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EFFECT OF MATERIAL DAMPING OF SOIL ON DYNAMIC BEHAVIOUR OF PILE FOUNDATION

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ABSTRACT:

In this paper effect of material damping of soil media on the dynamic behaviour of pile foundation is investigated. Two different kind of material damping namely, viscous and hysteretic is considered in the analysis. Using two different theories, effect of damping is investigated on the dynamic stiffness of soil as well as on the response of soil-pile system. This also presents a comparison of these two relevant theories.

Introduction:

In case of pile foundation, effect of kind of material damping of soil media is rarely discussed. For a soil stratum, much part of overall damping of soil layer comes from the radiation damping hence generally effect of behaviour of material damping on the soil-pile system is not given much attention. In this paper behaviour of a single end bearing pile is investigated considering viscous and hysteretic damping of soil. Viscous damping has been dealt using Tajimi's theory (1969) while hysteretic damping is analysed through Novak & Nogami (1977), referred as Novak's theory. Selection of these two theories give the advantage that all other assumptions, except kind of material damping are same in both the theories.

Assumptions:

Soil medium is assumed elastic, isotropic and homogeneous stratum resting on the bed rock. A pile of cylindrical shape whose bottom rests on the bedrock is fully embedded into the stratum. Vertical displacement of the surface layer is neglected because it is less significant than the other horizontal components. Input acceleration is applied on the surface of the bed rock. Material damping assumed is either frequency dependent viscous or frequency independent hysteretic damping.

Formulation:

Here, only the brief outline is discussed. Since vertical displacement is neglected, analysis requires solution of two wave equations in cylindrical coordinates with appropriate boundary conditions. Frequency dependent complex soil stiffness of soil medium is found by expressing resistance of soil in terms of displacement and for horizontal vibration is given by

$$p(z) = \pi\mu \sum_{n=1}^{\infty} \alpha_{hn} U_n \sin(h_n z) \qquad \text{with} \qquad h_n = \frac{\pi}{2H}(2n-1) \quad n = 1,2,3,\ldots \tag{1}$$

where dimensionless resistance factor α_{hn} for n th mode is given by

For Novak's Theory $$\alpha_{hn} = r_0 \sum_{n=1}^{\infty} [(1+iD_s)h_n^2 - (\tfrac{\omega}{v_s})^2]T_n \tag{2a}$$

For Tajimi's Theory $$\alpha_{hn} = (\tfrac{\pi}{2}\xi_n \tfrac{r_0}{H})^2 T_n \tag{2b}$$

where $$T_n = \frac{(4K_1(q_n r_0)K_1(s_n r_0) + s_n r_0 K_1(q_n r_0)K_0(s_n r_0) + q_n r_0 K_1(s_n r_0)K_0(q_n r_0))}{q_n r_0 K_0(q_n r_0)K_1(s_n r_0) + s_n r_0 K_1(q_n r_0)K_0(s_n r_0) + q_n s_n r_0 K_0(q_n r_0)K_0(s_n r_0)} \tag{3}$$

in this expression q_n and s_n are given by

For Novak's Theory $$q_n^2 = \frac{(1+iD_s)h_n^2 - (\omega/v_s)^2}{\{\eta^2 + i[(\eta^2-2)D_v + 2D_s]\}} \quad \text{and} \quad s_n^2 = \frac{(1+iD_s)h_n^2 - (\omega/v_s)^2}{1+iD_s} \quad \text{with} \quad \eta = \frac{v_l}{v_s} = \sqrt{\frac{2(1-\nu)}{(1-2\nu)}} \tag{4a}$$

For Tajimi's Theory $$q_n = \frac{\xi_n \omega_g}{v_l} \quad \text{and} \quad s_n = \frac{\xi_n \omega_g}{v_s} \tag{4b}$$

$$\text{with} \quad \xi_n = \sqrt{n^2(1 + 2ih_g \tfrac{\omega}{\omega_g}) - (\tfrac{\omega}{\omega_g})^2} \quad \text{and} \quad \omega_g = \frac{\pi}{2H} v_s = \frac{\pi}{2H}\sqrt{\frac{\mu}{\rho}}$$

In above expressions μ, ρ, ν represent shear modulus, density and Poisson's ratio for the soil media respectively; while v_l and v_s represent longitudinal and shear wave velocity; D_v and D_s are hysteretic damping ratios associated with the volumetric and shear strains respectively and are considered frequency independent; h_g denotes the critical damping ratio (viscous) for fundamental frequency of soil layer; r_0 and H denotes radius and length of pile respectively. Once soil resistance at a particular frequency is known, solution of soil-pile system is obtained as a beam equation.

