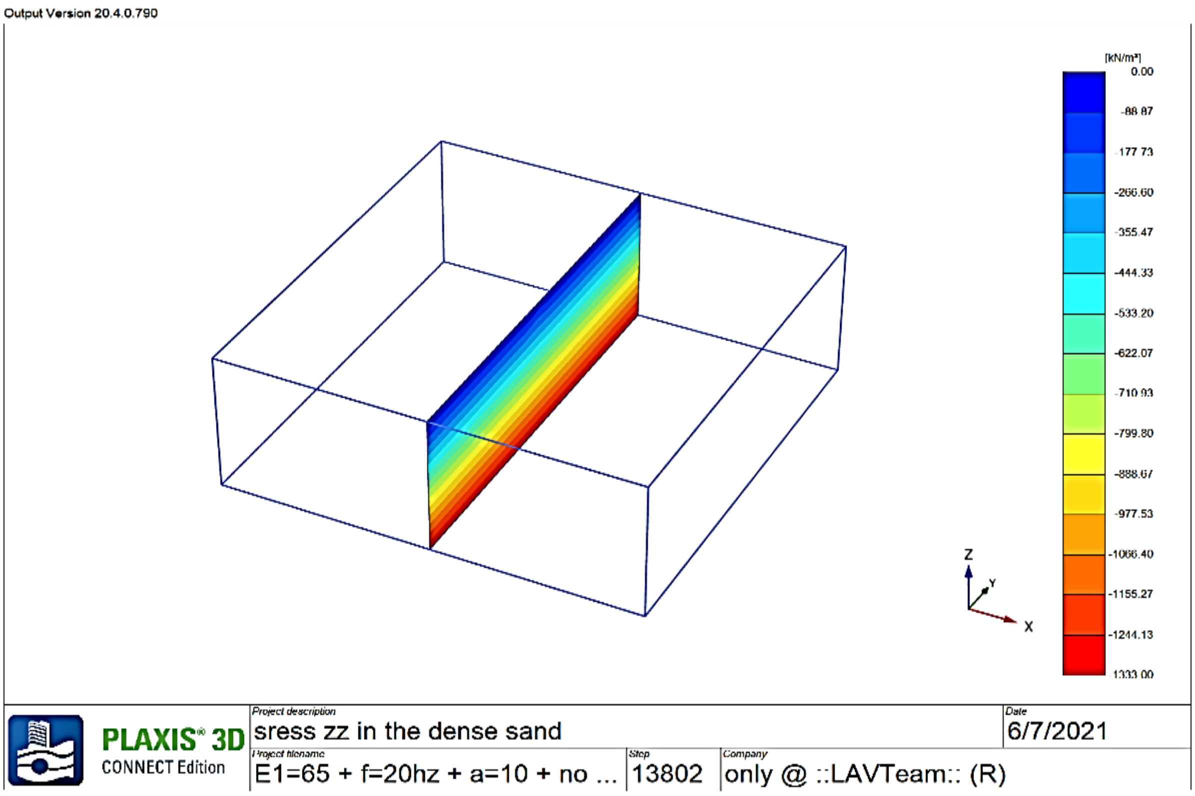

Figure 12. Total vertical stress across a section in the dense sand when (f=20) HZ.

