Radiation Damping of Soil - Foundations Interaction Systems

Yang Xianjian
4th Design and Research Institute of Ministry of Machinery Industry, China

Jiang Bei
4th Design and Research Institute of Machinery Industry, China

Proceedings: Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, March 9-12, 1998.

RADIATION DAMPING OF SOIL−FOUNDATIONS INTERACTION SYSTEMS

Paper № 4.06

Yang Xianjian
4th Design and Research Institute of Ministry of Machinery Indutry, China.

Jiang bei
4th Design and Research Institute of Machinery Industry, China.

ABSTRACT

Based on the theory of wave scatter and the velocity, the wave radiation which is caused in soil of dynamic foundation and the range of the affected depth are presented in this paper . It is pointed out that the mass ratio of foundation and the location of the foundation in the layered soil, and its propagation velocity in the affected depth, are the major factors affecting radial damping of soil−foundation system on the half space.

KEYWORDS

Radiation damping Half space Layered strata Envelope velocity

INTRODUDTION

An important step in current methods of dynamic analysis of soil−foundation interaction problems is the determination of the rddiation damping of the rigid shallow foundation. The energy corresponding to radiation damping is generally carried away by body waves and surface waves. (prakash, S., puri, V.K.1988; and Yan R.J. Wang Y.S.etc.1981.) It is known, however, that energy of wave are propagnated by envelope velocity. When the different layered strata exists at a certain depth below the base of foundtion, it prevents the propagation of the body by scattering (with a small size layered strata in wide direction below the base) or refleting (with a large size one) them back to foundation and to the ground surface; as a result, their energy are lost within the layered media due to radiative damping and its material damping. When a rigid rock base exists at a certain depth below the soil base of foundation, their energy is either lost within the soil due to the material damping, or at some distance from the fondation, gets converted into surface wave energy (Gazetas, G. 1983.1991).

RADIATION DAMPING OF SURFACE FOUNDATION

Damping of Wave Stress

As pointed out in references, the foundation block is assumed to be rigid mass, and the medium below the foundation may there fore be considered to be an elastic half rod as shown in fig.1.

The amplitude at operating freguency can be obtained by using theory of wave stress (Yang, X.J.1987) :

$$A_z = \frac{Q}{\sqrt{(K_Z - \omega^2 M)^2 + (A\rho V_p^2 h)^2}} e^{i(\omega t - \alpha)} \quad (1)$$

$$tg\alpha = \frac{A\rho V_p^2 h}{K_Z - \omega^2 M} \quad (2)$$

in waich

$$\left. \begin{aligned} h &= \frac{\omega}{V_s} \varphi \\ \varphi &= \sqrt{(1+\zeta^2) / \eta^2} \end{aligned} \right\} \quad (3)$$

when $\zeta=0$, and $\varphi=\frac{1}{\eta}=\frac{V_s}{V_p}$

the damping item of the dynamic system in equation (1) is $(C_z\omega)^2=(A\rho V_p\omega)^2$

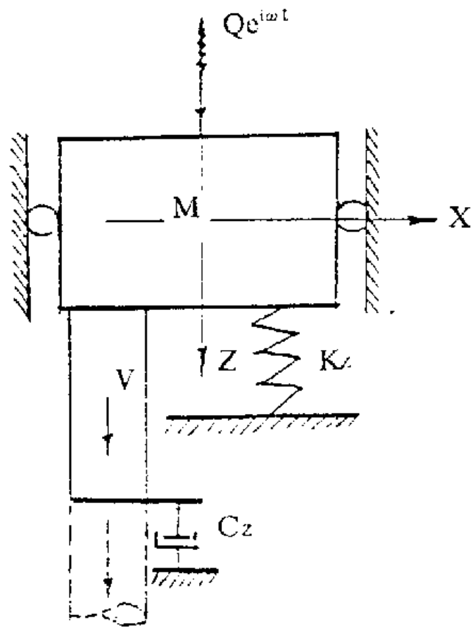

Fig.1 Model of damping of wave stress

$$C_Z=A\rho V_P \tag{4}$$

in which

A - -the area of the foundation

ρ - -unit mass density of soil

Vs - -shear wave velocity of soil

V_p - -longitudinal wave velocity of soil

Equation (4) is the radial damping coeffccient of the soil below the foundation (Gazetas, G., 1983; Yama hara 1964)

