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EFFECT OF BOUNDARIES ISOLATION ON DYNAMIC RESPONSE OF PILE GROUPS

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ABSTRACT

It is well known that the dynamic response of a pile group is strongly affected by the applied frequencies. The aim of this paper is to investigate the effect of boundaries isolation on the behavior of the soil-pile system. The dynamic behavior of three circular piles grouped with a rigid pile cap is analyzed under vertical harmonic steady load. The proposed model for the soil-pile-cap system consists of reinforced concrete elements to simulate piles and concrete cap, uniform dry sand to represent the ground medium and the polystyrene as isolation or absorbing boundary conditions. A physical model container made of steel plates of square shape in plan of dimensions 700 × 700 mm and 800 mm in height is used to accommodate the soil-foundation model. A gap is presently left between the cap and sand surface in order to idealize the response of piles alone. The pile group was excited using an oscillator which applies a series of different frequencies. Dynamic response of the experimental system is measured using vibration meter and accelometer fixed on the surface of pile cap. Two groups of measurements have been carried out; the first model was performed using unisolated boundaries, while the second was conducted on the system with isolated boundaries. The results indicated the occurrence of generally two peaks, minor and major in the displacement-frequency relation. The maximum displacements in the isolated case are markedly reduced in comparison with the unisolated case.

KEYWORDS: Dynamic Behavior, Isolation, Pile Group, Resonant Frequency.

INTRODUCTION

The damage to structures caused by dynamic action, such as earthquake, wind and ocean waves, is primarily dependent on the intensity of dynamic or inertial forces. The dynamic response of a structure is dependent also on the structural stiffness, and is influenced by the interaction between structure and soil. The resonant behavior of the structure is a typical factor for the damage, and may result in destructive damage (Kim et al, 2001).

Dynamic behavior of soil-pile group systems in dynamic loading processes is highly affected by nonlinear behavior of soil, soil plasticity and also gapping and sliding during extreme excitations. Several analytical and numerical studies as well as a few experimental studies investigated the vibration isolation using wave barriers (also known as vibration screening). These are in order to improve the understanding of vibration scattering phenomenon. Woods (1968) performed a series of

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scaled field experiments on vibration isolation by installing open trenches very close to the wave source (known as active isolation) as well as near the machine or structure to be protected.

Haupt (1981) carried out a series of scaled-model tests on the vibration isolation of various types of barriers in a laboratory setup. The investigated barriers include solid barriers (concrete walls) and lightweight barriers such as rows of bore holes and open trenches and the results were presented as a function of characteristic parameters in terms of wavelength-normalized dimensions

Puri (1988) concluded that the computed natural frequencies of vertical vibrations of the pile for the homogeneous and parabolic soil profiles are 46.0 and 38.8 Hz respectively and the observed natural frequency of vertical vibrations is 32.2 Hz.

Halabianl and Maleki (2008) presented a study of dynamic behavior of pile group using proper absorbing boundary conditions and simulating radiation effects.

The present research aimed at studying the effect of absorbing boundaries on the dynamic response of grouped piles under different dynamic frequencies as well as the effect of absorbing boundaries on the resonant frequencies which are not covered yet.

PHYSICAL MODEL

In the present study a physical model was represented by an open box made from steel plates with square dimension in plan (700 × 700 mm) and of height 800 mm. The first condition is unisolated case i.e., all walls were left without being covered by polystyrene as shown in Figure 1-a, while in the second case all walls were covered by polystyrene as an isolation mean, Figure 1-b. The box is used to study the effect of boundary conditions on the resonance frequencies in both conditions.

(a) (b)

Figure (1) Model Box (a) Unisolated Boundaries (b) Isolated Boundaries.

GROUP PILES MODEL

In reference to the piles group, the model of deep foundations with pile cap dimension of 250 x 250 x 30 mm is shown in Figure 2 along with 3 piles. The piles diameter and length are 30 mm and 400 mm, respectively.Two soil-pile systems were tested. The first system involves a group using isolation covering the boundaries of container walls as shown in Figure 3a. The pile cap was lifted about 50 mm from ground level. The second system employs the same configuration and geometry of piles without isolated boundaries; it is referred to as the reference model, Figure 3b.

The three piles and cap are of reinforced concrete material. The reinforcements for the piles and cap are of 3 mm bar. Gravel passing from sieve no. 4 was used in the mixture of concrete; w/c ratio is 0.45. The diameter of piles was 30 mm. The pile and cap were casted integrally as shown in Figure 4. All properties of concrete were specified according to (ACI-Code., 2008).