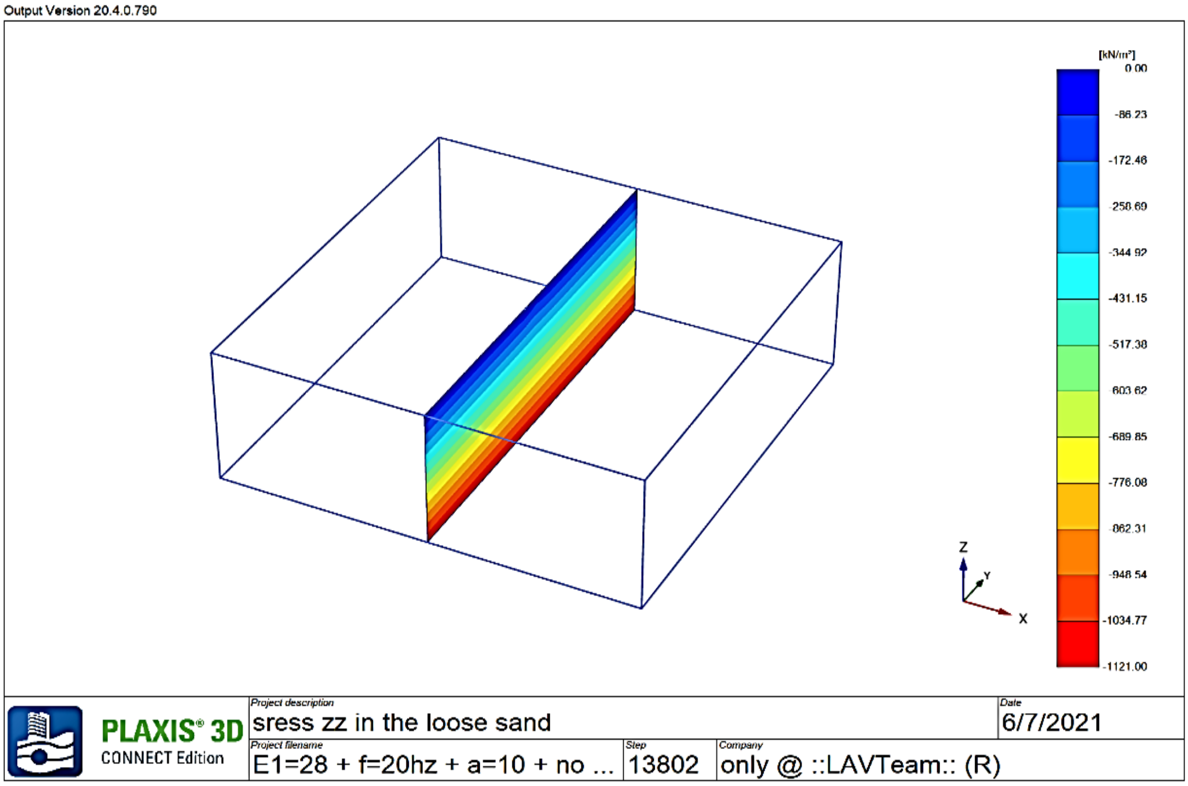

Figure 13. Total vertical stress across a section in the loose sand when (f=20) HZ.

5.2.2 Influence of the Embedded Depth of Dense Sand

Displacement in Z and X-direction:

For a safe design of machine foundation, it must have the ability to resist dynamic loads; this subject has taken considerable attention in recent years. Embedment has a significant effect on the foundation's response and must be careful when evaluated **(Hanash et al., 2020)**. The effect of three different embedded depths (at the surface, Df=1, and Df=2) has also been studied. **Fig. 14** shows the vertical displacement amplitude in dense sand, and **Fig. 15** draws horizontal displacement for dense sand. It was noticed that the displacement at depths (Df=1 and Df=2) was lower than that at the surface. The ratio was (15%) at the depths (Df=0 and Df=2) to dense sand. This implies that the insertion depth caused a meaning in the amplitude displacement among surface and insertion cases because of the increment in damping brought about by the soil-based foundation alongside the preparation for the soil-structure interaction (SSI) as a result of the embedded depth. Such notice closely agrees with the conclusions **(Mohammed Y Fattah et al., 2015) and (Al-Mosawi et al., 2015),** who induced that the displacement of loose, medium, and dense sands declined at the time of rising the foundations' embedding.

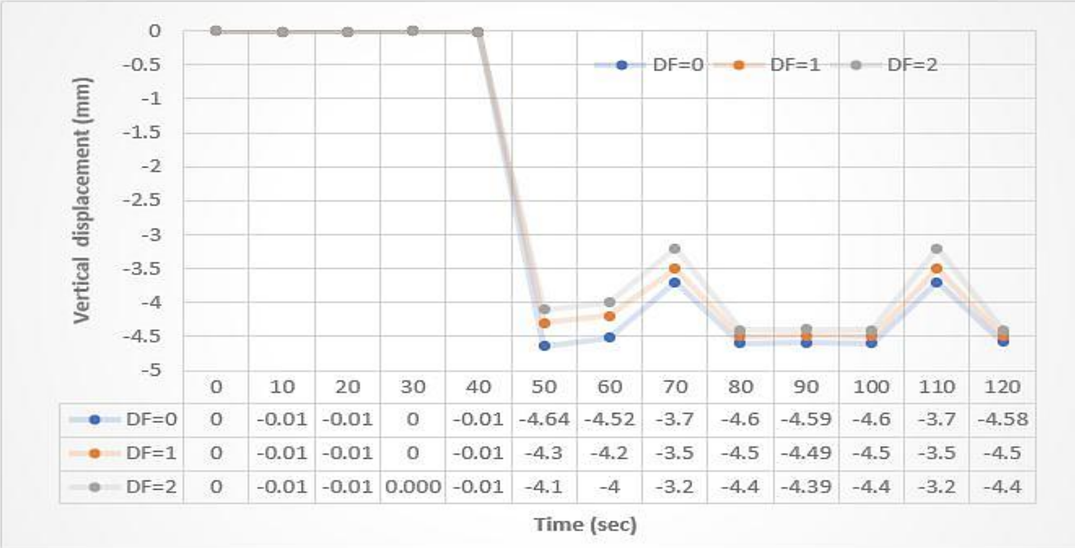

Figure 14. Total vertical displacement with time for different embedded depth when (f=20) Hz.

