

Vertical Dynamic Response of Foundation Resting on a Soil Layer over Rigid Rock using Cone Model

P K Pradhan, Associate Member

Dr D K Baidya, Non-member

Dr D P Ghosh, Non-member

In this paper, the impedance functions for a rigid massless circular foundation resting on a viscoelastic soil layer underlain by rigid rock under vertical harmonic excitation are found using one-dimensional wave propagation in cones taking into consideration the reflections at layer-rigid base interface and free surface, based on the theory of strength of materials. Linear hysteretic material damping independent of frequency is introduced by using correspondence principle. The frequency-amplitude response of a massive foundation is then found using impedance functions in the dynamic equations of equilibrium. Both static and dynamic response of the foundation predicted by the model compare well with the published results. Finally, for experimental verification of the model, the predicted resonant frequencies are compared with reported experimental results arrived from a total of 84 model footing vibration tests, which shows a good engineering accuracy (deviation of $\pm 15\%$) with a vast variation of influencing parameters. Thus, the novel method is accurate and compared to rigorous procedures based on three-dimensional elastodynamics, it is easier to apply, provides conceptual clarity and physical insight in the wave propagation mechanism and offers a cost effective tool in the design of foundations under dynamic loads.

Keywords: Circular foundation; Dynamic response; Impedance functions; Resonant frequency; Wave propagation; Layered soil; Material damping

NOTATION

| | | | |
|----------|---|-------------------------------------|--|
| a_0 | : dimensionless frequency | m | : mass of the foundation or total vibrating mass (mass of foundation plus machine in case of machine foundation) |
| B | : non-dimensional modified mass ratio | m_e | : unbalanced mass (on machine) |
| b_9 | : non-dimensional mass ratio | P_0 | : harmonic interaction force |
| c | : appropriate wave velocity | r_0 | : radius of circular foundation or radius of equivalent circle for non-circular foundation |
| $c(a_0)$ | : normalized damping coefficient | u_0 | : harmonic surface displacement for the layer |
| c_p | : dilatational wave velocity | \bar{u}_0 | : harmonic surface displacement for homogeneous half-space |
| c_s | : shear wave velocity | $ u_0 $ | : displacement amplitude for the layer |
| d | : depth of the soil layer | $\left \frac{u_0 Gr_0}{F} \right $ | : non-dimensional amplitude |
| $ F $ | : force amplitude on the foundation | θ | : angle for setting eccentricity in the oscillator |
| $F(t)$ | : harmonic force on foundation | ν | : Poisson's ratio of the soil |
| G | : shear modulus of soil | ξ | : hysteretic material damping ratio |
| $K(a_0)$ | : dynamic impedance | ρ | : mass density of soil |
| K_s | : static stiffness coefficient of foundation on homogeneous half-space | ω | : circular frequency of excitation |
| K_{SL} | : static stiffness coefficient of foundation on layer-rigid base system | | |
| $k(a_0)$ | : normalized stiffness coefficient | | |

P K Pradhan, Dr D K Baidya and Dr D P Ghosh are with the Civil Engineering Department, IIT, Kharagpur 721 302.

This paper was received on November 19, 2003. Written discussion on this paper will be received till January 31, 2005.

INTRODUCTION

The determination of resonant frequency and resonant amplitude of foundations has been a subject of considerable interest in the recent years, in relation to the design of machine

foundations, as well as the seismic design of important massive structures, such as, nuclear power plants. One of the key steps in the current methods of dynamic analysis of a foundation soil system to predict resonant frequency and amplitude under machine type loading is to estimate the dynamic impedance functions of an 'associated' rigid but massless foundation, using a suitable method of dynamic analysis. Over the years a number of methods have been developed for foundation vibration analysis, the extensive reviews of which are presented in Gazetas¹.

