Behaviour of Pile under Machine Induced Vibrations in Kolfe, Addis Ababa Ethiopia

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ABSTRACT

The results of an experimental investigation to study the response of short piles subjected to horizontal dynamic excitation has been reported herein. Four cast in-situ RCC short piles of length 2 m and diameters of 0.20 m, 0.30 m, 0.40 m and 0.50 m were cast for this investigation. This resulted in L/d ratios of 10, 6.67, 5 and 4 respectively, thus satisfying the L/d ratio criteria for short piles i.e. it should be less than 10. The piles were cast in a silty sand deposit. To generate horizontal sinusoidal vibrations a motor-oscillator assembly was used. Four foundation bolts were cast into the pile cap to enable the mounting of a motor-oscillator assembly.

For each pile, acceleration-frequency records were analysed to obtain resonant frequency of the soil-pile system and shear strain at ground level. Using this data, a procedure has been developed to obtain damping ratio and stiffness of the soil-pile system. Conclusions have been drawn relating (i) Exciting force level and resonant frequency, (ii) Soil-pile stiffness and strain level and (iii) System damping and strain level, considering each pile individually. The influence of L/d ratio on the dynamic response of the soil-pile system has also been demonstrated.

INTRODUCTION

Short piles are widely used to support structures such as wind turbines, traffic signals, transmission towers, highway overhead signs and water front structures. These structures, with small vertical loads, have to withstand significant lateral loads and overturning moments.

According to Matlock and Reese, a pile may be considered as a short rigid pile when its embedment depth is less than 2T, where T is a relative stiffness factor.

$$T = \left[\frac{E_p I_p}{\eta_h}\right]^{\frac{1}{5}} \qquad (1)$$

Here, E_pI_p is the bending stiffness of the pile and η_h is the coefficient of subgrade reaction of the surrounding soil.

Carter, J. P., and Kulhawy, F. H. (1992) proposed, based on the depth to diameter ratio of the pile, that a pile may be considered as a short rigid pile when its L/d ratio satisfies the condition.

$$.05\left[\frac{E_e}{G^*}\right]^{\frac{1}{2}} < L/d < \left[\frac{E_e}{G^*}\right]^{\frac{2}{7}} \qquad (2)$$

here, E_e is the effective Young's modulus of the pile, G^* is the equivalent shear modulus of the surrounding soil and L/d is the length to diameter ratio of the pile.

$$G^* = \left[\frac{E_s}{2(1+\mu)}\right]\left[1+\frac{3\mu}{4}\right] \qquad (3)$$

here, E_s is the Young's modulus of the soil and μ is the Poisson's ratio.

$$E_e = \frac{E_p I_p}{\left(\pi \frac{B^4}{64}\right)} \qquad (4)$$

here, B is the pile diameter.

Based on these criteria a set of short piles were cast and tested in-situ to study the effect of L/d ratio on Resonant frequency, stiffness, shear strain and damping.

INVESTIGATION PROGRAM

The experimental setup was located at the Kolfe, Addis Ababa Ethiopia. To identify the soil characteristics at the site a Standard Penetration Test was conducted upto a depth of 6m as reported in Fig. 1. N–values were obtained at intervals of 0.75 m soil samples were collected carefully from the split-spoon sampler. Specific gravity and moisture content tests and sieve analyses were carried out on these soil samples for classification of the soil. Angle of internal friction was estimated from the SPT N-value. Table 1 shows the properties of the soil at the test site.