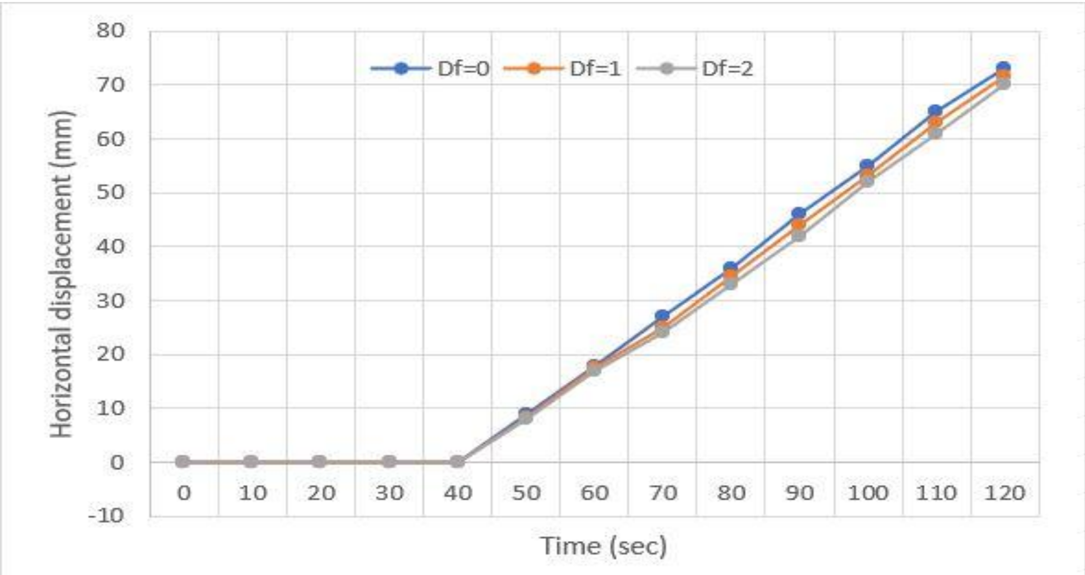

Figure 15. Total horizontal displacement with time for different embedded depth when (f=20).

Total stress in X and Z direction:

The process of including the foundation is of great importance in describing the stress curve, so it can be seen in **Fig. 16,** which hones of values of stress a point for at the surface of the soil that the foundation when it is at a surface, (i.e., Df = 0) and the point at the base of the foundation, the stress is a large amount compared to the foundation with (Df=2) where the point, in this case, becomes at the surface of the foundation, so it is far from the stress area, as shown in **Fig. 17 – 20** for a slice representing a section of the foundation, where the highest stress value at the apparent foundation is (1,333) kPa. The fully submerged It is (1,300) kPa in the vertical direction. As for the horizontal direction, it is (380) kPa for the (Df=0) and (370) kPa for (Df=2).

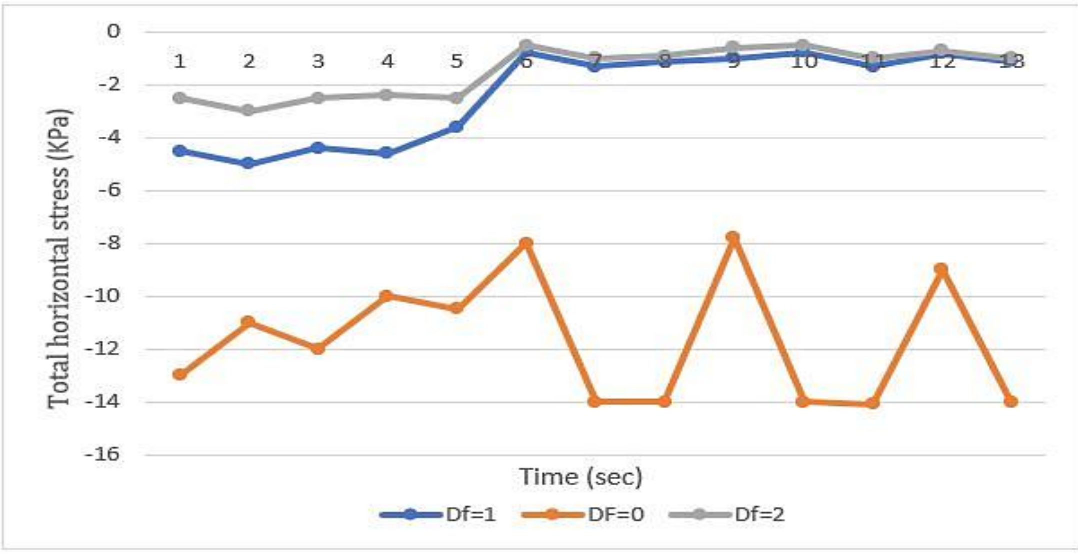

Figure 16. Total horizontal stress with time for different embedded depth when (f=20) HZ.