The soil in natural state is rarely homogeneous and it can exist in a state with a hard rock at shallow depth, consisting of different strata with different properties. Bycroft² first presented the solution for vibration for footing on a layered medium. The vertical vibration response of a circular footing on the surface of an elastic layer underlain by a rigid base was evaluated by Warburton³. He studied the effect of an elastic layer on the resonant frequency of the footing for two values of Poisson's ratio. Gazetas and Rosset⁴ have developed a solution for the vertical vibration response of a strip footing on the surface of an elastic soil layer overlying rock. They showed that the presence of a thin layer tends to increase the resonant frequency and amplitude compared to the half-space values. Based on variational principle and minimization of energy using Hamilton's principle Asik and Vallabhan⁵ computed the response of rigid strip and circular machine foundations resting on an elastic layer over rigid rock. Luco⁶, Kausel, *et al*⁷, Hadjian and Luco⁸, Kagawa and Kraft⁹, Tassoulas and Kausel¹⁰, Wong and Luco¹¹ to name a few, also considered the effect of layering or non-homogeneity in their analyses. Most of these works were confined to analytical or semi-analytical type.

Gazetas and Stokoe¹² discussed different types of experimental investigation related to vibrating foundations and also discussed the relative merits and limitations of each method. They also indicated that the case histories and field experiments are the best, since the propagation of elastic waves is not interrupted by the presence of artificial lateral boundaries as in laboratory tests. Studies by Baidya and Muralikrishna^{13,14} and Baidya and Sridharan¹⁵ can be mentioned as some of the recent important experimental works on layered soil.

The cone model was originally developed by Ehlers¹⁶ to represent a surface disk under translational motions and later for rotational motion¹⁷⁻¹⁸. Meek and Wolf¹⁹ presented a simplified methodology to evaluate the dynamic response of a base mat on the surface of a homogeneous half-space. The cone model concept was extended to a layered cone to compute the dynamic response of a footing or a base mat on a compressible soil layer resting on a rigid rock²⁰, and on flexible rock²¹. Wolf and Meek²² have found out the dynamic stiffness coefficients of foundations resting on or embedded in a horizontally layered soil using cone frustums. Also Jaya and Prasad²³ studied the dynamic stiffness of embedded foundations in layered soil using the same cone frustums. The major drawback of cone frustums method as reported by Wolf and Meek²² is that the damping coefficient can become negative at lower frequency, which is physically impossible. Pradhan, *et al*²⁴ have

computed dynamic impedance of circular foundation resting on layered soil using wave propagation in cones, which overcomes the drawback of the above cone frustum method. The details of the use of cone models in foundation vibration analysis are summarized in Wolf²⁵.

For foundation vibration analyses simple models, which fit the size and economics of the project and require no sophisticated computer code are sometimes better suited. For instance the cone models, which provide conceptual clarity with physical insight and is easier for the practicing engineers to follow. From the literature review it is found that the cone models available for layered soil (layered cone and cone frustum method) have got some drawbacks and limitations. Also to the best of authors' knowledge no literature is available with regard to the experimental validation of cone model. Hence, in the present investigation the dynamic response of the foundation resting on a soil layer over half-space under vertical harmonic excitation is found using wave propagation in cones, eliminating drawback of earlier cone models. The validity of the model is checked against reported rigorous analytical and experimental results.

PROBLEM FORMULATION

A rigid massless circular foundation of radius r_0 resting on the surface of a soil layer underlain by a rigid base is addressed for vertical degree of freedom (Figure 1). The layer with depth d has the shear modulus G , Poisson's ratio ν , mass density ρ and hysteretic damping ratio ξ . The interaction force $P_0(t)$ and the corresponding displacement $u_0(t)$ are assumed to be harmonic. The dynamic behaviour of the massless foundation (disk) is expressed by the dynamic impedance

$$K(a_0) = \frac{P_0(t)}{u_0(t)} = K_S [k(a_0) + ia_0 c(a_0)] \quad (1)$$

where $k(a_0)$ is the spring coefficient; $c(a_0)$, damping coefficient; $a_0 = \omega r_0 / c_s$, dimensionless frequency and $c_s = \sqrt{G/\rho}$, shear wave velocity of the layer; and $K_S = 4Gr_0 / (1 - \nu)$, static stiffness coefficient of circular disk on homogeneous half-space with material properties of the layer.

