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Dynamic response characteristics of pile group under axial harmonic loading

Furqan Arshad[1], Mohammad Habib Abdallah Al Rawashdeh[2]*

[1] Lahore University of Management Sciences, Pakistan
[2] China University of Geosciences

*Corresponding author E.mail: mohammadrawashdeh993@gmail.com

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Abstract

Pile-supported machine foundations are examined in this work to identify the dynamic features of linear and nonlinear theories. A three-pile group with a 3 m pile length and an outer diameter of 0.114 m is given axial harmonic loading before field-based forcing vibration testing. For four distinct eccentric moments, tests are carried out at a static load of 12 kN. Each eccentric instant's reaction in terms of frequency and amplitude is examined. The continuum approach technique is also used for theoretical analysis, which employs both linear and nonlinear solutions. All of the eccentric moments' dynamic field test findings are compared to theoretically expected frequency-amplitude responses. In comparison to the actual test findings, the linear solution's anticipated responses show lower resonant amplitudes and substantially higher resonant frequencies. The dynamic response curves predicted by the nonlinear solution fit the test findings rather well in this situation. To achieve this degree of agreement with nonlinear analysis results, precision in border zone parameters and soil-pile separation lengths was necessary

Keywords
Pile group, dynamic field test, axial harmonic group, dynamic response

Introduction

To withstand uncontrollable pressures such as earthquakes, ocean waves, and wind, piles are often utilized as foundations to support heavy machinery and other vibrating equipment. Because of the complicated interaction between piles, soil, and piles, geotechnical engineers often have difficulty designing pile foundations that can withstand dynamic stresses. Due to soil nonlinearity, soil-pile separation, and slippage between the pile and soil, machine foundations supported by piles respond nonlinearly and with large displacements.

When doing pile foundation analysis and design, it is important to incorporate machine-induced harmonic loading. Several scientists tested soil piles in the field while researching the dynamic and theoretical responses of soil piles to machine-induced harmonic stresses. The soil-pile system's stiffness and damping (also known as its impedance characteristics) have been well investigated in theory. Pile tests have been carried out by Elkasabgy, Naggar, Biswas, and Manna in the field (Biswas & Manna, 2018; Elkasabgy & El Naggar, 2013). According to continuum-based analysis, results were compared with theoretical curves.

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Assuming that the aftereffects of field testing under powerful stacking are to be accepted, the hypothetical examination gave an OK forecast of the recurrence plentifulness reaction bends. Utilizing Novak's strategy and the limited component model under hub symphonious pressure share a great deal practically speaking, say Khalil and partners (Khalil et al., 2020). Stacking recurrence extensively affects the actuated amplitudes, as indicated by the aftereffects of this review. Predicting border zone characteristics and separation length between the soil and the pile when subjected to harmonic loading is essential to effectively forecast nonlinear responses to these loads. The experimental confirmation of many theories was also neglected. Linear and nonlinear continuum techniques under machine-induced axial harmonic pressure are compared in this work using a three-pile grouping.

Site characterization and location

The Indian Institute of Technology Delhi in New Delhi, India, conducts dynamic field testing between blocks II and III during this research project. Several in-situ and laboratory approaches are used to investigate the subsurface soil conditions (Singh et al., 2019). During an SPT, soil samples from the borehole are collected from both disturbed and undisturbed areas. The soil's characteristics are analyzed using a variety of laboratory procedures. Clayey silt is identified in the soil layers by in-situ and laboratory testing. As can be seen in Table 1, the measured soil parameters of the various levels were compiled.

Soil property	Layer 1 (0.0-2.5 m)	Layer 2 (2.5-3.5 m)
Moisture content (%)	9.20	7.52
Bulk density (kN/m^3)	16.74	15.88
LL (%)	33.59	38.30
PL (%)	20.14	23.23
Particle size distribution	Sand 39%, Silt 43% Caly 18%	Gravel 3% Sand 36% Silt 42% Clay 19%
Shear modulus (KN/m^2)	1.3x10^4	2.3x10^4

Table 1 *Soil properties at test site*

Axial harmonic loading test

There are hollow steel pipes that measure 3.0 meters in length (l), 0.114 meters in outer diameter (d), and 0.003 meters thick (t). Plies with a standard slenderness ratio (l/d = 26) were selected for testing since they were used in the research. Using a tripod and an SPT hammer, piles are inserted into boreholes with an augur diameter of 0.1 m to guarantee that the earth and the piles are in perfect contact. To secure the pile's end bearing, a steel plate is used to seal the pile's bottom end. Driven piles are kept at a distance of three feet apart,

A mechanical oscillator generates the harmonic force on pile foundations. Force may be regulated by changing the rotational eccentricity () of the spinning masses. As an example, we may write the value of the produced eccentric moment as:

$$m.e = (W/g).e=[0.9\sin(\theta/2)]/gNsec^2 \qquad [1]$$

W represents weight and m represent the mass of eccentric rotating parts and e represents the eccentric distance of rotating mass, and g represents the acceleration due to gravity.