Radiation Damping of Surface Foundation on Half Space

1t is known from Lysmer's Analog that the damping coefficient of surface foundation on half space can be represented by.

$$Cz=\frac{3.4\ \ r_0^2}{1-v}\sqrt{G\rho} \tag{5}$$

Where

G - -the dynamic shear modulus of the medium;

v - -the poisson's ratio of the medium;

r_0 - -radius of the footing.

By swbstituting the values:

$$V_s=\sqrt{\frac{G}{\rho}} \quad \text{and} \quad A=\pi r_0^2$$

into Eq.(5), We get

$$C_z=A\rho V_{La} \tag{6}$$

Where

$$V_{LZ}=\frac{3.4}{\pi(1-v)}V_s$$

equation(6), which is known as Lysmer's Analog, illustrates that radial damping of a footing on elastic half-space can be represanted in terms of an elastic half rod as shown in Eq.(4) except abowt the V_{La} and V_p.

Damping Ratio

The radiation damping coefficient Cz Eq. (6) do not include the soil hysteretic damping β_0 (Gazetas, G 1983); to incorporate such damping, the total damping coefficient of the vertical vibrations, C is given by

$$C=C_z+\frac{2K_{zd}\beta_0}{\omega} \tag{7}$$

in which

$K_{zd}=\frac{4Gr_0}{1-v}f(v,a_0)$ —— the dynamic equivalent spring constant of the soil for vertical vibrations

$G=\rho V_s^2$ - -Shear moduIns of soil

V_s - -the phase velocity of shear wave of soil

β_0 - -the material damping coefficient of soil

The damping ratio Dz is given by

$$D_z=\frac{C}{2\sqrt{k_{zd}M}} \tag{8}$$

RADIATION EFFECT OF RADIATION DAMPING

It is known from theory of wave motion in the elastic half−space that energy of wave are propagated by envelope velocity rather than phase velocity, and the former are usually smaller than the latter. Recall,in an elastic half rod, that the envelope velocity is minimum at the $r_0/\lambda=0.45$. For this reason, the wave energy of radiation damping are generally carried away, in point of fact, by the smaller value from Eq.(6). For direct use in practcal application the corrected radiation damping of surface foundation on half space can be written as

$$C_z = A\rho V_{La} e^{-\pi(1-v)\delta} \tag{9}$$

and Lysmer' s Analog (Prakash, S.1988 and Richart. Jr. etc. 1970) damping ratio is obtained as

$$D_z = \frac{0.425}{\sqrt{B_z}} e^{-\pi(1-v)\delta} \tag{10}$$

in which, δ − −Constants in Table 1.

TABLE 1. Affected Parameters δ of Radiation Damping

$\frac{r_0}{\lambda}$	0.2	0.3	0.4	0.5	0.6	0.8	1.2	1.6	2.0
δ	0.110	0.285	0.450	0.400	0.330	0.240	0.205	0.185	0.170

RADIATION DAMPING IN LAYERED STRATA AND COMPLICATED BASE

When the elastic wave, which is applied below the footing, propagating in a medium encounters another medium which has different wave velocity and mass density from the propagation medium, the progressing wave will generate reflection, scattering and diffraction, and then the energy has been partly shielded. It has been foumd that Vs in Eq.(6) and Eq.(9), leds to results consistent with solutions for radial damping of surface foundations. In practical engineering, therefore, how to predict the Vs and the dependent poisson's ratio v in this kind medium in a simpie and clear way is a very important subject in engineering decision making. It can be assumed that the heterobody to be a barrier in the medium as follows (Yang X.J1991)

$$V_{SL} = T_u V_s$$

in which

$$T_u = \frac{U_t}{U_i} \tag{11}$$

in which

U_t − −the amplitude of vibration when the different layered strata exist below the footing.