Using the equations of dynamic equilibrium the dynamic displacement amplitude of the foundation with mass m and

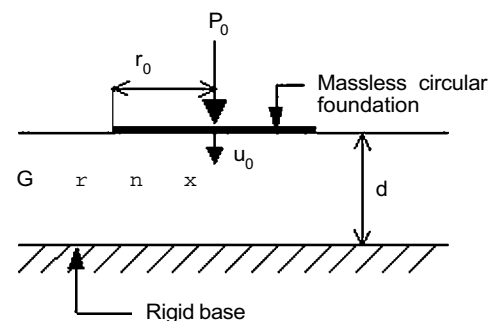


Figure 1 Massless foundation on soil layer over rigid base under vertical harmonic interaction force

subjected to a vertical harmonic force $F(t)$ is expressed as

$$|u_0| = \left| \frac{F}{K_S [k(a_0) + ia_0 c(a_0) - Ba_0^2]} \right| \quad (2)$$

where $|u_0|$ is the dynamic displacement amplitude under the foundation resting on the layer; $|F|$, force amplitude; and $B = b_0(1 - \nu)/4$, with $b_0 = m / \rho r_0^3$, the mass ratio, m being total mass of foundation (includes mass of machine in case of machine foundation) and ρ , mass density of soil layer.

In general, $|F|$ can be assumed to be constant or equal to $m_e e \omega^2$ which is created by the vibratory machine, where m_e is the unbalanced mass and e is the eccentricity.

Expressing the dynamic displacement amplitude given in equation (2) in the non-dimensional form

$$\left| \frac{u_0 G r_0}{F} \right| = \frac{1 - \nu}{4} \left| [k(a_0) + ia_0 c(a_0) - Ba_0^2] \right|^{-1} \quad (3)$$

WAVE PROPAGATION IN CONES

Figure 2 shows a massless foundation of radius r_0 resting on a layer underlain by a rigid base under vertical dynamic

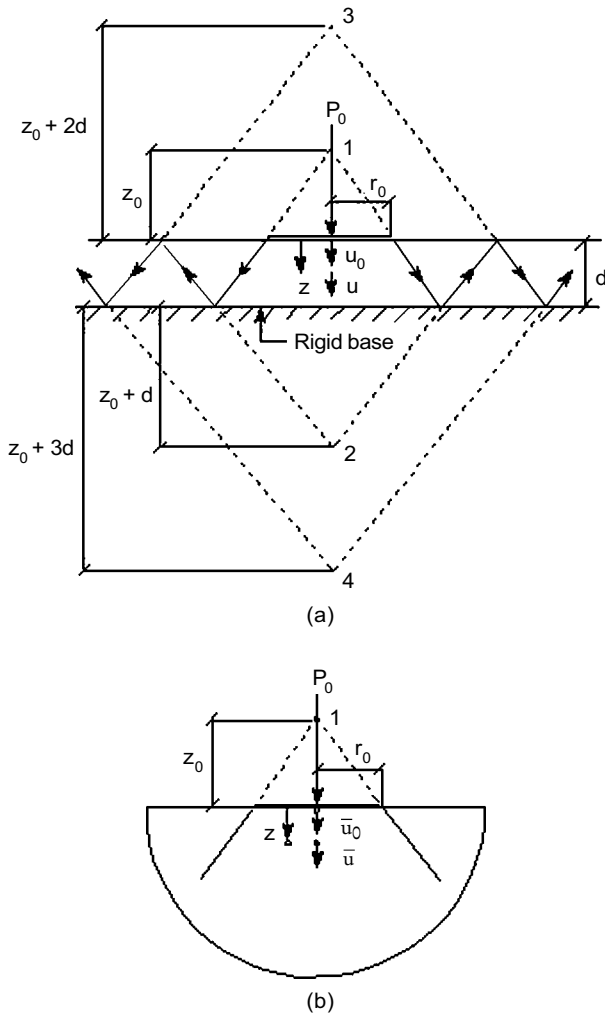


Figure 2 (a) Wave propagation in cones for the layer; and (b) Cone model for the half-space

