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A Study of the Effect of Reinforcement Layers on the Performance of Shallow Footing Under Machine Foundation Loads

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Abstract

This paper exhibits an experimental study of the effect of the number of layers of reinforcement on the behavior of shallow footing under a machine foundation. A reinforcement was inserted into the sandy soil of relative density 50% during the raining techniques with 30*30cm at distances (0.5B, B,2B,3B) in a steel container with dimensions (50*50*55) cm. The test was performed under a machine foundation at frequencies 10, and 15 HZ. This research aims to find the optimal number of layers of reinforcement with geogrid under the square foundation under the machine foundation. For this purpose, laboratory experiments were conducted. The factors that were studied to find the optimal number of layers of reinforcement include the optimal number of layers of reinforcement, as well as displacement amplitude, velocity, acceleration, and settlement. The results showed at frequency 10 HZ, the optimal number of layers was one layer. The percentage of improvement in displacement, velocity, and settlement was (26%,39%, and 75%), while acceleration increased when using one layer. At frequency 15 HZ, the optimal number of layers was four layers. The percentage of improvement in displacement, velocity, and settlement was (34%,44%, and 66%). We conclude from this research that the type of reinforcement gave good results in reducing displacement amplitude, velocity, and settlement, but does not give good results in reducing acceleration.

Keywords: Reinforcement Layers, Shallow Footing, Machine Foundation Loads

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1. Introduction

The use of soil reinforcing techniques has grown in favor of a cost-effective way to solve a variety of geotechnical engineering issues. The idea behind reinforced soil is to improve the soil characteristics by adding fibers, synthetic materials, and metallic strips to the soil. The most popular method for improving the rigidity properties of soil between various materials is soil reinforcing using geosynthetics [1-3].

Laboratory testing that takes into account vertical machine vibrations is used to study soil beds reinforced with multi-layer geocell systems that support machine foundations. The findings show that while the resonant frequency, shear modulus, and damping coefficient increased in the presence of geocell reinforcement, the resonant amplitude significantly decreased. within the range of the frequency and applied vibration load. It was found that the first geocell layer's ideal placement depth and the geocell layers' vertical spacing were, respectively, 0.1B and 0.05B of the foundation's width [4].

The study investigated the impact of multiple extrinsic variables on the vibration damping effectiveness of geocell-reinforced foundation beds. It was discovered that the ideal geocell placement depth and width were 0.1B and 5B, respectively. 50% less particle velocity was observed at the ideal width and depth of implantation. Likewise, a 53% decrease

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in the foundation bed's peak displacement amplitude was noted. It was discovered that as the footing embedment and infill material modulus increased in the geocell reinforced scenario, the vibration parameters decreased [5].

Many investigators looked into how the number of reinforcing layers affected the reinforced soil's settlement and bearing capability. A bearing capacity test was conducted [6] on a 7.6 cm wide strip footing that was set on reinforced Ottawa sand. The effective number of layers of reinforcement was examined in this research. It concludes that up to eight layers, the bearing capacity rose with an increasing number of layers. This study focuses on the initial reinforcing layer's effective depth. According to that, the maximum (BCR) happened at d1 = 25 mm.

In the study of Thomas et al. [7], the authors examined using geonet reinforcement the bearing capacity of ring foundations sitting on both reinforced and unreinforced sand. It is discovered that the depth and number of reinforcing layers affect the bearing capacity. The bearing capacity also increases as the number of layers.

Conducted a 2D numerical study for a restricted cell to investigate the reinforced soil's dynamic behavior while subjected to machine vibrations [8]. The findings demonstrate how the presence of restricted cells improves the soil bed's stiffness and damping ratio, which in turn reduces overall subgrade deformation. Despite these early efforts, there is a dearth of research on the effectiveness of geocell-reinforced foundation beds to reduce vibration, particularly when they are stacked beneath machine foundations [9].

Comparing the reinforced sand layer to the unreinforced sand, it is found that there is a notable improvement in bearing capacity. A presentation and determination of the ideal geocell geometry was made to maximize the capacity for bearings. Additionally, an experiment was conducted to identify the ideal spacing for a two-layer geocell system.

The behavior of reinforced earth regarding the bearing capacity and settlement of sandy soil was researched [10]. It is employed geotextile and geogrid as two different forms of reinforcement. Tenser SS1 Type geogrid was utilized, and Dupont Typer 3401 geotextile was used. The bearing capacity increased, according to the author, when The first layer was nearest to the ground. when there was little space between the layers. Additionally, it is noticed that when the geotextile's reinforcing tensile strength grew, so did its bearing capacity.

