

OBSERVED AND COMPUTED RESPONSE OF PILES UNDER DYNAMIC LOADS

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ABSTRACT: This paper presents a comparison of observed computed response of a single pile. Full scale dynamic pile load tests were conducted on a 450 mm diameter reinforced concrete pile driven 17m in a soil profile of uniform silty sand. Horizontal deflection of the pile at the mud line was measured by applying predetermined horizontal load increments during the static test. The dynamic load tests were conducted to determine the amplitude frequency response of the pile subjected to vertical and horizontal vibrations. The natural frequency of free vibrations in the horizontal direction was also measured. The soil properties were determined by conducting in-situ and laboratory tests. The response of the single piles was calculated and compared with the observed response.

1. INTRODUCTION

Piles are preferred choice of foundations in seismic areas. The seismic loading induces large displacements/strains in the soil. The shear modulus of the soil degrades and damping (material) increases with increasing strain. The stiffness of piles should be determined for these strain effects. The elastic solutions for determining response of piles subjected to dynamic loads have been presented by several investigators in the past. Procedures have also been developed in recent years to account nonlinear soil behavior. The pile response under dynamic loads can generally be obtained by making simplified spring-mass models. The soil springs are obtained from the shear modulus of the soil or from the modulus of sub-grade reaction. The non-linearity effects can be accounted for by using strain dependent values of shear modulus. Very little information is available on comparison of calculated response with the observed. A comparison of the observed and predicted response of a single pile for dynamic loading conditions based on the tests conducted by the authors is presented in this paper. In addition a comparison of the computed and observed pile response based on the data reported in literature is also presented briefly.

2. FIELD AND LABORATORY TESTS

Forced horizontal and vertical vibration tests were conducted on a 450-mm-diameter pile driven 17 m into the deposit of silty sand. A reinforced concrete cap measuring 1.2m x 1.2m x 0.8m (high) was cast monolithically with the pile head for mounting the vibration-generating equipment. The vibrations were monitored with the help of acceleration transducers mounted on the pile at mud line. The output from the acceleration transducers was amplified using universal amplifiers and recorded on strip chart recorder. A typical amplitude-versus-frequency plot for one of these tests is

shown in Fig. 1. Free horizontal vibration tests were also conducted on this pile by pulling and suddenly releasing it. A typical free vibration record is shown in Fig.2. The values of the observed natural frequencies and amplitudes are given below in 2.1:

2.1 Observed Values

Natural frequency of vertical vibrations $f_{nz}=32.2$ Hz

Natural frequency of free horizontal vibrations = 11.5 Hz

Natural frequency of horizontal vibrations $f_{n1} = 10.3$ Hz

Amplitude of horizontal vibrations at resonance $A_x=0.42$ mm

Soil properties such as modulus of sub-grade reaction and dynamic shear modulus were determined by in-situ and laboratory tests. The soil at the site was generally dense silty sand extending to a depth of about 22.5 m. It was generally non-plastic. The average value of the angle of friction for the soil as determined by conducting a number of tri-axial tests in the laboratory ranged from 36.2-38°. A horizontal plate load test was conducted at this site to determine the value of the constant of modulus of horizontal sub-grade reaction n_h . The values of the dynamic shear modulus at the site were determined by conducting block vibration, wave propagation and standard penetration tests. The data of these tests were interpreted following the approach suggested by Prakash and Puri (1988). The value of low strain shear modulus at the level of the pile tip were determined to be 63.7 MPa. The details of these soil property determination tests are not discussed here.

3. COMPUTATION OF THE PILE RESPONSE

The dynamic response of the pile was calculated for case vertical and horizontal vibrations assuming the case of uniform soil profile and parabolic soil profile. The spring stiffness and damping were determined using Novak and El-Sharnouby (1983). The details of the equations used

for these response calculations can be found in Novak and El-Sharnouby (1983), Prakash and Puri(1988) and Prakash and Sharma (1990). The computed value of natural frequencies and amplitudes are given below in