excitation $P_0(t)$. The waves emanate beneath the disk and propagate at velocity c (Table 1), reflecting back and forth at the rigid base and free surface, spreading and decreasing in amplitude. Let the displacement of the (truncated semi-infinite) cone modelling a disk with same load $P_0(t)$ on a homogeneous half-space with the material properties of the layer be denoted as \bar{u} with the value \bar{u}_0 under the disk. This displacement \bar{u}_0 is used to generate the displacement of the layer u with its surface value u_0 . Thus, \bar{u}_0 can also be called as the generating function. The first downward wave propagating in a cone with apex 1 (height z_0 and radius of base r_0) from the base of the disk under the vertical excitation $P_0(t)$ may be called as the incident wave, the displacement amplitude of which is inversely proportional to the distance from the apex of the cone and expressed as

$$u(z, t) = \frac{z_0}{z_0 + z} \bar{u}_0 \left(t - \frac{z}{c} \right) \quad (4)$$

The displacement of the incident wave at rigid base equals

$$u(d, t) = \frac{z_0}{z_0 + d} \bar{u}_0 \left(t - \frac{d}{c} \right) \quad (5)$$

Enforcing the boundary condition that the displacement at rigid base vanishes, the displacement of the first reflected upward wave propagating in a cone with apex 2

$$- \frac{z_0}{z_0 + 2d - z} \bar{u}_0 \left(t - \frac{2d}{c} + \frac{z}{c} \right) \quad (6)$$

At the free surface the displacement of the upward wave derived by substituting $z = 0$ in equation (6) equals

$$- \frac{z_0}{z_0 + 2d} \bar{u}_0 \left(t - \frac{2d}{c} \right) \quad (7)$$

Enforcing compatibility of the amplitude and of argument of the reflected wave's displacement at the free surface, the displacement of the downward wave propagating in a cone with apex 3 is formulated as

$$- \frac{z_0}{z_0 + 2d + z} \bar{u}_0 \left(t - \frac{2d}{c} - \frac{z}{c} \right) \quad (8)$$

In this pattern the waves propagate in their own cones and their corresponding displacements are found out. The superposition of all the down and up waves gives the resulting displacement in the layer

$$u(z, t) = \frac{z_0}{z_0 + z} \bar{u}_0 \left(t - \frac{z}{c} \right) + \sum_{j=1}^{\infty} (-1)^j \left[\frac{z_0 \bar{u}_0 \left(t - \frac{2jd}{c} + \frac{z}{c} \right)}{z_0 + 2jd - z} + \frac{z_0 \bar{u}_0 \left(t - \frac{2jd}{c} - \frac{z}{c} \right)}{z_0 + 2jd + z} \right] \quad (9)$$

where j is the number of impingements at the rigid boundary.

At the rigid base $u_d(t) = u(d, t)$ vanishes as required by the rigid base boundary condition and at the free surface the displacement of the foundation is obtained by setting $z = 0$ in equation (9).

$$u_0(t) = u(0, t) = \bar{u}_0(t) + 2 \sum_{j=1}^{\infty} \frac{(-1)^j}{1 + \frac{2jd}{z_0}} \bar{u}_0\left(t - \frac{2jd}{c}\right) \quad (10)$$

$$u_0(t) = \sum_{j=0}^{\infty} E_j^F \bar{u}_0\left(t - \frac{2jd}{c}\right) \quad (11)$$

with

$$E_0^F = 1 \quad (12(a))$$

and for $j \geq 1$

$$E_j^F = \frac{2(-1)^j}{1 + \frac{2jd}{z_0}} \quad (12(b))$$

E_j^F can be called as echo constant, the inverse of which gives the static stiffness of the layer normalized by the static stiffness of the homogeneous half-space with material properties of the layer.