U_i − −the amplitude of vibration on homogeneous half space below the footing

The transmissivity T_u is the function of the ratio of wave impedance α,in whch

$$\alpha = \frac{\rho_2 V_{sz}}{\rho_1 V_{s_1}} \tag{12}$$

Where

$\rho_1 V_{s1}$ − −The unit mass density and shear wave velocity of media below the footing

$\rho_2 V_{s2}$ − −The unit mass density and shear wave velocity of the different layered strata

It can be seen from the Eq. (12), when $\alpha=1$, no hetero−stratum exists in the medium, and $T_u=1$ (i.e. all incident wave passed through).

AFFECTED DEPTH FOR SURFACE FOUNDATION

By theory of wave analysis, this section presents the vertical "depths of influence" H_z below the footing as follows:

$$a_0 = 0 \sim 0.5, \quad H_z = (0.10 \sim 0.40)\lambda_R$$
$$a_0 > 0.8, \quad H_z = (0.80 \sim 1.55)\ B \quad (13)$$

in which

$a_0 = \frac{\omega r_0}{V_s}$ – –dimensionless frequency ratio

λ_R – –R wave length

B– –width of the footing

ω – –circular excitation frequency

CASE HISTORY

The results of tested and calculated case historys are tabulated in table 2. In this table, the F_1 is a large–sized press foundation was founded on the layers existing composite siltstone and clystone base. The wave radiation, which was caused by layered strata, was consisted in the design. The size the bulk of concrete of foundation was reduced 1160m³ than that of winkler–Viigt model. The beneficial result of the theory of envelope velocity and wave scatter in radiation damping with practical engineering value is gained.

TABLE 2 The Results of Tested and Calculoted Case Historys

№	b $(\frac{m}{\rho r_0^3})$	Stiffness of base		D_z		Calculated		Tested			Remarks
		Static K_z	Dynamic K_{zd}	Eq.(8) Eq.(9)	Eq.(10)	A_z(mm)	f_z(Hz)	A_z(mm)	f_z(Hz)	D_z	
F_1	6.10	193.0×10^6	174.0×10^6	0.253	0.332	0.172	37.43	0.125	31.64	0.248	
F_2	8.93	170×10^6	153.5×10^6	0.055	0.280	0.258	33.00	0.303	30.0	0.08	
F_3	8.16	2.23×10^6	1.12×10^6	0.311	0.215	0.533	7.30	0.606	11.0		
F_4	28.80	89.3×10^6	80.3×10^6	0.314	0.151	0.065	70.27	0.070	62.7	0.16	
F_5	2.53	6.7×10^6	5.03×10^6	0.610	0.469	0.016	6.82	0.015	6.90	0.33	
F_6	3.70	1.3×10^6	1.03×10^6	0.518	0.453	0.0242	33.10	0.0184	37.6	0.43	

CONCLUSIONS

Lysmer's Analog illustrates that radial damping coefficient of a footing on elastic half–space can be represented in terms of an elastic half rod except about the V_{La} and V_p.

In the elastic half–space that energy of wave are propagated by envelope Velocity and the wave energy of radiation damping are generally carried away by the smaller Value from Lysmer's Analog. The corrected radiation damping ratio can be written as Eq.(10).

The elastic wave propagated in a medium will generate reflection, scattering when encountering the different medium. In practical engineering can be assumed that the heterbody to be a barrier in the mediun. It has been found that $V_{SL} = T_u V_s$ leds to results consistent with solutions for radial damping of surface foundations. By engineering prototype measurement and theory analysis, it has been proved that the V_{SL} can be applied in practical engineering for radiation damping in layered media.