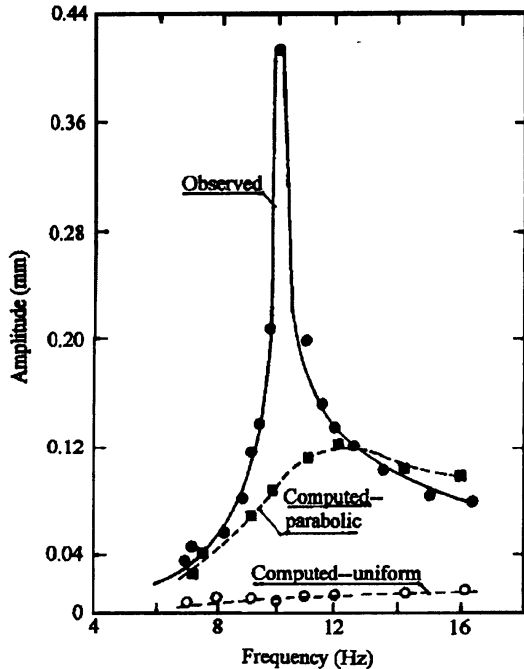


Figure 1. Amplitude of Horizontal Vibration versus Frequency

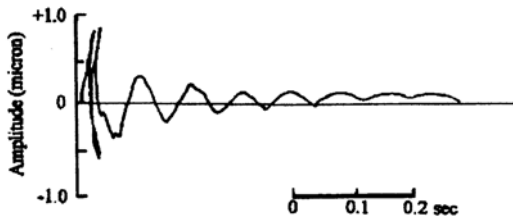


Figure 2. Typical Free Horizontal Vibration Record

3.1 Computed values

Uniform Soil Profile

Natural frequency of vertical vibrations $f_{nz}=46.0$ Hz
 Natural frequency of horizontal vibrations $f_{n1}= 30.9$ Hz
 Natural frequency of horizontal vibrations $f_{n2}= 77.6$ Hz

Amplitude of horizontal vibrations at resonance $A_x=0.0875$ mm

Parabolic Soil Profile

Natural frequency of vertical vibrations $f_{nz}=38.80$ Hz
 Natural frequency of free horizontal vibrations = 12.9 Hz
 Natural frequency of horizontal vibrations $f_{n1}=11.99$ Hz
 Natural frequency of horizontal vibrations $f_{n2}= 45.7$ Hz
 Amplitude of horizontal vibrations at resonance $A_x=0.116$ mm

OBSERVED Vs COMPUTED VALUES

A comparison of observed values in section 2.1 and Fig. 2 and the computed values in 3.1 brings out the following facts:

The computed natural frequencies of vertical vibrations of the pile for the homogenous and parabolic soil profiles are 46.0 and 38.8 Hz respectively. The observed natural frequency of vertical vibrations is 32.2 Hz. The computed values of natural frequency for the homogenous soil profile are 43% higher than of the observed natural frequency in vertical vibrations. For the parabolic soil profile, the calculated natural frequency is about 20.5% larger than the observed natural frequency.

For the case of coupled rocking and sliding, the calculated values of smaller natural frequency f_{n1} are 30.9 and 11.89 Hz for the homogenous and parabolic soil profiles respectively. The observed natural frequency is 10.3 Hz. The calculated natural frequency for the uniform soil profile is substantially higher than the observed natural frequency of horizontal vibrations. For the case of parabolic soil profile, the calculated natural frequency is about 15% higher than the observed natural frequency.

The calculated natural frequency of horizontal free vibrations for the parabolic soil profile is 12.9 Hz and is 12% higher than the observed frequency of free vibrations.

The observed value of the peak horizontal vibration amplitude is 0.42 mm, which is higher than the calculated amplitudes for the homogenous soil profile (0.08745 mm) and the parabolic soil profile (0.116 mm). In the frequency range considered (Fig. 1) the computed amplitudes of horizontal vibrations are generally smaller and near resonance they are substantially smaller than the observed values.

Because of the limited nature of the study, it is not possible to draw any general conclusions, but it seems that in this particular case the assumption of a parabolic soil profile has given reasonable values of natural frequencies both for vertical and horizontal vibrations.

The reasons for the differences between observed computed response of the piles may be partly explained by the assumptions made in modeling the pile behavior. It is generally observed that a softened zone of soil develops surrounding the pile during pile installation which affects the estimated pile stiffness. Also, the damping estimated by Novak and El-Sharnouby's approach may be on the higher side. Several researchers have attempted to make a comparison of the observed

and predicted pile response. Small scale pile tests, centrifuge tests and full pile tests have been conducted for this purpose (Gle,1981; Novak and ElSharnouby,1984; Woods, 1984; and Poulos,2007). Woods (1984) reported results of 55 horizontal vibration tests on 11 end bearing piles 15 - 48 m long. The outer diameter of piles was 35.56 cm and the wall thickness varied from 0.47 cm to 0.94 cm. Woods (1984) also compared the observed and computed response of the piles. The stiffness and damping values were obtained using computer program PILAY which uses continuum model accommodating soil layers and assumes homogeneous soil in the layer with elastic behavior. A typical comparison of the pile response so computed with the observed response is shown in Fig. 3. It may be observed from Fig. 3 that the calculated and computed responses do not match.