Applying Fourier transformation the above equation (11) and solving for $\bar{u}_0(\omega)$

$$\bar{u}_0(\omega) = H(\omega) u_0(\omega) \quad (13)$$

where $H(\omega)$ is the displacement transfer function and is given by

$$H(\omega) = \frac{1}{\sum_{j=0}^{\infty} E_j^F e^{-i\omega\left(\frac{2jd}{c}\right)}} \quad (14)$$

DYNAMIC IMPEDANCE

The interaction force displacement relationship for homogeneous half-space can be written as

$$P_0(\omega) = (K_S - \Delta M \omega^2 + i \omega C) \bar{u}_0(\omega) \quad (15)$$

where $K_S - \Delta M \omega^2$ is the spring coefficient and C , dashpot coefficient.

ΔM is the trapped mass and is given by

$$\Delta M = \mu \rho r_0^3 \quad (16)$$

with trapped mass coefficient μ , the values of which are given in Table 1.

Simplifying equation (15)

$$P_0(\omega) = K_S \left(1 - \frac{\mu}{\pi} \frac{z_0 r_0}{c^2} \omega^2 + i \omega \frac{z_0}{c}\right) \bar{u}_0(\omega) \quad (17)$$

Table 1 The parameters of semi-infinite cone, modelling a disk on homogeneous half-space under vertical motion²⁵

| Cone Parameters | Parameter Expressions |
|---|--|
| Aspect ratio $\frac{z_0}{r_0}$ | $\frac{\pi}{4} (1-\nu) \left(\frac{c}{c_s}\right)^2$ |
| Static stiffness coefficient K | $\frac{\rho c^2 (\pi r_0^2)}{z_0}$ |
| Normalized spring coefficient $k(a_0)$ | $1 - \frac{\mu}{\pi} \frac{z_0}{r_0} \frac{c_s^2}{c^2} a_0^2$ |
| Normalized damping coefficient $c(a_0)$ | $\frac{z_0}{r_0} \frac{c_s}{c}$ |
| Dimensionless frequency a_0 | $\frac{\omega r_0}{c_s}$ |
| Coefficient μ for trapped mass contribution | $\mu = 0$ for $\nu \leq 1/3$ $\mu = 2.4\pi \left(\nu - \frac{1}{3}\right)$ for $1/3 \leq \nu \leq 1/2$ |
| Appropriate wave velocity c | $c = c_p$ for $\nu \leq 1/3$ $c = 2c_s$ for $1/3 < \nu \leq 1/2$ where $c_p = c_s \frac{2(1-\nu)}{1-2\nu}$ |

Using equations (13) and (14) in equation (17), the interaction force displacement relationship for the layer-rigid base system becomes

$$P_0(\omega) = K_S \frac{1 - \frac{\mu}{\pi} \frac{z_0 r_0}{c^2} \omega^2 + i \omega \frac{z_0}{c}}{\sum_{j=0}^{\infty} E_j^F e^{-i\omega\left(\frac{2jd}{c}\right)}} u_0(\omega) \quad (18)$$

Substituting echo constant given in equation (12) in equation (18), the dynamic impedance equals

$$P_0(\omega) = K_S \frac{1 - \frac{\mu}{\pi} \frac{z_0 r_0}{c^2} \omega^2 + i \omega \frac{z_0}{c}}{\sum_{j=0}^{\infty} E_j^F e^{-i\omega\left(\frac{2jd}{c}\right)}} u_0(\omega) \quad (19)$$

RESULTS AND DISCUSSION

Comparison of Static Stiffness

In the static case, the normalized stiffness of the layer found using the model for three different values of Poisson's ratio and for different values of the depth of the layer are compared with the published results of Gazetas¹, which shows a very good agreement (Table 2). The maximum deviation of predicted stiffness, i.e., 7.68% is observed at lower depth of the layer ($d/r_0 = 1$) for incompressible soil ($\nu = 0.5$).