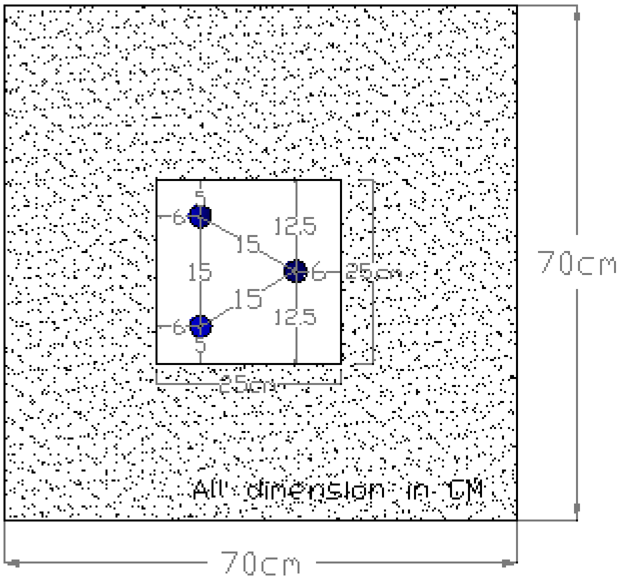
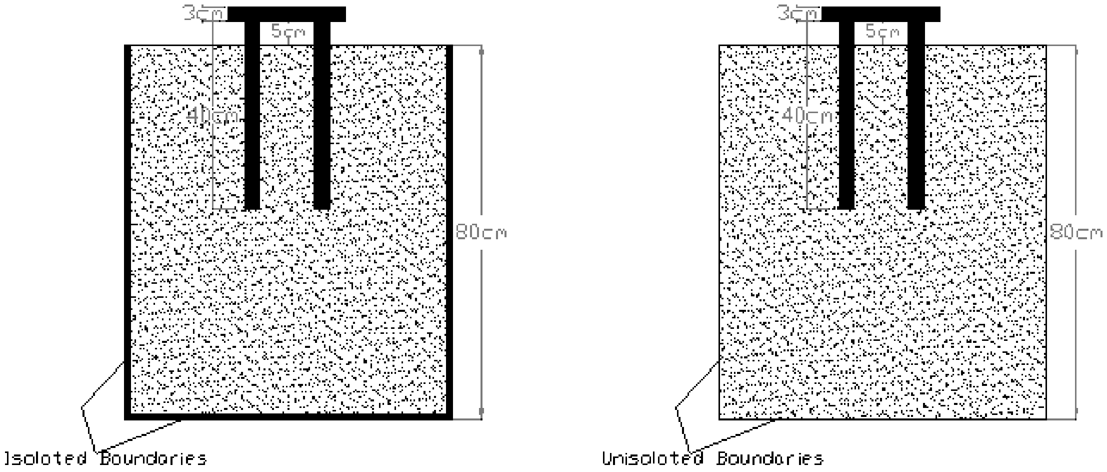


Figure (2) Plan of the Reference 3 Piles Group



(a) (b)

Figure (3) Section in Two Pile-Soil-Cap Systems (a) Isolated Boundaries (b) Unisolated Boundaries.

THE USED SOIL

The soil used in this study is dry clean sand with particle size between 1.0 mm and 0.15 mm. The standard tests are performed to determine the physical properties of the soil as given in table 1. The dry density of the sand in the model was obtained using sand raining method. Sand was rained through a mesh 4 x 4 mm opening using different heights of drop, which gave different values of density. A relative density of 51% was used to fill the steel container as shown in Fig 5. This relative density corresponds to a dry density of 15.8 kN/m^3 and void ratio of 0.76.

Figure (4) Deep Foundation Model

Figure (5) Raining Method to Control the Dry Density of Sand

Table (1): Physical properties of the dry sand

Parameters	Value	Units
Max. Dry Unit Weight, from Procter test ($\gamma_{dry\ max}$)	19.4	kN/m^3
Max. Dry Unit Weight, from Raining Method ($\gamma_{dry\ max}$)	17.64	kN/m^3
Min. Dry Unit Weight. ($\gamma_{dry\ min}$.)	14.23	kN/m^3
Optimum moisture content	8.5	(%)
Relative density used (%)	51	(%)
Specific gravity, Gs	2.78	-

EQUIPMENTS FOR THE APPLIED LOAD AND MEASUREMENTS.