In an experimental study discovered that the stiffness and damping ratio of the soil mass were enhanced by adding geogrid underneath the machine foundation [11].

The numerical research of a machine foundation resting on soil beds reinforced with geocell by changing the dynamic loading frequency while maintaining the same force amplitude, the response of these examples was examined. The geocell and geogrid structure was rearranged with a different depth. When compared to the unreinforced foundation bed, the amplitude of the displacement was decreased by 61% due to the appropriate positioning of the geocell. Similarly, the addition of geocell led to a reduction in displacement of almost 50% when compared to geogrid. It was shown that the resonance frequency varies with the type of reinforcing mechanism [12].

The geosynthetic-reinforced soil beds that support the model machine base were examined. The tests are conducted using a Lazen type mechanical oscillator under six distinct dynamic force levels. The displacement amplitude of vibration was found to be greatly reduced in the presence of geosynthetics, according to experimental results. Resonant amplitude is reduced by 61% and the soil system's natural frequency is raised by 1.38 times in comparison to the state without reinforcement. Furthermore, it was discovered that the geocell reinforcement, when placed 0.5 meters away from the footing face, reduced the PPV by 48% [13].

According to study of Abu-Farsakh et al. [14], 0.25B to 0.50B is the ideal range for the initial reinforcing layer's depth. They also came to the conclusion that three reinforcing layers were the ideal number.

In the present study, there is a high displacement, velocity, and acceleration for machine foundation and settlement for shallow footing so, we need to reduce them by using 4 layers of reinforcement.

2. Materials and Methods

2.1 Soil Used

Samples of soil were taken between 0.75 and 1.5 meters below the surface of the ground, the sample was brought to Frome AL-Ukhaider quarry in Karbala, Iraq the chosen samples were then put through routine laboratory testing to determine the type of soil. The sample characteristics are explained below in Table 1 and Fig. 1.

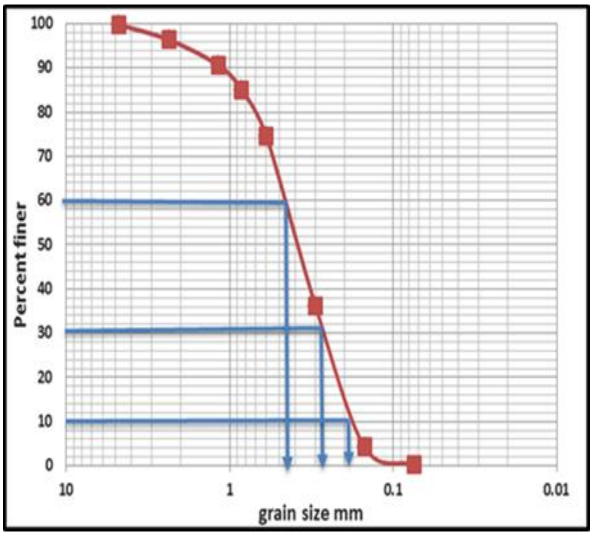

Fig. 1 Grain Size Distribution.

Table 1: Soil Properties.

Properties	Values	Standards
Effective size, D10 (mm)	0.18	ASTM D 422 and ASTM D 2487 (2006)
D30 (mm)	0.31	
Mean size, D50 (mm)	0.42	
D60 (mm)	0.47	
Coefficient of uniformity, Cu	2.6	
Coefficient of curvature, Cc	1.13	
Classification (USCS)	SP	
Specific Gravity, Gs	2.63	ASTM D 854 (2006)
The angle of Internal Friction (Ø)	36	ASTM D 3080- 04(2006).
γd (max.) (kN /m3)	18.44	ASTM D 4253 - (2006)
γd (min.) (kN /m3)	15.35	ASTM D 4254 - (2006)

2.2 Steel Container

The Square container which manufactured at the local market. This container is made from stainless with dimensions (length of 50 cm, width of 50 cm, and 55 cm in height). The steel container plate is made with 4mm thickness as shown in Fig. 2.

Fig. 2 Steel Container

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2.3 Reinforcement Type.

Geogrid form (Netlon CE121) is used. The geogrid characteristics that were used in this study are listed in Fakhreddin's Table 2 [15]. In Fig. 3 the geogrid forms are displayed. Four geogrid layers were used inside the 30 cm to 30 cm measure of sand soil layer [16].