Table 2 Comparison of normalized static stiffness of the layer

| Layer depth, d/r_0 | Normalized static stiffness, K_{SL}/Gr_0 | | | | | |
|----------------------|--|---------------|----------------|---------------|----------------|---------------|
| | $\nu = 0$ | | $\nu = 0.3$ | | $\nu = 0.5$ | |
| | Present Method | Gazetas, 1983 | Present Method | Gazetas, 1983 | Present Method | Gazetas, 1983 |
| 1 | 8.42 | 9.12 | 13.39 | 13.03 | 16.84 | 18.24 |
| 2 | 6.20 | 6.56 | 9.58 | 9.37 | 12.41 | 13.12 |
| 3 | 5.46 | 5.70 | 8.27 | 8.15 | 10.91 | 11.41 |
| 4 | 5.09 | 5.28 | 7.62 | 7.54 | 10.17 | 10.56 |
| 5 | 4.87 | 5.02 | 7.24 | 7.18 | 9.73 | 10.04 |
| 6 | 4.72 | 4.85 | 6.98 | 6.94 | 9.44 | 9.70 |

Comparison of Impedance Functions

A layer resting on rigid base is examined with $d = 2r_0$, $\nu = 1/3$ and $\xi = 0.05$. The impedance functions normalized by $K_{SL} (1 + 2i\xi)$ with K_{SL} , the static stiffness of the layer-rigid base system and ξ , hysteretic material damping ratio, are found using the cone model and compared with the results of Gazetas¹ obtained by a rigorous analytical method, as shown in Figure 3. Excellent agreement is observed in both spring coefficient and damping coefficient in the lower frequency range. But in the higher frequency range the trends of the predicted spring and damping coefficients are found to be almost same though there is some deviation.

Comparison of Resonant Frequency

Also, the validity of the model is checked comparing the predicted resonant frequencies with the published analytical as well as experimental results. It is seen that for $\nu = 1/4$, the variation of non-dimensional resonant frequency with mass ratio is in good agreement with rigorous analytical results of Warburton³ based on constant force amplitude for all the five values of d/r_0 (Figure 4), as the maximum difference is within 5%.

The resonant frequency predicted by the model is compared quantitatively with the experimentally observed values of Baidya and Muralikrishna¹³. They studied the dynamic

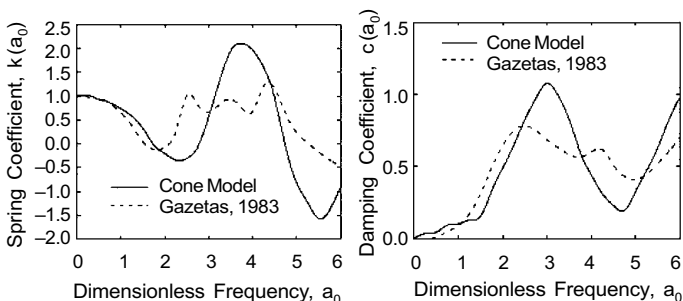


Figure 3 Comparison of normalized impedance functions ($d = 2r_0$, $\nu = 1/3$ and $\xi = 0.05$)