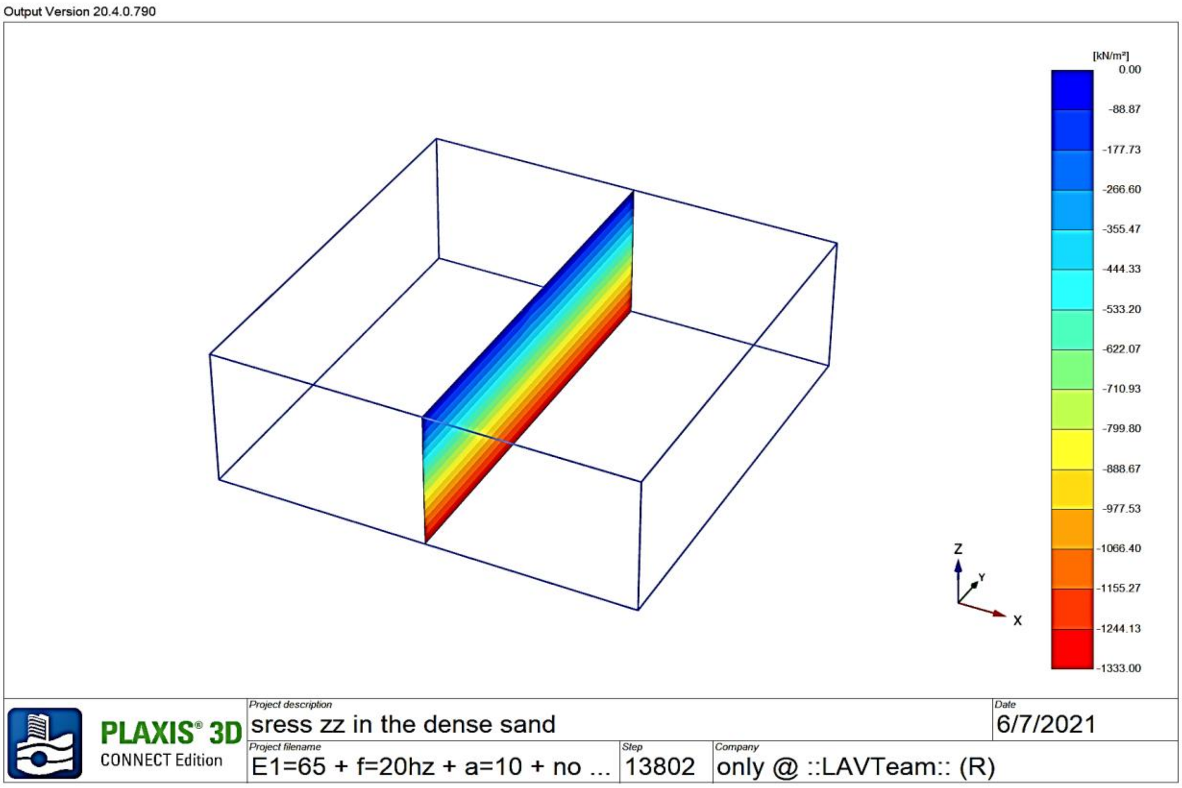

Figure 17. Total vertical stress in the dense sand when Df=0.