The vibration load has been applied using a mechanical oscillator consists of an electrical motor having a maximum rated speed of 9500 rpm through a shaft. A rotating disc is connected to the rotating shaft; it is manufactured from steel of diameter 80.0 mm and thickness 5.0 mm. A single mass m_e is placed on the rotating disc at an eccentricity e_o of 30 mm from the axis of rotation. Depending on the orientation of the counter-rotating shaft, a centrifugal dynamic force can be applied. The maximum vertical force F_o produced as presented by Srinavaslu and Vaidyanathan (1990) is:

$$F_o = m_e e_0 \omega^2 \qquad (1)$$

where, ω is the circular frequency of the system. For this type of oscillator, the function of the harmonic vertical mode of vibration is sinusoidal. Therefore, the applied dynamic force at any time (t) is given by:

$$F_{(t)} = F_o \sin \omega t \qquad (2)$$

The required associated equipment for inducing vibration is an electrical motor and speed control unit. By varying the voltage supplied to the motor with the help of the speed control unit, the speed of the motor and hence the oscillator can be varied which, in turn, causes a change in frequency of vibration induced by the oscillator.

The vibration-displacement amplitudes are most often measured in foundations ranging from millionths to thousandths of a centimeter and occur at frequencies ranging from less than 10 Hz to more than 100 Hz (Chowdhury and Dasgupta, 2009).

A vibration meter VM-6360 is readily adapted to measure the response of the system by producing an electrical signal that can be observed with an oscilloscope or recorded for subsequent analysis.

EXPERIMENTAL WORK

The soil-pile-cap systems were subjected to the dynamic forces and the response of the pile cap is evaluated. In this study, various frequencies were applied on pile-soil systems. The time-displacement for each frequency which represents the response of the pile group is investigated in detail in a form of series of analyses. In each analysis only the effect of one parameter, insulation, is investigated, while the remaining parameters are kept constant. The cap is assumed to be floating. The overall system of pile-soil, oscillator, vibration meter, tachometer and speed control are shown in Figure 6, the steel angles are removed during the test.

Figure (6) The Overall System

RESULTS

Isolated Boundaries

The main aim of this study is to find out the effect of insulation on the dynamic response of piles group, the accelometer (pick up) was fixed on cap of pile to investigate the displacement response.

The historic time versus displacement was considered for each frequency. Figure 7 shows some of the historic time versus displacement for isolated boundaries, while Figure 8 shows a bar chart of the frequency against maximum displacement for the same boundary conditions. From these two figures, it was found that the resonant frequency is 421.49 rad/sec with maximum displacement of 0.228 mm and the frequency which causes the oscillation of system to vanish is 152.19 rad/sec.