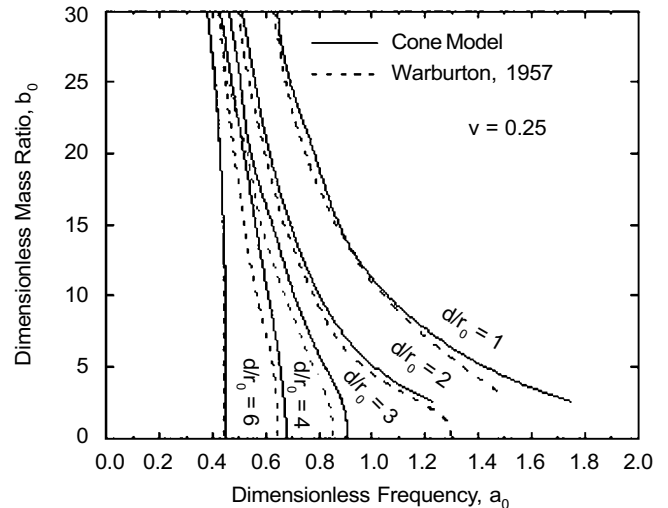


Figure 4 Comparison of resonant frequency with Warburton's results

response of a foundation resting on a layer underlain by a rigid base by conducting vertical vibration tests using a model concrete footing of size 400 mm \times 400 mm \times 100 mm and a mechanical oscillator (Lazan type) with different static weights and different force levels. Sand and sawdust were used as material of the layer. For each material six different depths of layer were used ($d/r_0 = 1.77, 2.66, 3.55, 4.43, 5.32$ and 5.98). Static weights of 8.0 kN and 8.9 kN for sand layer and 4 kN and 4.9 kN for sawdust layer were used. Tests on sand layer were conducted at four different force levels, *ie*, eccentricity $\theta = 8^\circ, 10^\circ, 12^\circ$ and 14° . For sawdust layer three force levels ($\theta = 4^\circ, 8^\circ$ and 12°) were applied. Thus, a total of 84 tests were conducted. The frequency dependent dynamic force amplitude in N was expressed by

$$m_e e \omega^2 = \frac{W_e e}{g} \omega^2 = \frac{0.9 \sin(\theta/2)}{g} \omega^2 \quad (20)$$

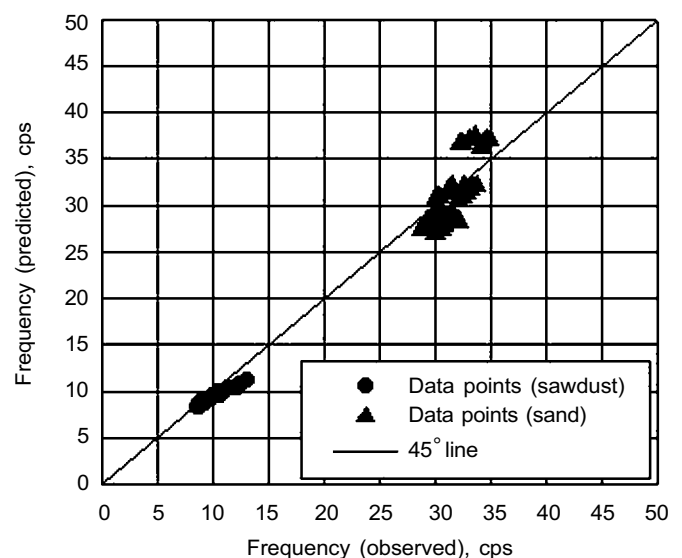


Figure 5 Comparison of resonant frequency with experimental results

Table 3 Shear modulus values for sand and sawdust¹³

| Static Weight, kN | Eccentric Angle, θ | Shear Modulus (G), kN/m ² | |
|-------------------|---------------------------|--------------------------------------|---------|
| | | Sand | Sawdust |
| 8.0 | 8° | 19473 | — |
| | 10° | 19346 | — |
| | 12° | 19028 | — |
| | 14° | 18491 | — |
| 8.9 | 8° | 19664 | — |
| | 10° | 19219 | — |
| | 12° | 19155 | — |
| | 14° | 18837 | — |
| 4.0 | 4° | — | 1354 |
| | 8° | — | 1288 |
| | 12° | — | 1260 |
| 4.9 | 4° | — | 1578 |
| | 8° | — | 1465 |
| | 12° | — | 1381 |