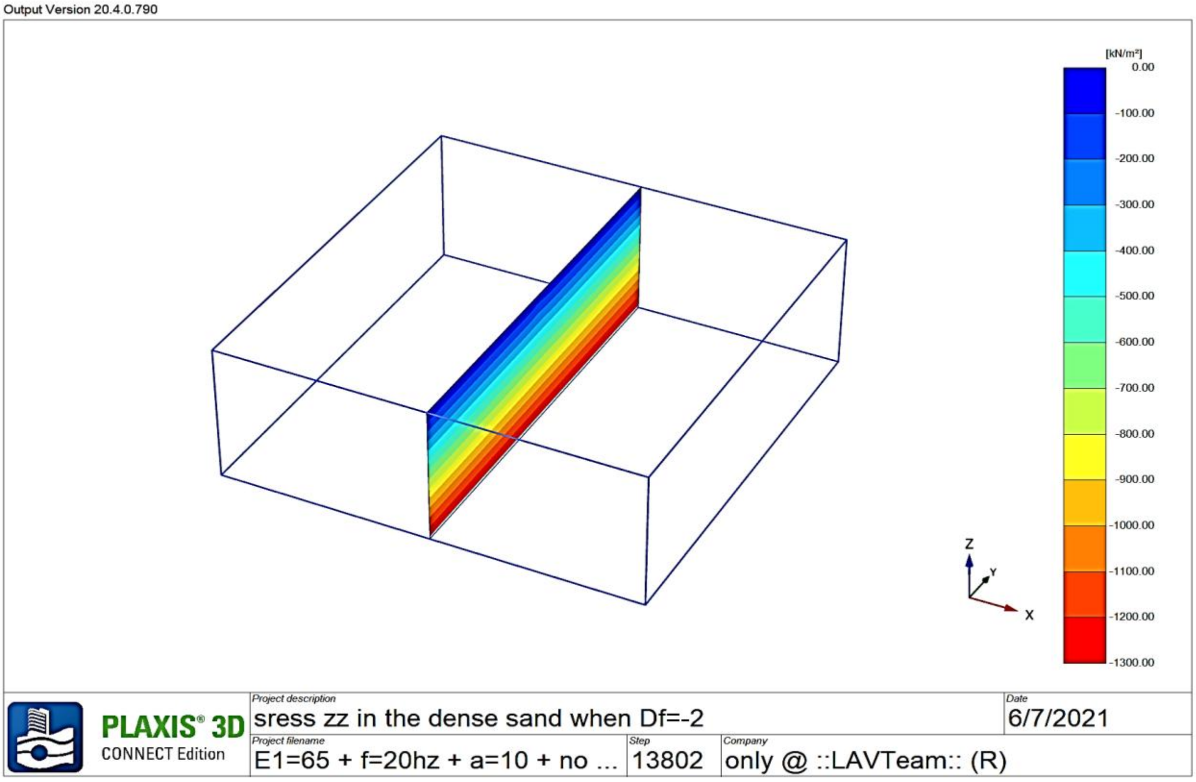

Figure 18. Total vertical stress in the dense sand when Df=2.

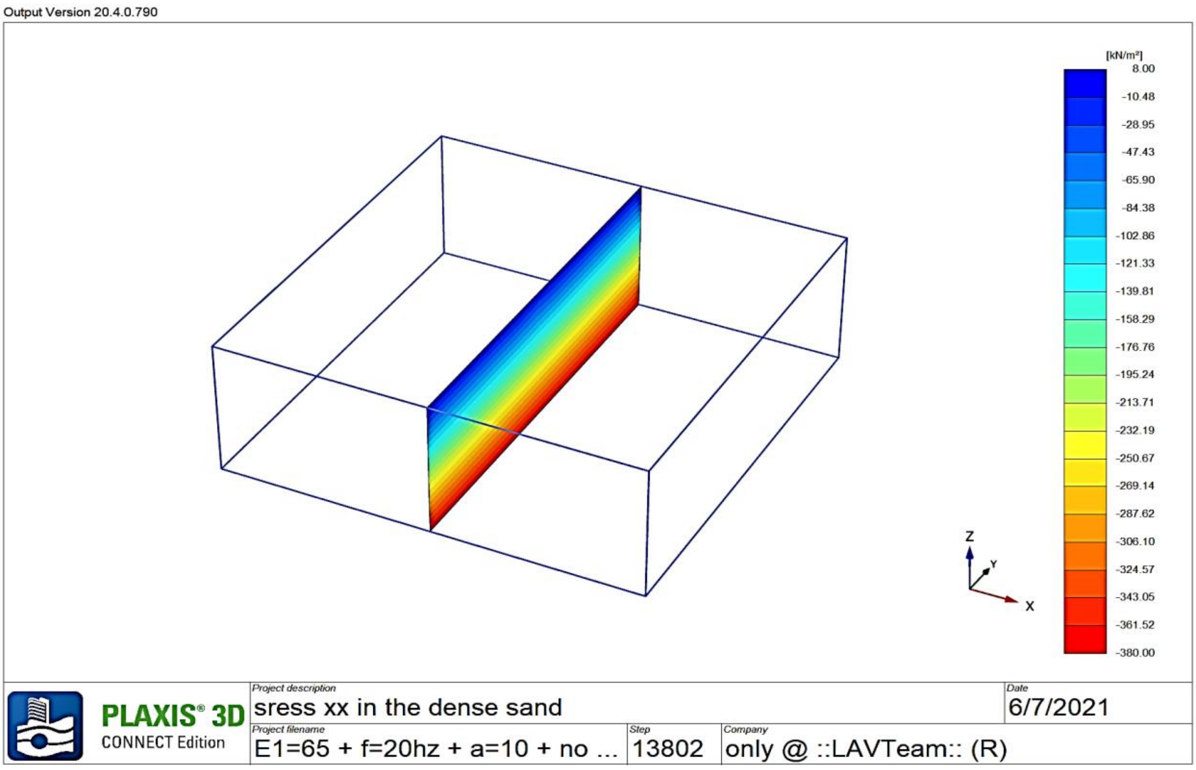

Figure 19. Total horizontal stress in the dense sand when Df=0.

