SOIL-STRUCTURE INTERACTION OF DYNAMICALLY LATERALLY LOADED PILE BASED ON DISCRETE-ELEMENT METHOD

by
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SYNOPSIS

An analytical method based on discrete-element model was developed to study the soil-structure interaction of a vertical pile under dynamic and transient lateral loads. In order to obtain specific test results for use in verification of the discrete-element method, small dimension beams and piles were tested under controlled conditions. This paper briefly summarises the tests conducted and comparison of test results for moments and deflections with the analytical solutions.

INTRODUCTION

The soil-structure interaction of a pile under dynamic lateral loads has so far not been studied extensively to consider the nonlinear soil properties and various combinations of loads and moments. This study was undertaken to develop an analytical method based on discrete-element model and to verify the same by an experimental study under variety of loads, frequencies, and support conditions.

DISCRETE ELEMENT METHOD

The discrete-element method of solving fourth order differential equation of a beam involves the representation of the differentials in a finite difference form. The physical model consists of rigid bars, connected end to end with pin joints and elastic springs to input the flexural stiffness. The soil is represented by infinitely closely spaced springs, their effect being concentrated at the joints. Any constraint, distributed throughout the bar, is replaced by an equivalent parameter at the joints, which is the average of the constraints in the two bars adjascent to the joint in question. All the loads are assumed to be harmonic and the system to respond by vibrating at the same frequency and to lead the motion by phase angle. By following a procedure similar to that used by Matlock and Haliburton(1965), the equation describing the response of a pile under dynamic lateral loads is obtained to include viscous damping and mass of pile and vibrating soil. Seperating the coefficients of $\sin\omega t$ and $\cos\omega t$, the two equations for each station are obtained, written in a seven terms wide banded matrix (Agarwal 1971), and solved by numerical techniques on a digital computer to determine deflections at all joints. Knowing deflections, shearing forces, bending moments, and support reactions are calculated using the difference equation relationship.

For transient loads, the equation of motion is homogenous and the net effect is to establish some initial conditions to the governing equation. Using the method of seperation of variables, the solution is the product of two functions; one, a function of distance only, and the other, a function of time only.

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The nonlinear soil modulus is represented by an equivalent combination of a force and a linear spring. The nonlinear behaviour of soil mass versus pile deflection is treated in the same manner. Only linear parameters are used for transient loads.

A computer program (PILE 10) was written in FORTRAN IV on IBM 360/40, but is compatible to be used on most computers. The program, consisting of a main program and 13 sub-programs is discussed by Agarwal (1971) to handle: (1) Harmonic excitation of a continuous beam or pile, (2) Natural frequancy estimate and normalised mode shape, and (3) Transient loading.

EXPERIMENTATION VERIFICATION

To obtain test results for use in verifying discrete-element methods an instrumented pile with two strain gages fixed diammetrically opposite each other at six locations was tested. The pile was 0.95 cm in diameter, with wall thickness of 0.076 cm, 30.5 cm long, and made of structural brass.

Beam tests

The tests were conducted on a cantilever beam under static loads and at frequencies of 10, 15, and 20 cps at varying loads. Bending moments and deflection for each test were obtained and compared to the analytical solutions. The error was calculated as percentage of maximum measured moment and deflection respectively. It was observed that the analytical solutions agreed with the experimental results within reasonable accuracy for the tests conducted below the natural frequency.

Pile tests under steady state dynamic loads

A pile embedded in two different materials having nonlinear properties was tested. The properties of the two materials are as follows:

Plastellina:- Average density- 1.73 kg/cm^3; Average shear strength- 0.485 kg/cm^2; and Mineral component - Kaolinite.

Clayey soil: Liquid Limit - 51.7; Plasticity index - 26.7; average density 1.73 kg/cm^3; Moisture content - 30.0 percent; degree of saturation - 95 percent; average shear strength - 0.135 kg/cm^2.

The load was applied at 0.32 cm from the free end. Tests were conducted under static loads and at frequencies of 15, 20, 20, 25, and 30 cps at varying loads. Soil density, shear strength, stress strain characteristics, nonlinear soil modulus, natural frequency and damping of soil-pile system, and mass of vibrating clay were determined experimentally.

Analytical solutions, obtained by using the soil and pile properties were compared to the experimental results for moments at six locations and deflection at one location for the tests conducted upto the natural frequency. For all the tests below the natural frequency,the analytical solutions for moments agreed very closely with the experimental results, but had greater discrepancy for deflections. For the tests conducted close to natural frequency, the agreement between the analytical and experimental solutions was not so close. The discrepancy may be due to the following factors: (a) By representing the clay by independent springs in the analytical solutions, the interaction between them is neglected: (b) A nonlinear relationship between the mass of vibrating soil versus pile deflection and nonlinear damping may be required to be included; (c) Use of accelerometer to measure deflections may yield erroneous results; (d) Experimental errors such as a time lag in testing the pile and soil samples, change in clay properties due to one recorder being used for all the gages, methods of placing the clays, and the discrepancies in determining pile properties.

Tests on pile embedded in clayey soil under Transient loads

The pile was tested under initial displacements of 0.05 and 0.1 cm at the pile head. Stress strain characteristics were determined by testing soil samples in an impact testing equipment. Other soil properties were determined in the same was as for steady tests. Secant soil modulus using the early part of the curve was used. The test data for the first cycle was analysed. Good agreement existed between the analytical and experimental moments within reasonable accuracy. The causes of discrepancy between the analytical and experimental solutions may be the same as (a) for beams in determining pile properties, (b) for soil properties as discussed under steady state tests, and (c) in the determination of soil modulus under impact loads, as the impact testing equipment may need some improvement.

CONCLUSIONS

An analytical method based on discrete-element model was developed for a vertical pile subject to dynamic lateral loads and verified by conducting tests on beams and piles under variety of loads, frequencies, stiffness, and soil conditions. From the study of all cases, the comparison showed good agreement within acceptable accuracy for the tests conducted below the natural frequency.

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