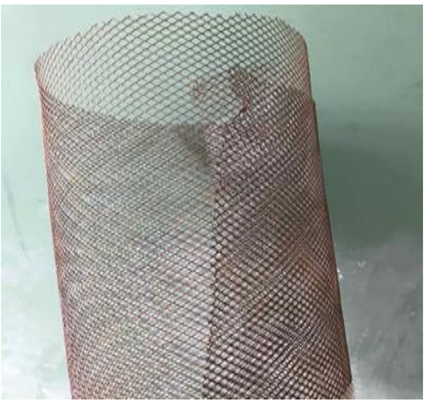

Fig. 3 Netlon CE121.

Table 2: The geogrid (Netlon CE121) properties

Description	Properties
Mesh type	Diamond
Type of polymer	PP
Colour	Black
Elastic modules, GPa	0.39
Tensile strength, MPa	9
Tensile Peak resistance KN/m	6.4

2.4 Footing Model and Source of Vibration

A mechanical oscillator set on a foundation of (100 * 100 * 4) mm is the vibration source for vertical vibration testing. The mechanical oscillator has a rotating disc made of steel with (60) mm diameter and (4) mm thickness. A small eccentricity mass (me) is placed on a rotating disc of the rotational axis (an eccentricity) of (20) mm as shown in Fig. 4 and calculated in Equation 1. This study uses a single kind of eccentric setup with a value of (55) grams. the equation of vibration induced by the machine.

$$Fo = me\ \omega 2\ m\ e \quad (1)$$

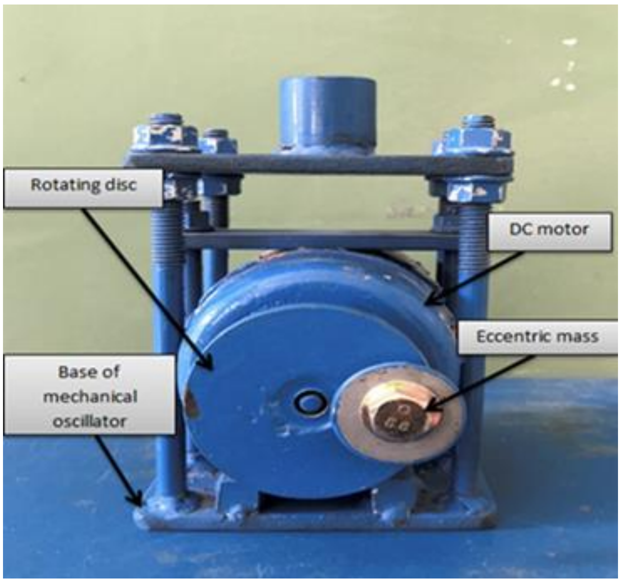

Fig. 4 Device for measuring Vibration Response

2.5 Density Control

The rainy technique approach is used to prepare the soil to achieve a static relative density of all the sandy soil layers in the study container. The rate at which sand grains fall and the amount of discharge influence the formation of sandy soil in this test and achieve a uniform soil deposit with the required density. The relative density required by the study is 50% at a fall height of 65 cm. The sand container is filled in layers of 10 centimeters for every 10 cm of container height, with a fall height of 65 cm. After the first layer is filled, the dirt cone is raised by 10 cm using a lifting roller to fill the second layer and maintain the fall's height. This results in a relative density of 50%, as shown in Fig. 5.

Fig. 5 Density control

2.4 Equipment and Devices.

Many equipment and Devices are used in experimental work as shown in Fig. 6.

1-Mechanical oscillator.
2-Electronic Dial Gauge
3-Vibration meter
4-Static load
5-Digital Tachometer
6-Stand of container
7-Container, steel mode
8-Variable frequency drive
9-Weight holder