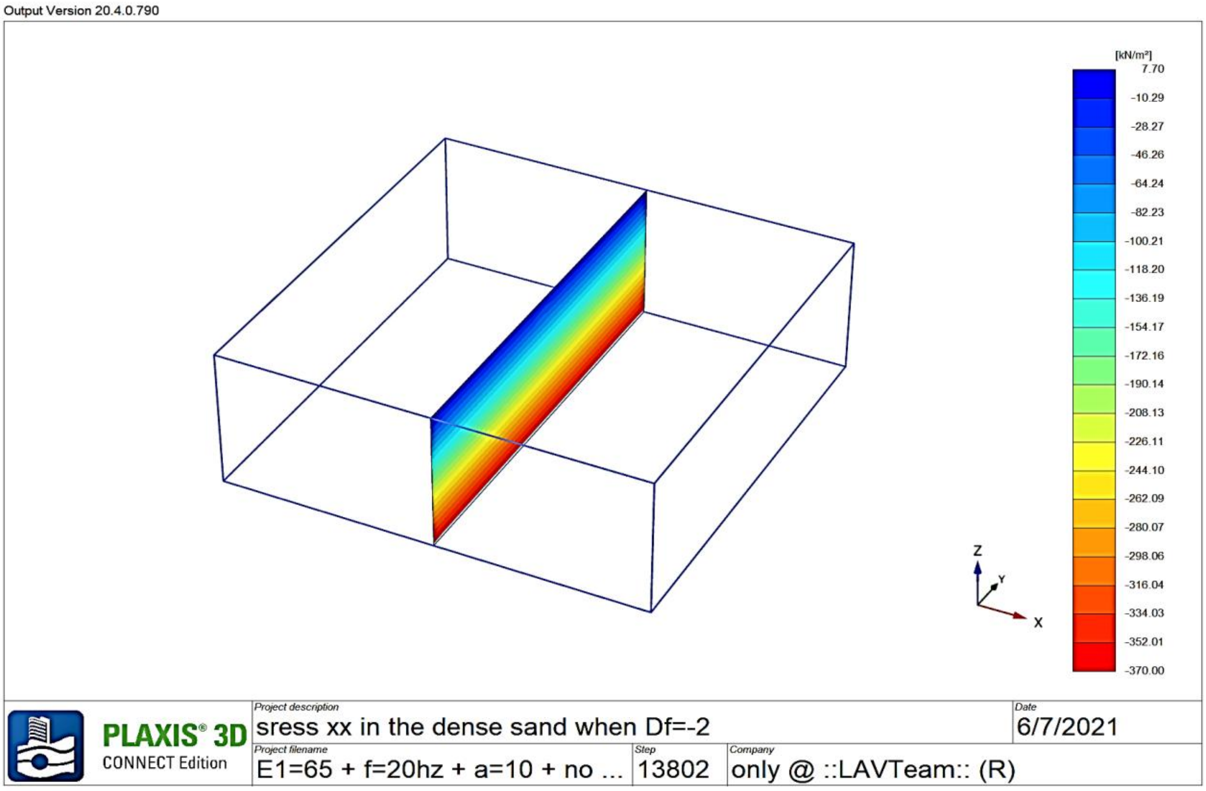

Figure 20. Total horizontal stress in the dense sand when Df=2.

5.2.3 Influence of the Frequency of Machine for Medium Sand

Displacement in X and Z-direction:

Fig. 21 and 22 show the relationship between the operating frequency ($f_{\circ}$) and the medium sand's total vertical and horizontal displacement. It has been noticed that when the frequency increases (10HZ) to (20HZ), a decline in the total vertical displacement occurs with (6.5%). In contrast, the effect is less in the horizontal displacement values than in the vertical displacement. Such behavior closely agrees with the conclusions made by Fattah and **(Mohammed Yousif Fattah et al., 2007).**

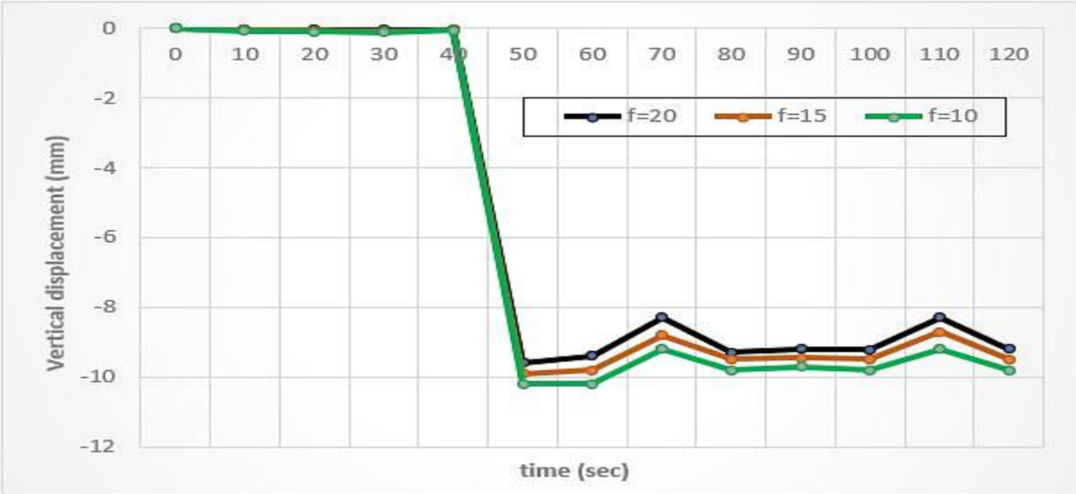

Figure 21. Total vertical displacement with time for different frequencies of machine.