Keywords: Pile Foundation, Hysteretic Damping, Viscous Damping, Dynamic Stiffness, Response

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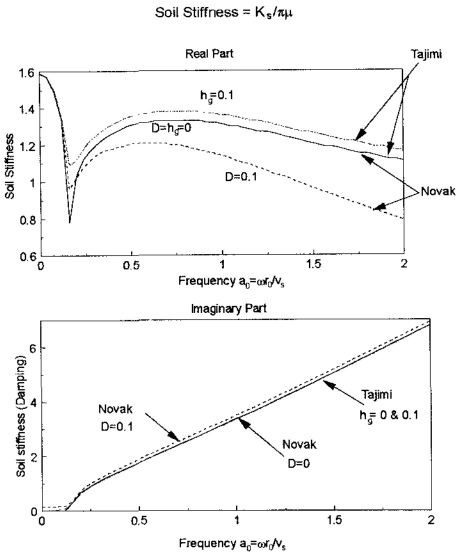

Fig. 1. Effect of Material Damping on Dynamic Stiffness of Soil

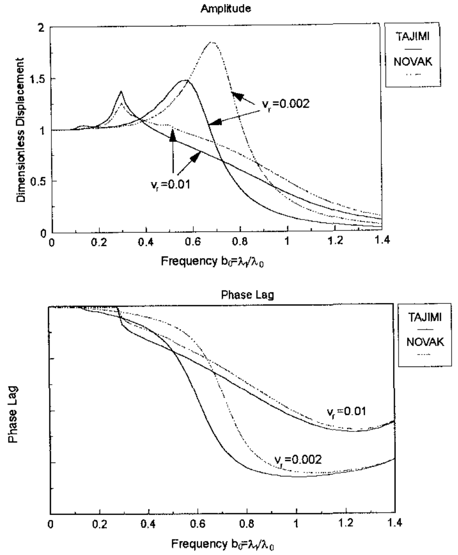

Fig. 2. Effect of Material Damping on the Response of Pile Head

Results:

Fig. 1. shows the variation of complex soil stiffness with frequency and material damping, for first mode. To represent frequency ω, a dimensionless parameter i.e. $a_0 = \omega r_0/v_s$ is used while stiffness is normalised by using shear modulus of soil. Here it is assumed that D_v=D_s=D. As can be seen from equation 2a and 2b as well as from Fig. 1 that in the absence of material damping of soil, solution given by both theories are exactly equal. While in Tajimi's theory material damping increases real part of dynamic stiffness, contrary to it, this decreases in Novak's theory. Again in Tajimi's theory material damping have no effect on imaginary part, i.e. on total damping but in Novak's theory it have a little effect. Further it can be seen that below resonance there is negligible effect of material damping on real as well as imaginary part. Such difference in stiffness using these theories is obvious, since it can be justified in the light of the nature of damping force used.

Fig. 2 shows variation of dimensionless displacement (normalized w.r.t. static value) with frequency and wave velocity ratio. Where wave velocity ratio v_r and nondimensional frequency parameter b_0 is defined by the following relations

$$v_r = \frac{v_s}{v_p} = \sqrt{\frac{\mu\rho_p}{E_p\rho}} \quad (5)$$

$$b_0 = \bar{\lambda}/\bar{\lambda}_0 \quad where \quad \bar{\lambda} = H\left(\frac{m\omega^2}{EI}\right)^{1/4} \quad (6)$$

while $\bar{\lambda}_0$ = the lowest value of $\bar{\lambda}$ at which the stiffness of a free standing pile without soil become zero. It can be seen from Fig. 2 that at lower frequencies (comparing to resonant frequency) response given by both the theories are almost same while at higher frequencies Novak's theory gives higher displacement, which can be justified by the fact that material damping (hysteretic) decreases real part of the stiffness. Also it can be seen from this figure that difference in phase lag given by both the theories is not so much as it is for magnitude of displacement, which is also justified from Fig. 1.

Conclusion:

The way in which material damping is modelled has a considerable effect on the real part of the dynamic stiffness of soil, since viscous damping increases it while hysteretic damping decreases the same. This greatly effects response of the soil-pile system. Thus while analysing soil-pile system due consideration should be given to material damping of soil.

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