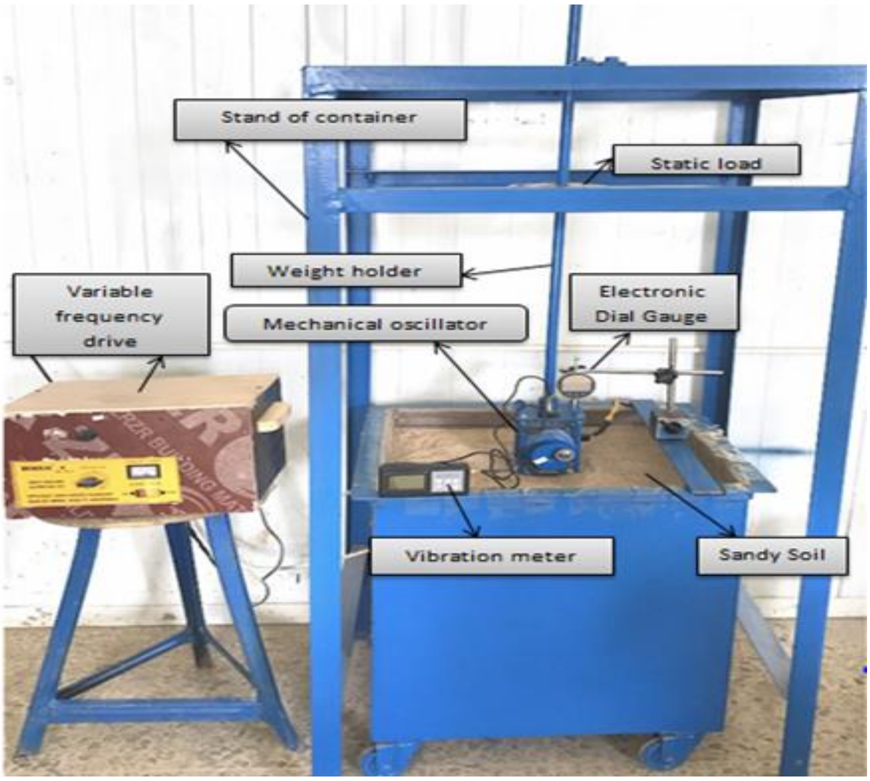

Fig. 6 Equipment and Devices.

2.7 Testing Procedure for Model

The test is performed in the dry condition and according to the following steps:

1. Rubber is placed to prevent the wave from bouncing inside the container. The weight of the sandy soil that is placed in the container is (213kg) and it is divided into 5 layers, each layer is placed (42.6kg).
2. The sandy soil is placed in the container using the raining technique (note that the relative density of the soil is 50%), which is considered medium density. The vertical distance for each layer is calculated, which is (65cm), and according to the shape of each layer, the reinforcement material is then applied at depths (0.5B, B,2B,3B).
3. Amachine foundation is placed on the surface of the soil in the middle of the container. After that, the dead loads are placed on the machine foundation using a base fixed in the middle of the weight holder. The weight of the dead loads is(5kg), while the weight of the motor is (5kg).
4. An electronic dial cage is installed, which reads the settlement of the foundation as shown in Fig. 8, and the displacement, speed, and acceleration are calculated using a vibration meter, as well as a digital tachometer to measure frequency.
5. The required time is 30, and the machine foundation is set to rotate in the middle downwards, then the test begins. The displacement, speed, and acceleration are recorded, and readings are taken every (2) minutes for (30) minutes.
6. 6-Two frequencies are used in the test namely 10,15 Hz. Also, its mansion 4 layers of reinforcement are used under the footing.

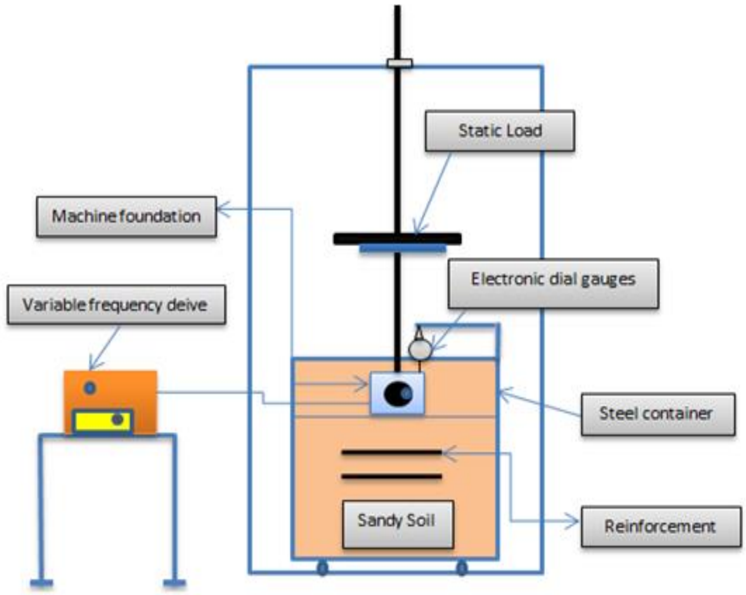

Fig. 7: Schematic of Testing Procedure for Model

3. Results and Discussion.

To understand the effect of the number of layers on the behavior of a shallow foundation exposed to the machine foundation, two frequencies are used, 10 and 15. Using Fine Wire Mesh, the results showed the following:

Fig. 8 shows the relation between displacement and time with and without reinforcement. The value of displacement amplitude with and without reinforcement is not severe based on the Richart chart because the frequency of 10 Hz is not severe. The using of reinforcement in soil reduced displacement by about 6%. In general, the displacement oscillates during the period of the test.