Along with the oscillating mechanism and steel plates, it's put on top of the pile. Testing for axial harmonic loading in the field using a three-pile group configuration under a static load of 12 kN each yielded four distinct eccentric moment values (W.e = 0.868, 1.270, 1.631, and 1.944 Nm). At different frequencies (0–50 Hz), the system's frequency-amplitude responses are measured. Acceleration may be monitored via a vertical accelerometer attached to a central plate of dirt pile loading. The DC motor is fitted with a frequency measuring sensor before the dynamic testing begins. Using these curves, frequency-amplitude curves may be created. Measurement of temporal acceleration and frequency response is done using an axial harmonic test Experiment setup is shown in Figure 1.

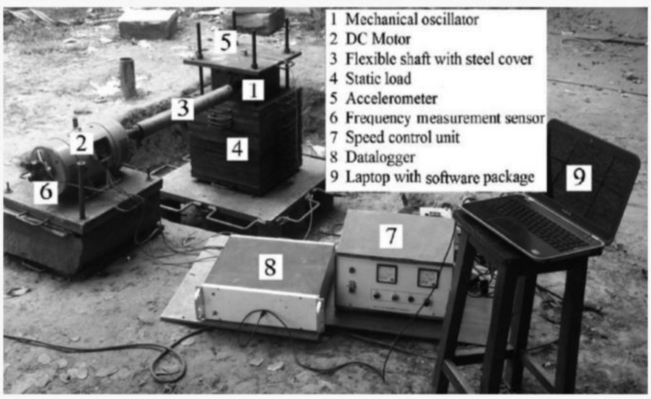

Figure 1 *Axial harmonic loading Test*

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Theoretical analysis

Using the continuum method (Novak and Aboul-Ella, 1978), the linear and nonlinear dynamic responses of a three-pile group are determined. Both a linear and a nonlinear soil model are being examined in the present study (with boundary zone parameters). Forcing a boundary zone that is less elastic and more damping than the surrounding free field, the boundary zone helps to avoid the reflection of waves from the cylinder zone's artificial contact with its surroundings. Slope, soil-pile separation, and slippage may all be found in this border area. Uses DYNA 5, a software suite that incorporates this theoretical technique.

Boundary zone parameter

Here, we investigate a 3-pile group's linear and nonlinear dynamics using the continuum approach. Soil models are being examined in this study, one linear (without border zone parameters) and the other nonlinear (with boundary zone parameters) (Sonkar et al., 2022). Wave reflections are prevented by creating lower shear modulus and increased damping surrounding the cylinder to avoid the formation of an artificial contact with the outside world. Slippage, soil-pile separation, and nonlinearity are all possible at the border zone. Uses DYNA 5, a software suite that incorporates this theoretical technique.

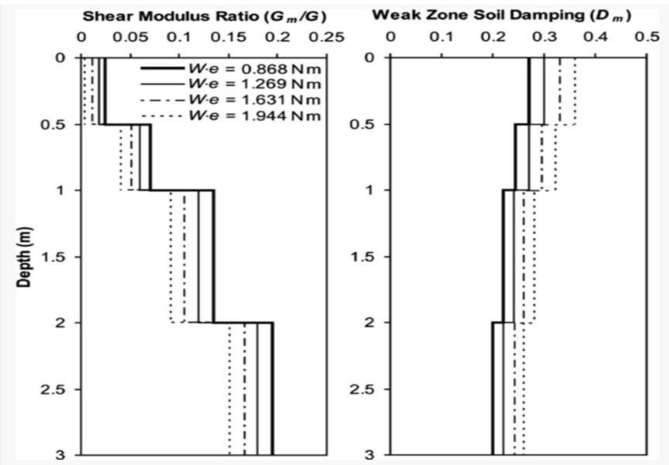

Figure 2. *Variations of boundary zone parameters with depth under axial loading condition*

Theory Versus Experiment

Linear Analysis. According to theoretical linear response curves for different eccentricities, the results of the field test are shown in Figure 3.

