THE INFLUENCE OF EMBEDMENT IN DRY SAND ON THE DYNAMIC CHARACTERISTICS OF MODEL PILES

D.M. LILLEY[1], R.D. ADAMS[2] AND W.J. LARNACH[1]
UNIVERSITY OF BRISTOL, (1) DEPARTMENT OF CIVIL ENGINEERING
(2) DEPARTMENT OF MECHANICAL ENGINEERING

1. Introduction

This investigation forms part of a wider study into methods of non-destructively testing piles for the presence of defects such as bulbs or necks. The principles used are based on measurements of structural natural frequencies and it is important to understand initially how "perfect" piles interact with the soil under vibration.

The purpose of this work was to investigate the effect of embedment in dry sand on the dynamic properties of both steel and concrete model piles and to compare theoretical predictions and experimental results. The influence of the surface roughness of the pile, the stiffness of the material below the pile tip and the depth of embedment were studied.

2. Experimental programme

The experimental work involved the forced axial vibration of straight, cylindrical, model piles both in air and in sand. The axial resonant frequencies were determined by both maximum receptance and phase angle measurements, together with the values of receptance at resonance and the specific damping capacity. The strain mode shapes were also examined.

The vibration tests on piles in air were performed with the pile in a horizontal position.

Next, the piles were installed vertically in dry sand using a sand spreader device to create uniform beds of sand around the piles. The vibration tests were repeated using the same instrumentation as before.

Embedment caused a change in the resonant frequencies of the pile, a decrease in the value of mechanical receptance at resonance, and an increase in the specific damping capacity. The surface roughness of the pile and the stiffness of the material below the pile tip appeared to have only a minor influence on the effects of embedment. An increase in the depth of embedment produced a corresponding increase in the change in the observed dynamic characteristics of the embedded pile.

3. Theory

A mathematical model was developed for predicting the dynamic characteristics of embedded model piles. Three different finite element models were used to analyse

(i) a fully embedded pile in a linear-elastic soil;
(ii) a pile supported only at its base by a linear-elastic soil; and

(iii) a fully embedded pile in a visco-elastic soil.

The dynamic properties of the dry sand (elastic modulus, shear modulus and damping coefficients) were determined from values and expressions found in existing literature relating to small amplitude vibration of soils.

A standard finite element program was used to provide eigenvalue solutions of the first and second models. The predicted undamped resonant frequencies and mode shapes (displacement and strain) were evaluated from the results. The models were modified to introduce damping to the soil-pile system, and a modal superposition method was used to determine the theoretical damped mode shapes.

The third finite element solution was based on an existing soil-pile model in which the soil is assumed to possess visco-elastic properties. The mass of the soil is ignored throughout the calculations, except where it influences the dynamic soil properties. The predicted resonant frequencies were determined by iteration using both maximum receptance and phase angle measurements in a manner similar to that used to determine the experimental values. The predicted values of receptance at resonance and the specific damping capacity were determined for each of the first three modes of resonant axial vibration, together with the mode shapes (displacement and strain).

4. Discussion and Conclusions

The results from the first and second models were unacceptable as the predicted values of the axial resonant frequencies were significantly lower than the corresponding experimental frequencies. The significant change in the theoretical resonant frequencies is most likely due to the inclusion of the mass of the soil.

In general, the analyses of embedded piles using the visco-elastic soil model produced results which were more consistent with those determined empirically than the other two forms of analysis. However, it proved impossible to predict the specific damping capacity associated with the first resonant mode of axial vibration of the model concrete piles. This problem is linked with a major difficulty arising within the visco-elastic model in the evaluation of modified Bessel functions with small complex arguments.

Of the three models, the visco-elastic soil model (number (iii)) provided the most acceptable theoretical results when these were compared with the experimental results. The results from model (i) improved when the soil-pile system was modified to ignore the mass of the soil while retaining the soil stiffness. However, the predicted resonant frequencies were still not as close to the experimental values as those determined from model (iii). The main advantages of the visco-elastic soil model over the other solutions are that:

(i) it relates to the mechanical process of vibration to a much greater extent than an eigensolution, which is a mathematical solution to the free vibration of a system of masses and springs, and

(ii) it accepts realistic damping coefficients for the sand, evaluates the dynamic properties of the soil-pile system in a manner similar to that used in the experiments, and produces meaningful results when compared with the corresponding experimental values.

It was deduced from the theoretical and experimental results that the major influence on the dynamic characteristics of an embedded model pile in dry sand is the stiffness of the soil around the pile. The effect of material damping within the soil appeared to be insignificant. It may also be concluded that the soil contributes very little to the mass of the vibrating soil-pile system.