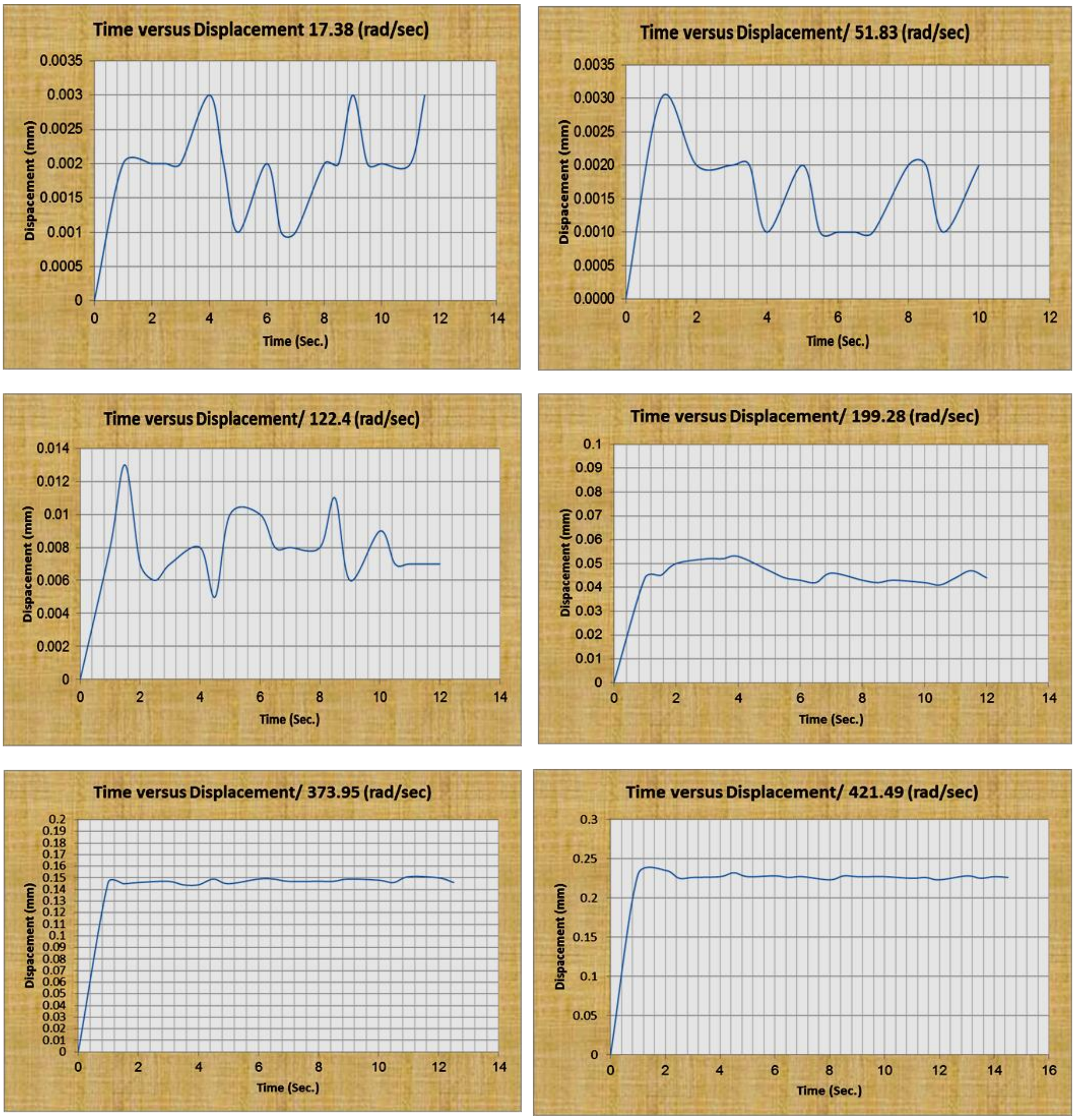


Figure 7: Time Histories of Piles Head Displacement of Isolated Boundaries.