Fig. 9 shows the variation of velocity values with and without reinforcement. The maximum velocity occurred in the case of without using reinforcement. When using reinforcement reduce the velocity value by about 39%. The values of velocity with and without reinforcement are small and should not exceed the limits of (8mm/s) for buildings that are considered sensitive to vibration, or for residential buildings of (15mm/s) and for industrial buildings of (50mm/s) according to (DIN 4150-3).

Fig. 10 shows the relation between acceleration and time with and without reinforcement. The value of acceleration without and with reinforcement is highly fluctuating but, the acceleration value without reinforcement did exceed the limit (0.07m/s²) according to FTA. It is argued that the acceleration value for one layer and during the time (2-20) min will exceed the limits (0.07m/s²) but, during the time (22-30) min the value of one layer is close to without reinforcement.

Fig. 11 shows the variations of settlement values with time of test with and without using reinforcement in soil. The case of not using reinforcement gives the maximum settlement reached 3.5mm at the end of the test. The use of reinforcement in the soil below the machine foundation reduced the settlement to 75%. The use of reinforcement in soil to decrease settlement and increase bearing capacity. This is due to an increase in interlocking between mesh and soil.

Fig. 12 shows the variations of displacement amplitude values with a time of test for with and without reinforcement in soil as1, 2, 3, and 4 layers. It was shown from such figure that the value of displacement amplitude of the machine foundation without reinforced soil is severe according to an extremely fluctuating [17]. It can be seen there is too much fluctuation for all the cases and they are lubing each other. The maximum displacement happened in case of not using reinforcement especially in time 22 min reduced 0.17mm. The use of reinforcement as a layer in soil reduced displacement by about

47%,25%,21%, and 36% for 1, 2, 3, and 4 layers respectively. It is noticed from this figure that it is possible to use one layer of reinforcement because it gives the highest percentage of improvement 47% compared with other layers. In general, the displacement oscillates during the period of the test.

Fig. 13 shows the variations of velocity values with a time of test for with and without reinforcement in soil as 1, 2, 3 and 4 layers. It can be seen there is too much fluctuation for all the cases and they are lubing each other. So, there is no advantage to using one layer and multi-buy layers to improve the velocity value. It can be seen that this type of reinforcement has worsened the case. It is not recommended by the other to use any such type of reinforcement of this type and this situation. Refer to Figure 12 Even if a full scale of reinforcement is used it is useless. The velocity value will not beyond is the limits (8mm/s) for buildings sensitive to vibration, (15mm/s) for residential buildings, and (50mm/s) for industrial buildings according to DIN 4150-3.

Fig. 14 shows the variations of acceleration values with a time of test for with and without using reinforcement in the soil as 1, 2, 3 and 4 layers. The change in acceleration of the machine foundation with time and no steady state was reached since the time of the test is limited nonetheless. It can be seen from this figure that the general trend of behavior of 3 layers of reinforcement and unreinforced are similar and close to each other, like the other layers of reinforcement which give negative results otherwise it can consider layers 1, 2 and 4 are ineffective in reducing the acceleration. No improvement potent even 3layers due to economy others do not recommend using reinforcement in for this layer of reinforcement and 15 Hz. It is well known that the resonance of sand is nearly 17-19 Hz, so it may be close to the resonance state. It may be that no improvement was portending terms of acceleration no improvement can be opted for except for 3 layers. It can be seen as close to reinforcement with negligible improvement. These values exceed the acceptable values (0.07m/s²) stated by FTA.

Fig. 15 shows the variations of settlement values with a time of test for with and without using reinforcement in the soil as 1, 2, 3 and 4 layers. The case of not using reinforcement gives the maximum settlement reached 9mm at the end of the test. The using of reinforcement in the soil below the machine foundation as a layer reduced the settlement to 37%, 40%, 55%, and 60% for the 1st, 2nd, 3rd, and 4th layers respectively. Therefore: the using of reinforcement in the soil leads to decreased settlement and this reduction in settlement increases with an increased number of reinforcement layers. This is due to an increase in interlocking between reinforcement and soil and this increases the anchorage resistance of soil to the vibration load of the machine. economically not necessary to use 4 layers because they cover with 3 layers and not necessary to use 2 layers because they converge with 1 layer. If we want to go down, just using 1-layer gives an improvement of about 40%.