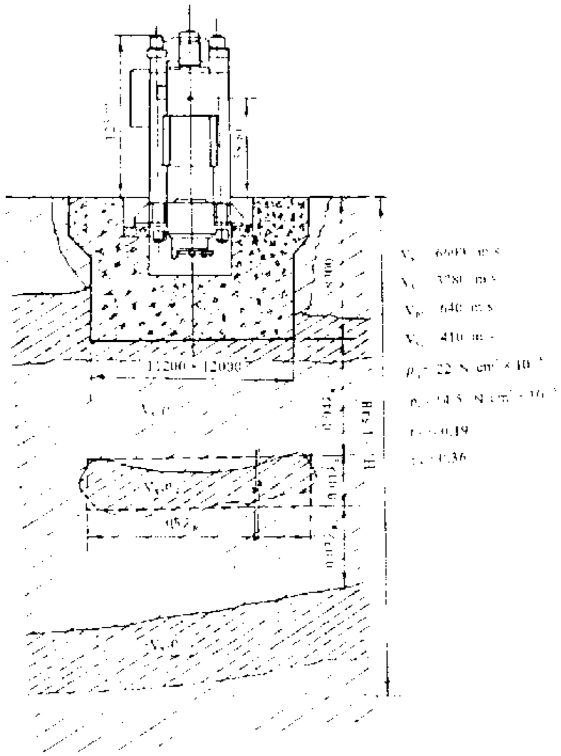

Fig.2 The block and the base soil of press foundation

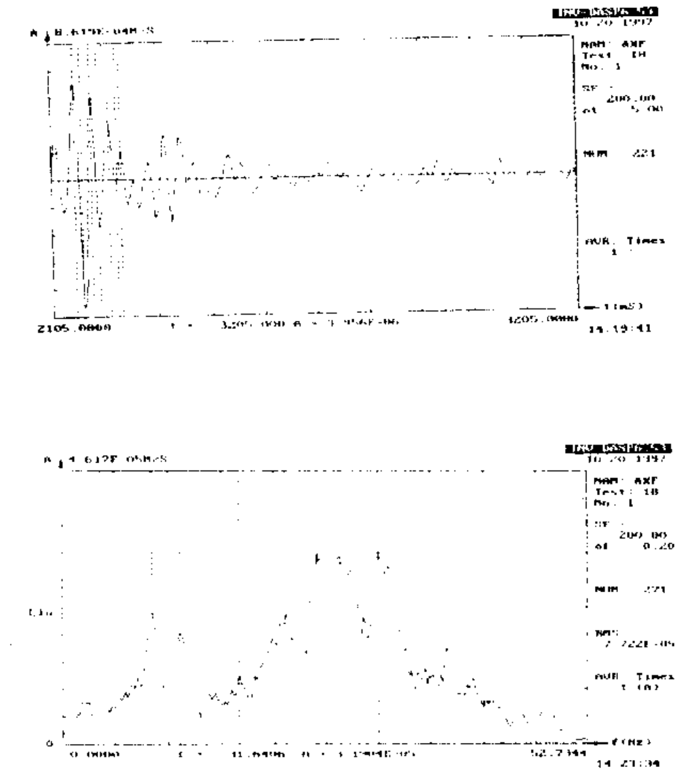

Fig.3 Tested Curves of press foundation

REFERENCES

Gazetas, G. [1991]. "Foundation Vibrations.", in Foundation Engineering Handbook, (H. Y. Fang, ed) Van Nostrand Reinhold, New York, N.Y.pp 553 ~ 593.

Gazetas, G. [1983]. "Analysis of machine foundation vibrations: state of the art", Soil Dyn. and Earthquake Engrg., №1 (2), PP.2 ~ 42.

Prakash, S., Puri, V.K.,[1988] "Foundations for machines: analysis and design" Wiley Series in Geotechnical Engrg,. JOHN WILEY AND SONS, New York.

Richart, Jr, f. E.; Woods R. D.; Hall, J. R. [1970] "Vibralions of soils and foundations" PRENTICE-HALL, INc. Englewood Cliffs, New Jersey.

Yan, R. J.; Wang,Y.S.; Han, Q.Y., [1981]. "Indroduction of Half Space on Dynamics Founda tion" Building Engrg. pub, Soc. CHINA.

Yang X.J., [1987], "Method of wave stress Damping in Foundation Vibration" Engrg. Mechanics, VL4, № 2. PP 92 ~ 97.

Yang X.J.[1991] "Ground Vibration isolated by silo and pile barriers", 2nd Int. Conf. Rec. Adv. Geot. Earth-quake engrg. and Soil Dyn. St. Louis, MO 1991, Vol. II pp 1557 ~ 1562.