I－B402 NONLINEAR SEISMIC RESPONSE OF PILE FOUNDATION

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ABSTRACT:

A new approach to include the nonlinear effects of soil media in pile analysis is proposed. Approach is based on Green's function formulation for the linear pile analysis while equivalent linearization technique is used to include material nonlinearity of the soil media. Hyperbolic model is used to define nonlinear stress-strain relationship of the soil. This method which works in frequency domain is applied to find the nonlinear pile head response of a single pile as well as pile group. Study is useful in examining the nonlinear effects of soil.

Assumptions:

First linear analysis is carried out and for this it is assumed that soil medium is a viscoelastic layered halfspace. For linear analysis properties of all the layers and halfspace is assumed same though it may be varying from layer to layer. It is assumed that soil and pile are in perfectly contact for linear as well as nonlinear analysis. Seismic excitation is assumed to be consist of vertically propagating shear waves and for simplicity it is assumed harmonic with a fixed amplitude but varying frequency.

Modelling:

As soil medium is divided into a number of layers, pile is also divided into same number of segments with pile tip resting on the halfspace. Actual force distribution is replaced by piecewise constant distribution.

Formulation:

For the linear analysis a very rigorous three dimensional approach proposed by Kaynia and Kausel (1982) have been used. Only very brief formulation is described here. In this formulation after doing manipulation and applying boundary conditions one can get a relationship relating forces at pile heads and tips with displacements at these points. This relationship can be described as-

$$Pe = Ke * Ue + Q \qquad ...(1)$$

where Pe and Ue are the forces and displacement vector referred to the end of the piles (i.e. pile head and pile tip). Ke is an equivalent stiffness matrix and Q is a load vector due to seismic effects which are defined as-

$$Ke = [Kp + \Psi^T (Fs + Fp)^{-1} \Psi] \qquad ...(2)$$

$$Q = -\Psi^T (Fs + Fp)^{-1} \Psi Us \qquad ...(3)$$

Where Us represent seismic displacement in the medium and Matrices
F_s = Soil-flexibility Matrix when there is no pile in the medium
F_p = Pile flexibility Matrix for clamped end pile
K_p = Pile stiffness matrix relating forces at the end of pile with end displacements
Ψ = A shape function matrix relating displacement at any point of pile with end displacements

Nonlinearity of soil is modeled using hyperbolic model defined by the following equations:

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$$\frac{G}{G_{\max}} = \frac{1}{1+\gamma/\gamma_r} \qquad ...(4)$$

$$D = \frac{4}{\pi}\left[1 + \frac{1}{\gamma/\gamma_r}\right]\left[1 - \frac{ln(1+\gamma/\gamma_r)}{\gamma/\gamma_r}\right] - \frac{2}{\pi} \qquad ...(5)$$

where G and D represent the shear modulus and damping at a particular strain γ while $G_{\max}$ & γ_r represent maximum value of G & reference strain for the given soil media respectively. Seismic excitation is considered of the form:

$$u(t) = u_0\exp(i\omega t) \qquad ...(6)$$

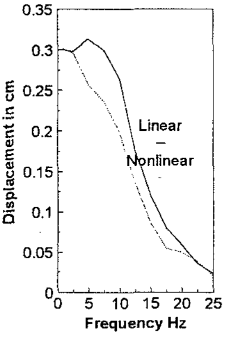

Fig. 1 Single Pile in Clay

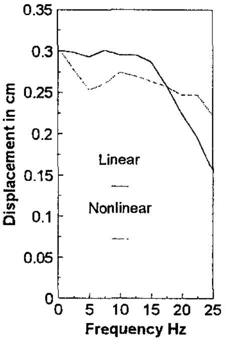

Fig. 2 Single Pile in Sand

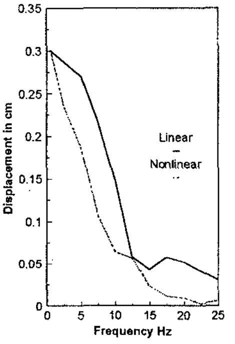

Fig. 3 Pile Group in Clay

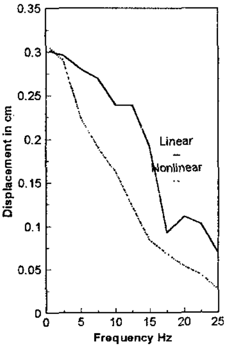

Fig. 4 Pile Group in Sand

Results:

Linear and nonlinear pile head (or pile cap in case of group) response is obtained for a single pile as well as for a 2*2 pile group. Further two types of soil media i.e. Toyoura sand and an undisturbed clay is considered. Displacement amplitude of harmonic excitation is assumed to be 0.3 cm with varying frequency. This amplitude is taken to provide realistic strain in soil media. Figs. 1-4 represent these results from which it can be observed that for most of the frequency range nonlinear response is less than linear one. Trends are almost same for single pile as well as pile group for both types of the soil. For single pile in sand (Fig. 2) at higher frequency, nonlinear response is little more compare to linear one.

Results are justified in view that as strain level in soil media increases, shear strength decreases while damping increases. Thus if impedance functions of pile (or group) is calculated than it is seen that at higher strains its real part decreases while imaginary part increases. Since response at pile head is controlled both real and imaginary part of impedance functions, hence it's overall effect depends on the relative values of real and imaginary part. Here it was seen that due to nonlinearity, increase in damping is much higher hence response is decreased. Further increase in response in Fig. 2 can be explained with similar reason that in this case at higher frequency real part of impedance function is dominant.

Conclusion:

Effect of nonlinearity on the pile head response is investigated. It is seen that due to nonlinearity response of pile head may increase or decrease depending on the frequency of excitation and reference strain of the soil media.

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