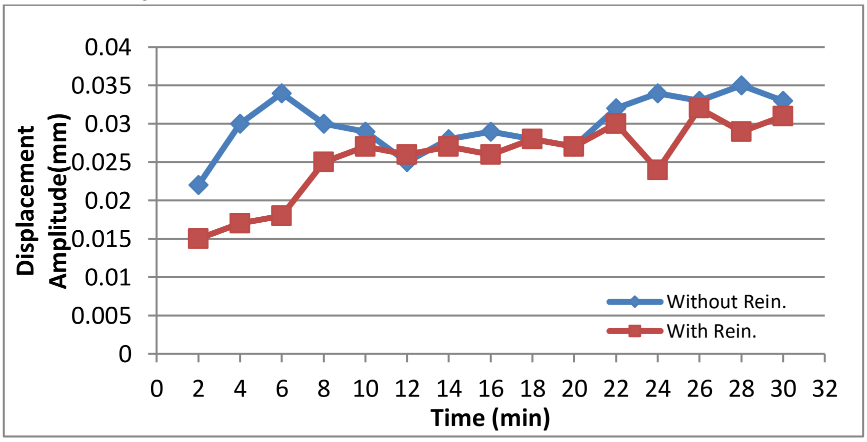

Fig. 8 Relation between displacement and time for with and without reinforcement (Freq =10 Hz, B=10cm, and L=3B) with fine wire mesh.

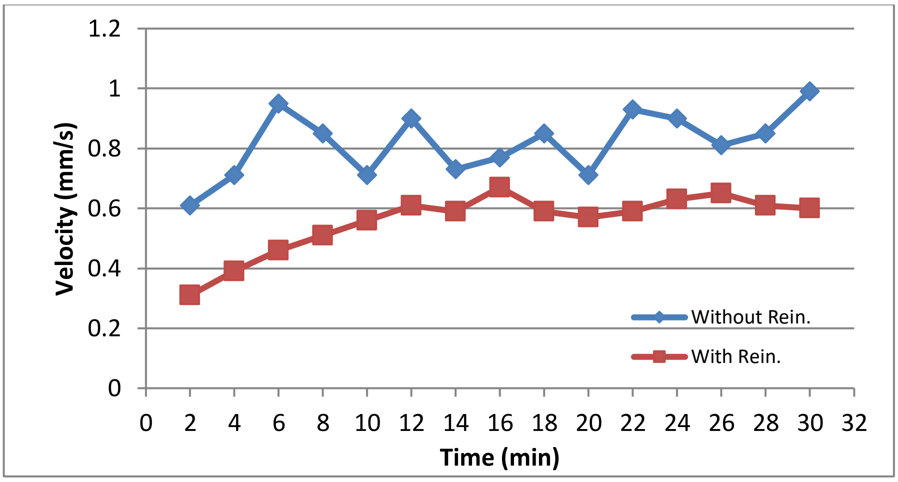

Fig. 9 Relation between velocity and time for with and without reinforcement layers (Freq =10 Hz, B=10cm, and L=3B) with fine wire mesh.

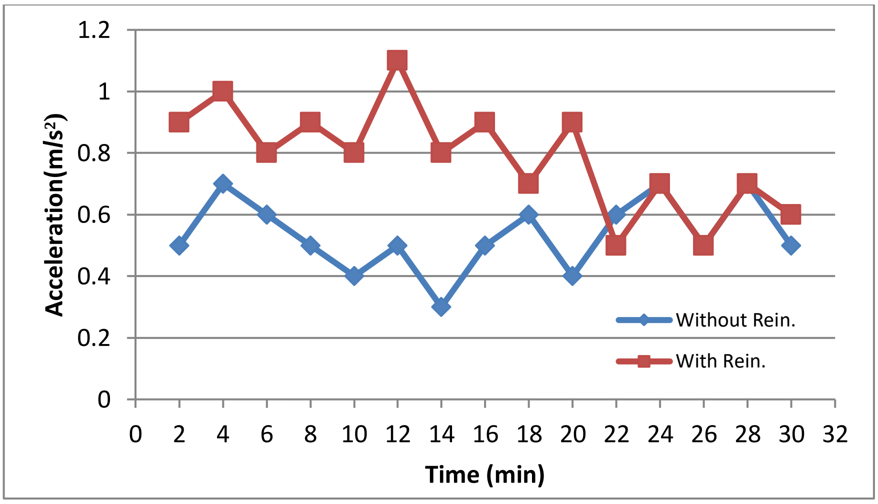

Fig. 10: Relation between acceleration and time for with and without reinforcement layers (Freq =10 Hz, B=10cm, and L=3B) with fine wire mesh.