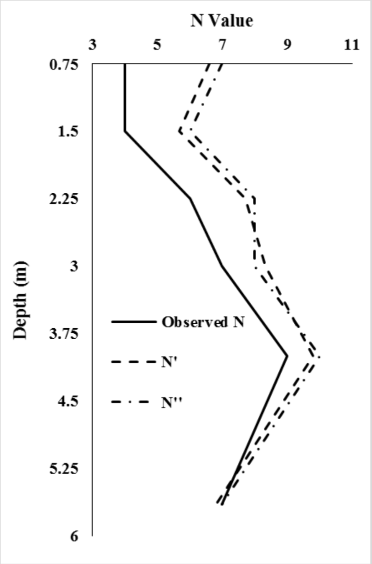

Fig. 1. SPT - N Profile

Table 1. Soil properties at the site

Property	Value
Soil Type	SM
Uniformity Coefficient (C_u)	3.3
Coefficient of Curvature (C_c)	1.49
Mean Specific Gravity (G)	2.64
Angle of Internal Friction	30°

Four cast in-situ RCC short piles having diameters of 0.20 m, 0.30 m, 0.40 m and 0.50 m and a length of 2m were cast at the site. This resulted in L/d ratios of 10, 6.67, 5 and 4 respectively. The computed value of 2T was greater than 2m for all the pile diameters and the range of L/d ratios was between 2.58 and 9.89, thus satisfying the criteria suggested by Matlock and Reese (1960) (L_s < 2T) and Carter, J. P., and Kulhawy. F. H. (1992) for a short pile. The dimensions of the pile cap were 0.70 m x 0.70 m x 0.30 m (height). Four foundation bolts were cast into it so that a mechanical oscillator-motor assembly could be centrally mounted on it. The motor-oscillator assembly was used to generate horizontal sinusoidal forces of different magnitudes.

Forced horizontal vibration tests were conducted on each of the four piles. Three acceleration transducers were suitably mounted on the vertical face of the pile cap to monitor the induced accelerations. Fig. 2 depicts the test set up for horizontal vibrations. Each pile was excited to different acceleration levels either by using different eccentricity settings within the mechanical oscillator or by varying the motor speed. Eccentricity settings used in the testing program are given in Table 2 below. Motor speeds were varied from 3 Hz to 45 Hz for each eccentricity setting of the oscillator.

Fig. 2. Investigation Site

Table 2. Various eccentricities with pile diameter

Pile Diameter (m)	Eccentricity Setting (Degrees)
0.20	20,30,40
0.30	20,30,40,50
0.40	20,30,40,50
0.50	30,40,50,60

RESULTS AND ANALYSES

In the horizontal vibration tests, three accelerometers were used to record the induced accelerations along the depth of the pile cap. From these acceleration values displacements were calculated and plotted along the pile cap height. The line joining the three displacements makes an angle (A_θ) with the vertical. A_θ is the rotational amplitude. A plot between rotational amplitude and frequency was made and resonant frequency and (A_θ)$_{max}$ were obtained, for each eccentricity setting of a pile. Fig. 3 shows a typical rotational amplitude versus frequency plot.