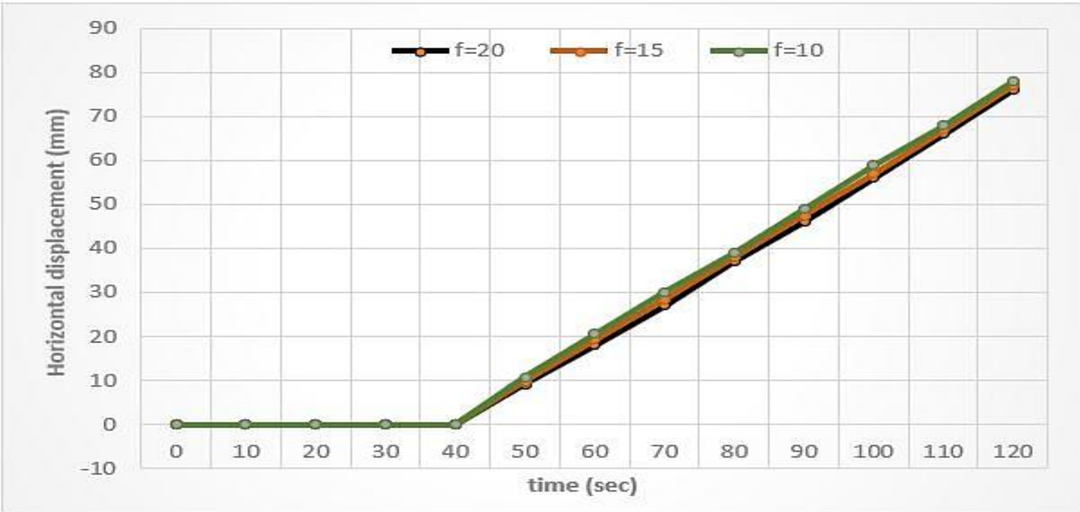

Figure 22. Total horizontal displacement with time for different frequencies of machine.

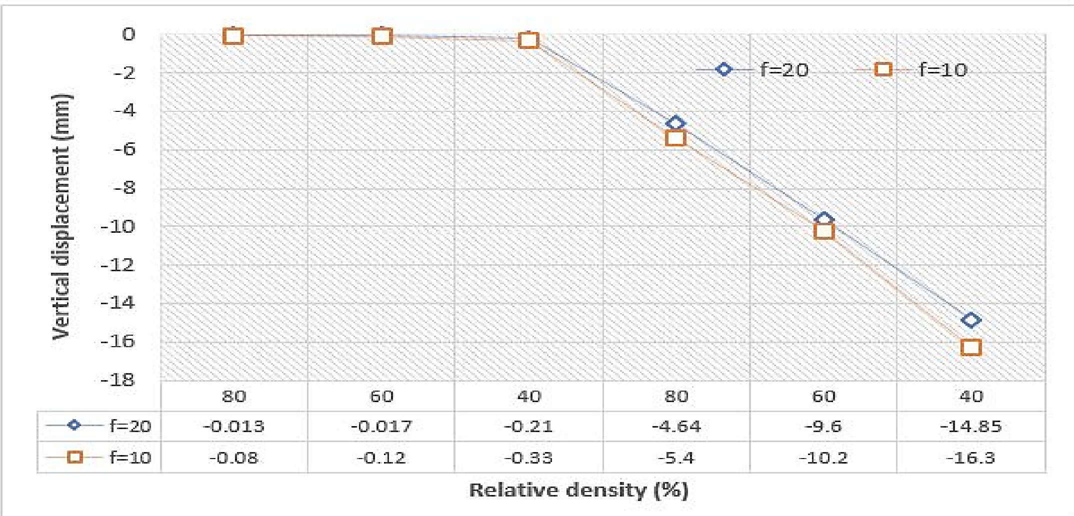

Figure 23. Vertical displacement with relative density for different frequencies of machine.