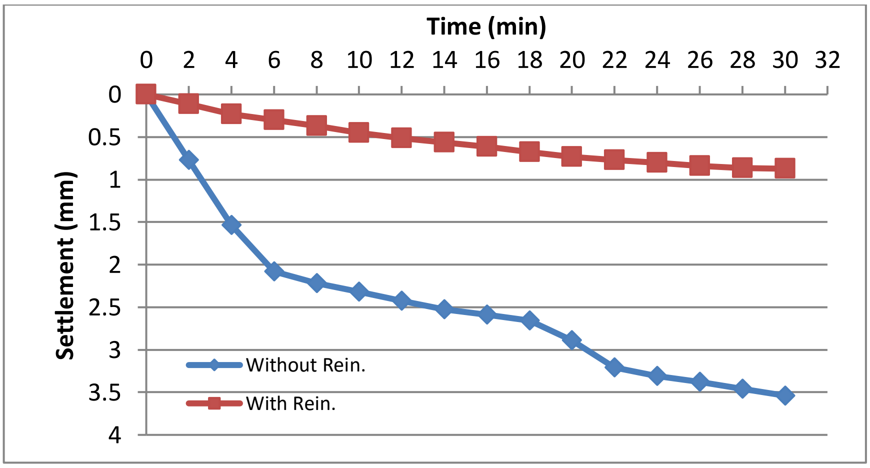

Fig. 11 Relation between settlement and time for with and without reinforcement layers (Freq =10 Hz, B=10cm, and L=3B) with fine wire mesh.

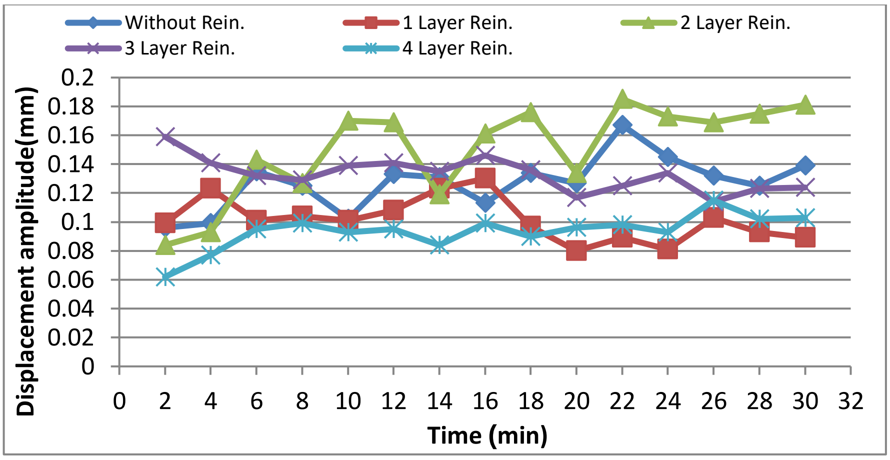

Fig. 12 Relation between displacement and time for various numbers of reinforcement layers (Freq =15 Hz, B=10cm, and L=3B) with fine wire mesh.

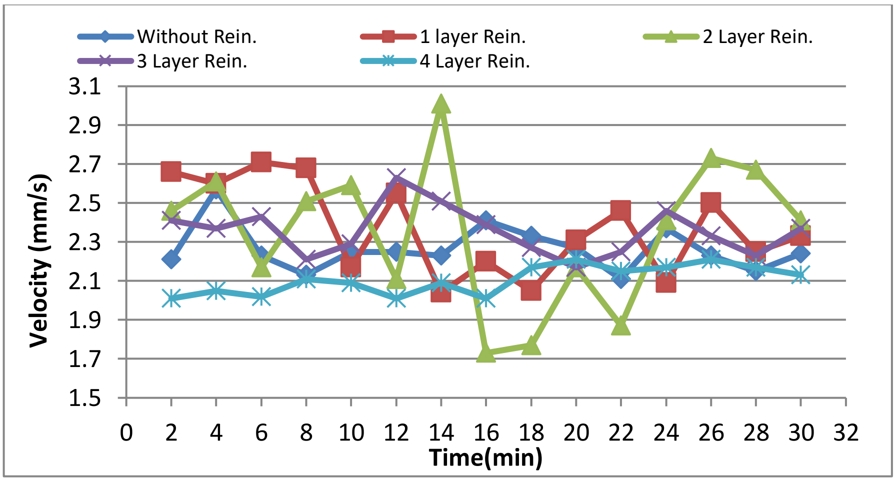

Fig.13 Relation between velocity and time for various numbers of reinforcement layers (Freq =15 Hz, B=10cm, and L=3B) with fine wire mesh.