The projected linear response reveals lower axial amplitudes and substantially higher resonant frequencies compared to the field test findings. The theoretically expected resonance frequency is 25 percent higher and the resonant amplitude is 19 percent lower than the findings of the field test (Jiao, 2020). The discrepancies in pile reactions may be caused by a misunderstanding of soil nonlinearity and the assumption of flawless pile-soil connection. A soil-pile separation may occur in the field owing to nonlinearity and slippage that results in a change in the stiffness of the soil-pile system as a result of increased dynamic loads.

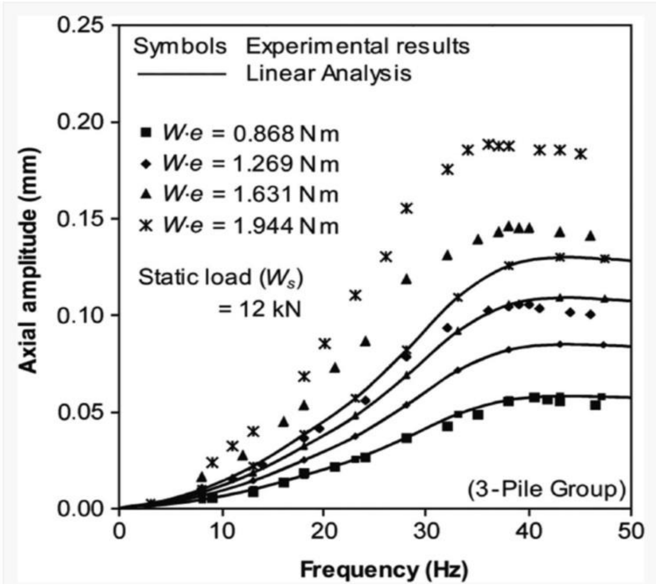

Figure 3. *Comparison of response curves of 3-pile group under axial loading obtained from experiments and linea*

Non-linear analysis. The dynamic reaction of the pile foundation cannot be accurately predicted using a linear approach. As a result, the pile foundation's frequency-amplitude response is determined using DYNA 5 software, which performs a nonlinear dynamic analysis (Prendergast et al., 2013). Nonlinear solutions for dynamic response testing and dynamic response testing are shown in Figure 4. Analytical findings are more consistent with resonant frequency and amplitude test results than with linear analysis. The correlation diagrams show that when the excitation powers rise, the resounding frequencies and amplitudes diminish and increment disproportionally. This example of reaction bends shows nonlinearity in both the exploratory and hypothetical ways to deal with the issue.

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Axial stress tests and theory demonstrate that the pile foundation moves mostly in one direction in that frequency range, which is in agreement with experimental findings and theory.

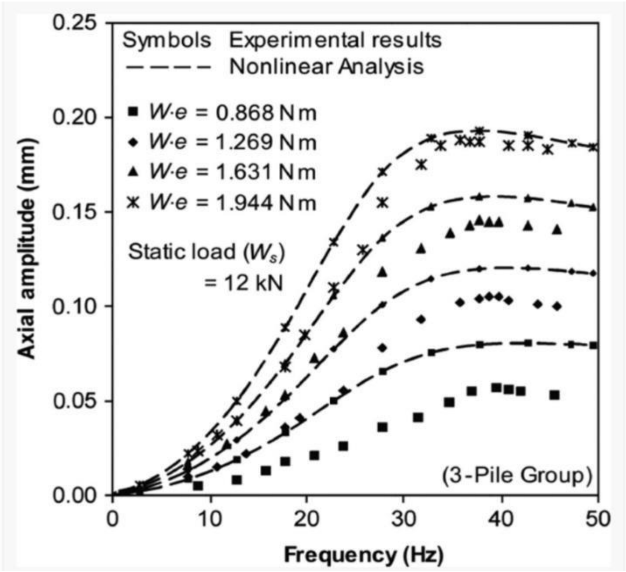

Figure 4. *Comparison of response curves of 3-pile group under axial loading obtained from experiments and nonlinear analysis*

Conclusions

Under axial harmonic stress, the 3-pile group's frequency-amplitude response was examined for various eccentric moments. Testing shows that pile field response curves exhibit nonlinear behavior with decreasing resonant frequencies and increasing disproportionally with variations in eccentric moments of the resonant amplitudes theoretically, it can be shown that the linear technique undervalued and exaggerated the resonance amplitudes and frequencies of piles when subjected to axial stress. It is possible to utilize a nonlinear analysis to reduce the discrepancy between anticipated and actual values of resonant frequency and amplitude. The selection of boundary-zone parameters seems to be important for nonlinear response forecasting. Direct examination is less precise than nonlinear investigation with a limit zone and soil-heap division for every single flighty second. Heap elements might be demonstrated utilizing nonlinear soil models.

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