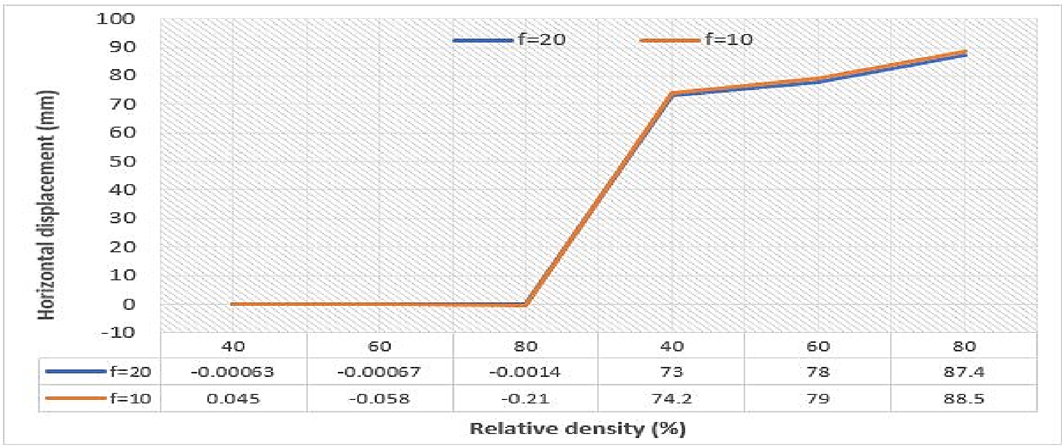

Figure 24. Horizontal displacement with relative density for different frequencies of machine.

6. CONCLUSIONS

From the parametric review that was carried out in this research using the finite element program **(PLAXIS 3D 2020)** to analyze the foundations of the machine under seismic load placed on sandy soils of different relative densities and frequencies for a rectangular foundation, it can be drawn following:

i. Three-dimensional analysis using the finite element method can be used to analyze the foundations of the machine under the seismic load on the soil in a successful way.
ii. It has been noticed that a decrease in the vertical displacements by about 6.5% when changing the frequency of the machine from 10 to 15 Hz. In contrast, it was found that this effect is less for the horizontal displacement, which is clear from the results that the displacement curve with time can be described as sharp.
iii. By studying the effect of the embedding depth on the vertical and horizontal displacements, it was found that when the embedding depth increases, the vertical and horizontal displacements decrease by 15%, and the value of vertical and horizontal stress decreases in proportions that vary according to the point chosen.
iv. The ratio between displacement caused by the earthquake and displacement caused by the vibration of the machine 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 vertical displacement diminishes by half when the relative density increments as the kind of soil are sandy.

REFERENCES

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

- Abdul-Kaream, K. W. (n.d.). *Effect of Uncertainties of Soil Shear Strength Parameters on the Reliability of Machine Foundations A.*
- Al-Ameri, A. F. I., 2014. Transient and steady state response analysis of soil foundation system acted upon by vibration. *University of Baghdad, Iraq*.

- 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).

- Al-Mosawi, M. J., Fattah, M. Y., and Al-Ameri, A. F. I., 2015. Effect of saturation of sandy soil on the displacement amplitude of soil foundation system under vibration. *Journal of Engineering*, *21*(2), 20–36.

- Boumekik, A., BELHADJ, M. S., and Meribout, F., 2010. *Experimental analysis of the dynamic stress distribution at the soil foundation interface*.

- Brinkgreve, R. B. J., Engin, E., and Swolfs, W. M., 2013. PLAXIS 3D 2013 user manual. *Plaxis Bv, Delft*.

- Fattah, Mohammed Y, Salim, N. M., and Al-Shammary, W. T., 2014. Numerical Analysis of Machine Foundation Resting on Saturated Sandy Soil. *Engineering and Technology Journal*, *32*(10 Part (A) Engineering).

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

- Hadi, K., and Al-Helo, I., 2015. Dynamic Behavior of Machine Foundation on Two-Layer Soil System Introduction. In *Journal of Engineering and Development* (Vol. 19, Issue 1).

- Hanash, A. A. A., Ahmed, M. D., and Said, A. I., 2020. Effect of Embedment on Generated Bending Moment in Raft Foundation under Seismic Load. In *Journal of Engineering* (Vol. 26, Issue 4, pp. 161–172). https://doi.org/10.31026/j.eng.2020.04.11

- KAREAM, K. W. A., FATTAH, M. Y., and KHALED, Z. S. M., 2020. Response of Circular Machine Foundation Resting on Sandy Soil to Harmonic Excitation. *Journal of Engineering Science and Technology*, *15*(2), 831–845.

- Mitchell, J. K., and Soga, K., 2005. *Fundamentals of soil behavior* (Vol. 3). John Wiley & Sons New York.

- Piyush K. Bhandari, A. S., 2014. (n.d.). *Piyush K. Bhandari, Ayan Sengupta (2014). Dynamic Analysis Of Machine Foundation.Assistant Professor, Dept of Civil Engg, PDVVP COE, Ahmednagar, Maharashtra, India.*

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

- نور خالد ادريس ، (2020) ، تحليل وتصميم اسس المكائن باستخدام الطرق الرياضية والعددية ، علوم الهندسة المدنية ميكانيك التربة وهندسة الاسس ، جامعة الموصل ، العراق.