El Marasafawi et al (1990) conducted horizontal vibration tests on a 0.32 m diameter, 7.5 long piles and compared with the calculated theoretical response after accounting for the weak zone surrounding the piles. This comparison is shown in Fig. 4. Similar data for a six pile group is shown in Fig. 5. The comparison of the observed and computed response for these particular cases appears reasonable.

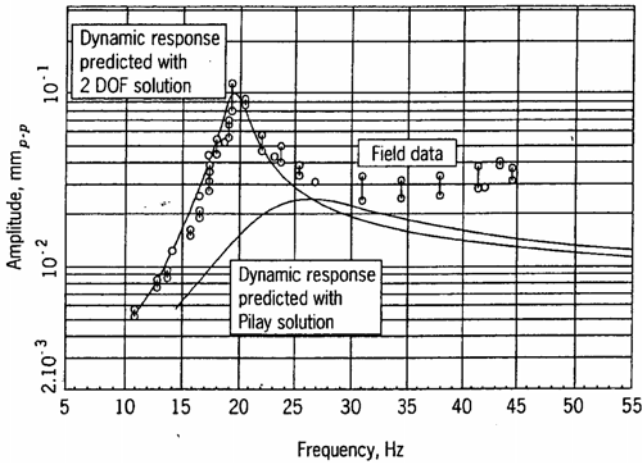


Figure3. Typical response curves predicted by PILAY superimposed on measured pile response (Woods, 1984)

Efforts were made to obtain a match between observed and predicted response by using reduced values of stiffness obtained from PILAY, which did not help much. A better match could, however, be obtained when a considerably softened or weakened zone was assumed surrounding the piles (program PILAY 2) simulating disturbance to soil during pile installation. A loss of contact of the soil with the pile for a short length close to the ground surface also improved the predicted response.

El-Sharnouby and Novak (1984) performed tests on 102 model pile groups using steel pipe piles. It was observed by El-Sharnouby and Novak (1984), Novak (1991) and Prakash and Sharma (1990) that the observed and predicted response for horizontal vibrations shows better agreement when a softened zone surrounding the piles and separation between pile and soil near the ground surface are accounted for in calculations

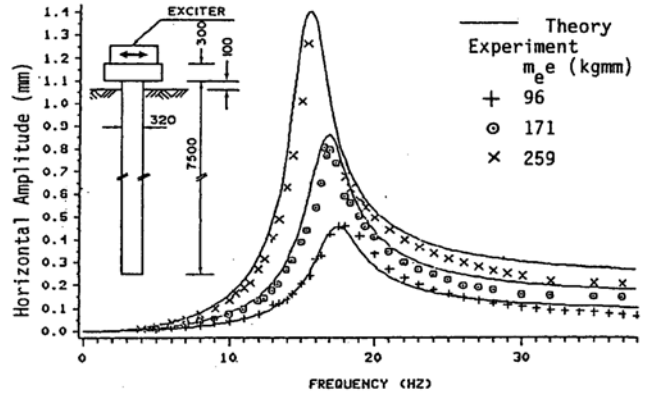


Figure 4. Theoretical and experimental horizontal response of concrete pile for three levels of harmonic excitation (El Marsafawi et al., 1990)

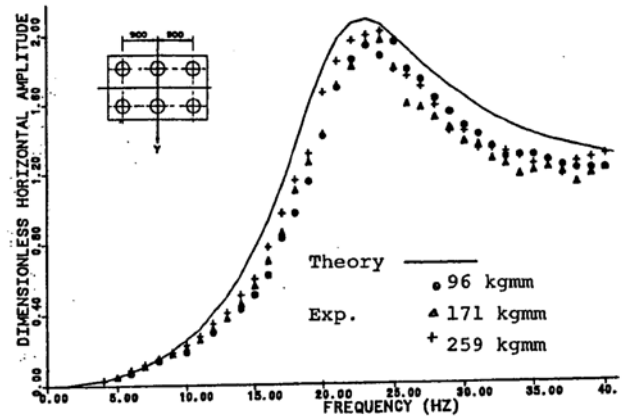


Figure 5: Horizontal theoretical and experimental response in Y-direction for group of six concrete piles 7.50 m long, 0.32 m in diameter (El Marsafawi et al., 1990)

4. CONCLUSIONS

1. The comparison of observed and predicted dynamic response of a single test pile shows that the assumption of a parabolic soil profile yields reasonable values of natural frequencies for the case of vertical as well as horizontal vibrations. However, a general conclusion is not justified because of the limited nature of data.
2. It is necessary to account for the effect of softened soil zone in designing piles subjected to dynamic effects.

5. REFERENCES

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