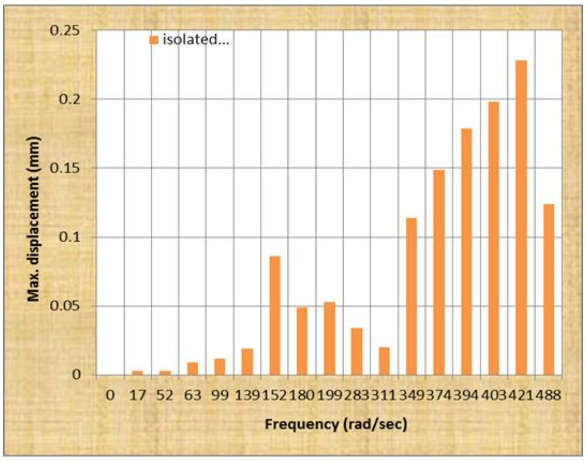
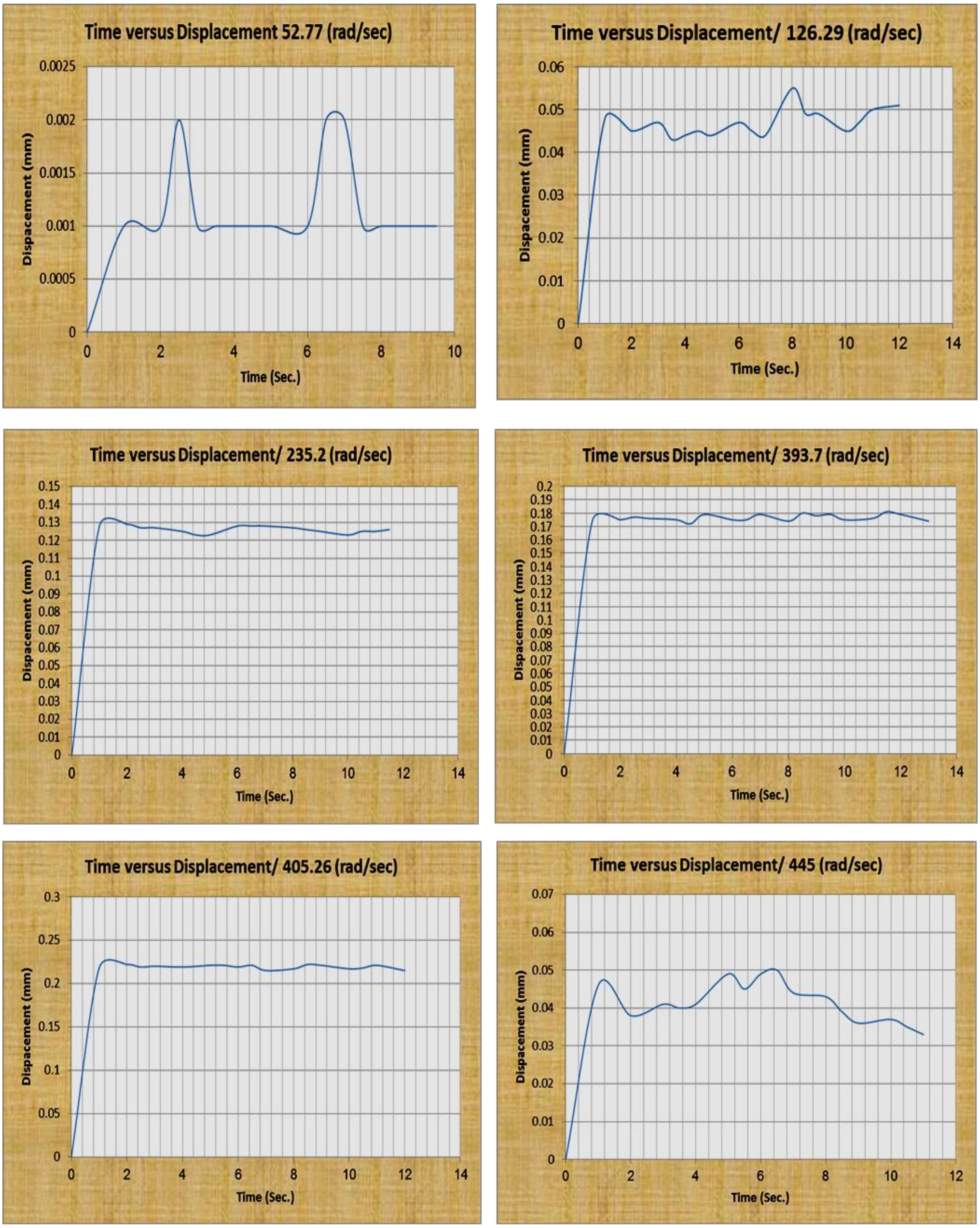


Figure 8: Frequency versus Maximum Displacement bar Chart for Isolated Boundaries

Unisolated Boundaries

Figure 9 shows some of the historic time versus displacement for the unisolated boundaries and Figure 10 shows a bar chart of frequency against maximum displacements. From these two figures, the resonant frequency is 405.26 - 421.49 rad/sec with a maximum displacement of 0.222 mm and the frequency at which oscillation of system vanishes is 150 rad/sec.



Time versus Displacement 52.77 (rad/sec)

Time versus Displacement/ 126.29 (rad/sec)

Time versus Displacement/ 235.2 (rad/sec)

Time versus Displacement/ 393.7 (rad/sec)

Time versus Displacement/ 405.26 (rad/sec)

Time versus Displacement/ 445 (rad/sec)

Figure 9: Time Histories of Piles Head Displacement of Unisolated Boundaries.

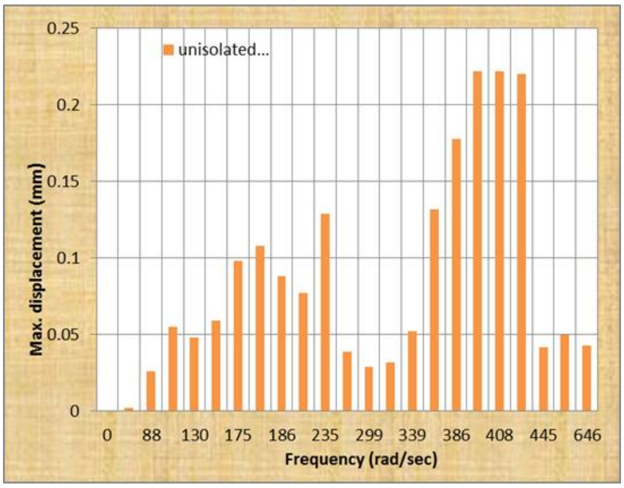


Figure 10: Frequency versus Maximum Displacement Bar Chart for Unisolated Boundaries