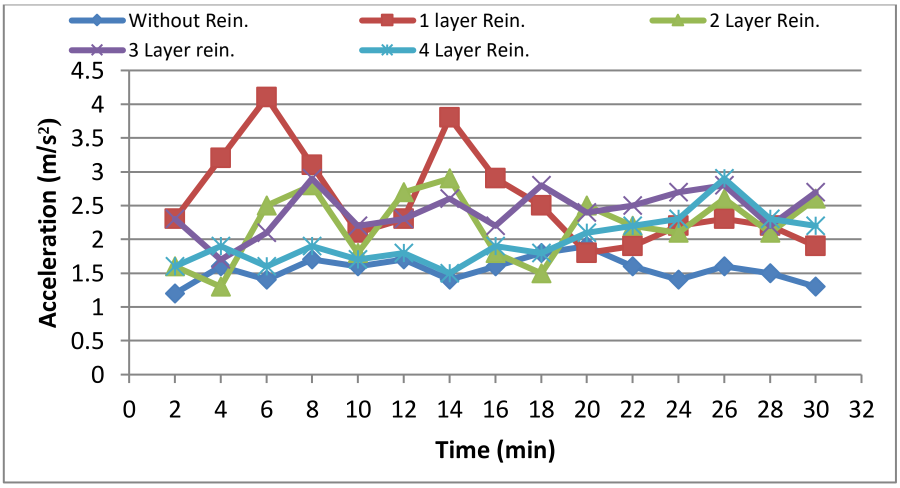

Fig. 14 Relation between acceleration and time for various numbers of reinforcement layers (Freq =15 Hz, B=10cm, and L=3B) with fine wire mesh.

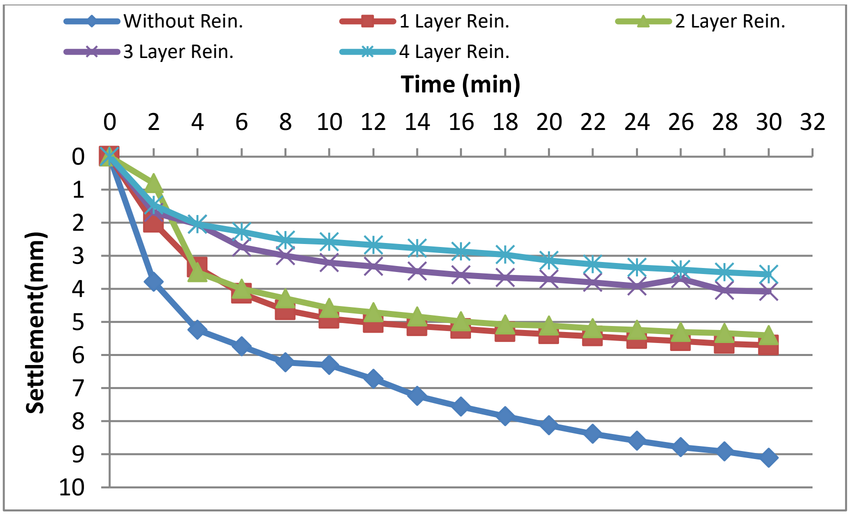

Fig. 15 Relation between settlement and time for various numbers of reinforcement layers (Freq =15 Hz, B=10cm, and L=3B) with fine wire mesh.

Conclusion

1. The effect of a frequency of 10 Hz is small. When using fine wire mesh the improvement in displacement amplitude was 6%, velocity was 39%, settlement was 75% and acceleration there is no improvement.
2. The improvement ratio in displacement at a frequency of 15 Hz was 47% for one layer. The other layers are useless.
3. There is no advantage to using one layer and multi-buy layers in improving the velocity value at a frequency of 15 Hz.
4. In terms of acceleration no improvement when using fine wire at a frequency 15 Hz.
5. The percentage of settlement decreases with an increase in the number of layers.

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