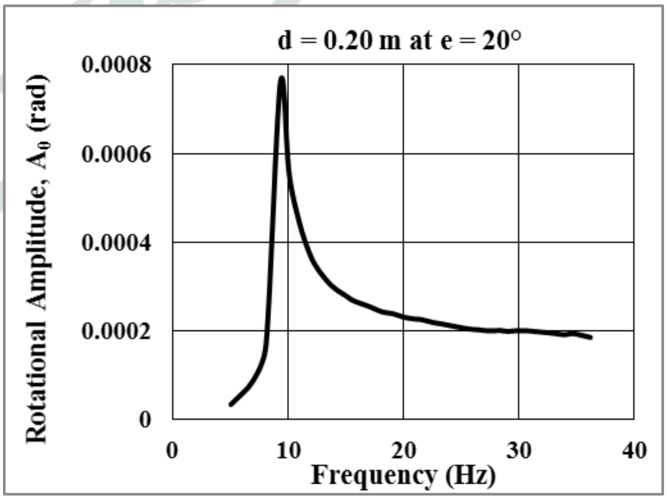

Fig. 3. Variation of rotational amplitude with frequency

As the pile was firmly embedded no lateral movement was assumed when the pile was excited. Hence only one resonant peak was observed as the soil-pile system behaves as a SDOF system. In order to calculate the damping ratio (ξ) and stiffness (K_θ) of the soil-pile system, the following iterative procedure was adopted. A damping ratio value was assumed and using this assumed damping ratio, undamped natural frequency, magnification factor, static displacement (rad) and exciting moment were calculated. The slope of the curve between exciting moment and static displacement (Fig. 4) gives the stiffness of the soil-pile system corresponding to the assumed damping value. Damping ratio was recalculated using this stiffness value and the process was repeated till the two values i.e. the assumed damping value and the calculated damping value converged. This converged value is the damping ratio (ξ) of soil-pile system and the corresponding stiffness is the stiffness (K_θ) of the soil-pile system.

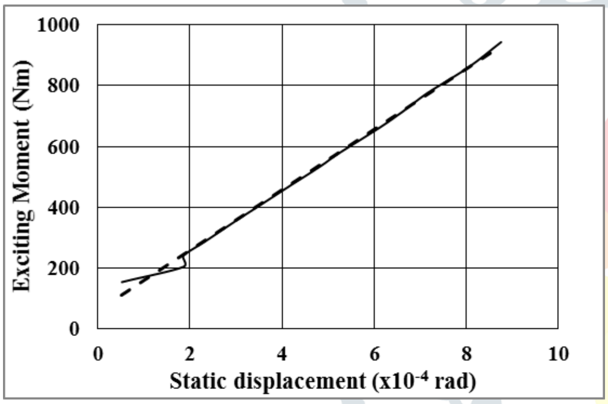

Fig. 4. Variation of exciting moment versus static displacement

Using the above procedure, stiffness and damping ratio of the soil-pile system, was evaluated for each eccentricity setting of the oscillator, for each individual pile.

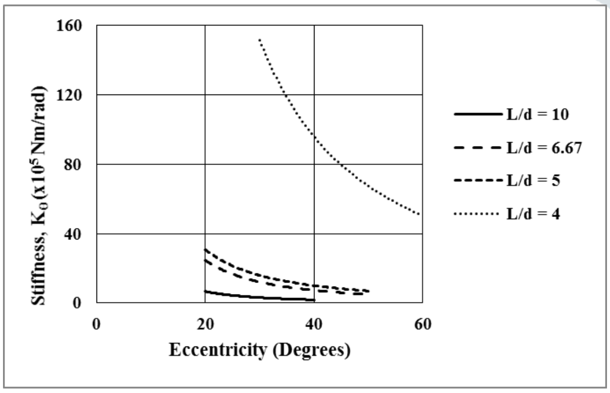

Fig. 5. Variation of stiffness with eccentricity setting of oscillator

Fig. 5 depicts the variation of stiffness with eccentricity setting of the oscillator for the four pile diameters considered. It is observed that the stiffness decreases with an increase in the force level i.e. eccentricity setting of oscillator. Further this decrease in stiffness is more pronounced for the pile of 0.50 m diameter when compared to the other pile diameters. This may be attributed to the fact that the strain level decreases with an increase in the diameter of the pile, for the same force level.