DISCUSSIONS AND CONCLUSIONS

A small scale experimental test program was carried out to investigate the effect of insulation of boundaries on the response of pile group embedded in dry sand. Figure 10 shows the maximum displacement-frequency curves for the two cases, from this figure and the aforementioned results, the following points may be concluded:

The experimental work yielded generally two peaks of resonance amplitude, the first peak occurs in the domain of low inducing frequencies and the second peak occurs in the domain of high inducing frequencies. This result agrees with that found by Gazetas (1983) and Prells and Less (2000).

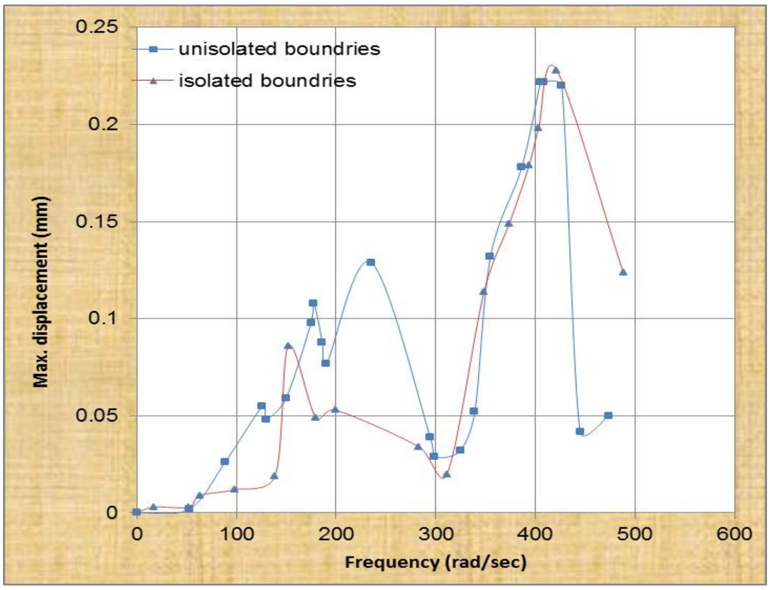


Figure 10: Frequency versus Maximum Displacement Curves of the Two Boundaries

At low frequencies, the response of deep foundations in the unisolated boundaries case is not as consistent as in the isolated case. The maximum displacement amplitude was 0.129 mm at a frequency of 235.2 rad/sec. while for isolated boundaries; the maximum displacement was 0.086 mm at a frequency of 152.15 rad/sec. Thus, there was an increase in displacement and frequency in the unisolated case, which may be ascribed to the reflection of the induced waves on unisolated steel boundaries and there was no absorption for the propagated dynamic waves. Gazetas (1983) stated that the response of foundation under a rotating-mass-type excitation differs from case to case in the maximum displacement amplitude, which is apparently controlled by the inertia characteristics and the radiation damping of each system.

Therefore, to minimize the reflected waves form boundaries and increase the radiation damping of soil, the boundaries should be surrounded by absorbing materials. Wang et al (2008) emphasized on the importance of the isolated boundaries at discretized region to minimize the dissipation effect of infinity, ideally absorbing all energy propagating outwards and allowing no energy back into the examined system, these boundary conditions are known as transmitting boundaries.

In the high frequency zone, the response of the deep foundations for isolated and unisolated boundaries was consistent and apparently similar in maximum amplitude. The resonant peak of displacement was 0.22 mm for both cases of boundaries, but for unisolated boundaries there was a continuation in resonance case which started at a frequency of 405.26 rad/sec and went on to 426.41 rad/sec keeping constant displacement, so the point of maximum displacement takes a flat shape. Gazetas (1983) ascribed this phenomenon to standing waves in the soil stratum and hence, they are very little influenced by the foundation inertia.

It may be noted that the response of pile-soil system for insulated boundaries is relatively progressive because the insulation reduces the standing waves and absorbs induced energy. The outgoing waves in such a system will be damped and non-reflected back towards the bounded domain (Al Wakel, 2010).

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