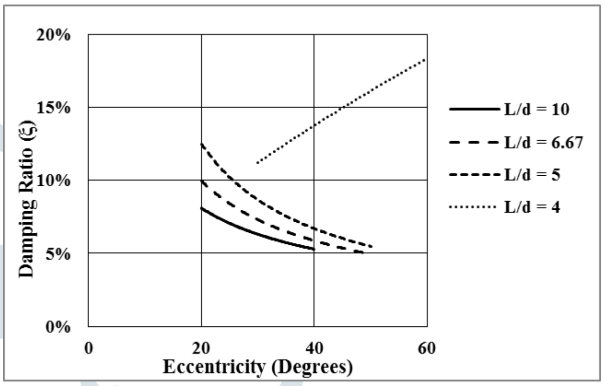

Fig. 6. Variation of damping ratio with eccentricity setting of oscillator

Fig. 6 depicts the variation of damping ratio with eccentricity setting of the oscillator for the four pile diameters considered. It is observed that damping ratio decreases with an increase in the force level, except for the 0.50 m diameter pile. This may be attributed to the fact that very small strain levels are induced in the 0.50 m diameter pile, hence radiation damping is predominant when compared to the hysteresis damping. For the other piles with an increase in force level soil-pile separation increases, hence radiation damping decreases and hysteresis damping is predominant. Similar trend was reported by Teerawut Juirnarongrit and Scott A. Ashford (2001).

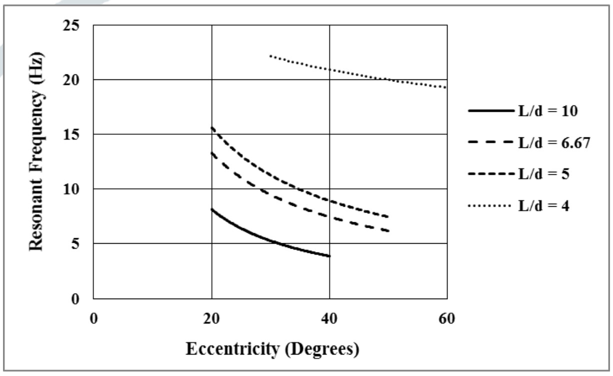

Fig. 7. Variation of resonant frequency with eccentricity setting of oscillator

Fig. 7 depicts the variation of resonant frequency with eccentricity setting of the oscillator for the four pile diameters considered. It is observed that resonant frequency decreases with an increase in the force level for all the piles. This is due to the fact that soil stiffness decreases with an increase in the force level.

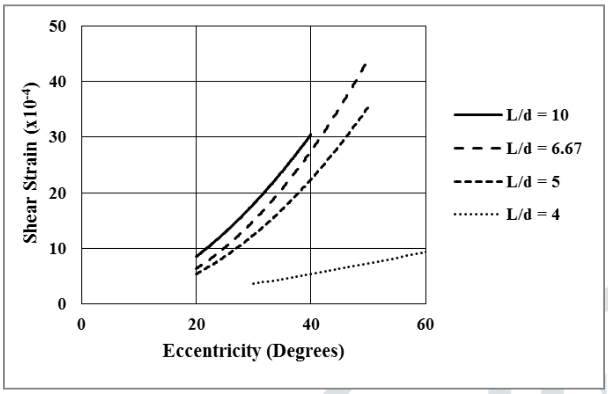

Fig. 8. Variation of shear strain with eccentricity setting of oscillator

Fig. 8 depicts the variation of shear strain with eccentricity setting of the oscillator for the four pile diameters considered. It is observed that the shear strain increases with an increase in the eccentricity setting of the oscillator. This variation is more pronounced for the 0.20 m diameter pile when compared to the 0.50 m diameter pile. This may be attributed to the fact that for a small diameter pile, a small change in the force level creates a larger change in the strain level induced.

CONCLUSIONS

Following conclusions may be drawn from the experimental studies performed herein.

1) Stiffness of the soil-pile system decreases with an increase in the excitation force level i.e. eccentricity setting of the oscillator. The decrease in stiffness is more for larger pile diameters.
2) Damping ratio of the soil-pile system decreases with an increase in the excitation force level. However for the 0.50 m diameter pile a reverse trend was observed.
3) Resonant frequency of the soil-pile system decreases with an increase in the excitation force level.
4) Shear strain at ground level increases with an increase in the excitation force level. This variation is more pronounced for the 0.20 m diameter pile when compared to a 0.50 m diameter pile.
5) Stiffness, Damping ratio and resonant frequency decreases whereas shear strain increases with an increase in L/d ratio, for the same excitation force level.

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