Note : $\gamma_{\text{sand}} = 17 \text{ kN/m}^3$; $\gamma_{\text{sawdust}} = 2.6 \text{ kN/m}^3$;
 $\nu_{\text{sand}} = 0.3$ (assumed) ; and $\nu_{\text{sawdust}} = 0.0$ (assumed)

Experimentally evaluated shear modulus values reported by Baidya and Muralikrishna¹³ are shown in Table 3. Resonant frequencies are predicted using the proposed model for the above 84 tests (assuming material damping ratio $\xi = 0.05$) and compared with experimental results which is shown in Figure 5. This figure indicates that the predicted resonant frequencies match well with observed values. Maximum difference between predicted and observed values is found for the stiffer layer (sand) and at the lowest value of the depth of layer considered ($d/r_0 = 1.77$).

CONCLUSIONS

In contrast to rigorous methods, which address the very complicated wave pattern consisting of body waves and generalized surface waves working in wave number domain, the proposed method based on wave propagation in cones with reflection at layer-rigid base interface and free surface considers only one type of body wave for the vertical degree of freedom considered. The sectional property of the cones increases in the direction of wave propagation both downwards as well as upwards, preserving physical insight. Also, the model gives accurate results when compared against the few available comprehensive analytical solutions and experimental results from the literature. Thus, the model provides physical insight — which is often obscured by the complexity of rigorous numerical solutions, exhibit adequate accuracy, easier to use and offer a cost-effective tool for the design foundations under dynamic loads.

REFERENCES

1. G Gazetas. 'Analysis of Machine Foundation Vibrations: State-of-the-art.' *Soil Dynamics and Earthquake Engineering*, vol 2, no 1, 1983, pp 2-42.
2. G N Bycroft. 'Forced Vibrations of a Rigid Circular Plate on a Semi-infinite Elastic Space and on an Elastic Stratum.' *Philosophical Transactions of Royal Society of London*, vol 248, no A 948, 1956, pp 327-368.
3. G B Warburton. 'Forced Vibration of a Body on an Elastic Stratum.' *Journal of the Application Mechanics Transaction ASME*, 1957, pp 55-58.
4. G Gazetas and J M Rosset. 'Vertical Vibration of Machine Foundations.' *Journal of the Geotech Engineering ASCE*, vol 105, no 12, 1979, pp 1435-1454.
5. M Z Asik and C V J Vallabhan. 'A Simplified Model for the Analysis of Machine Foundations on a Non-saturated, Elastic and Linear Soil Layer.' *Computers and Structures*, vol 79, 2001, pp 2717-2726.
6. J E Luco. 'Impedance Functions for a Rigid Foundations on a Layered Medium.' *Nuclear Engineering and Design*, vol 31, 1974, pp 204-217.
7. E Kausel, J M Rosset and G Wass. 'Dynamic Analysis of Footings on Layered Media.' *Journal of the Engineering Mechanical, ASCE*, vol 101, no 5, 1975, pp 679-693.
8. A H Hadjian and J E Luco. 'On the Importance of Layering on Impedance Functions.' *Proceedings of Sixth WCEE*, New Delhi, 1997, pp 1675-1680.
9. T Kagawa and L M Kraft. 'Machine Foundations on Layered Soil Deposits.' *Proceedings of Tenth International Conference Soil Mechanical and Foundation Engineering, Stockholm*, vol 3, 1981, pp 249-252.
10. J L Tassoulas and E Kausel. 'Elements for the Numerical Analysis of Wave Motion in Layered Strata.' *International Journal for Numerical Meth in Engineering*, vol 19, 1983, pp 1005-1032.
11. H L Wong and J E Luco. 'Tables of Impedance Functions for Square Foundation on Layered Media.' *Soil Dynamics and Earthquake Engineering*, vol 4, no 2, 1985, pp 64-81.
12. G Gazetas and K H Stokoe II. 'Vibration of Embedded Foundations: Theory versus Experiment.' *Journal of Geotechnical Engineering ASCE*, vol 117, no 9, 1991, pp 382-1401.
13. D K Baidya and G Muralikrishna. 'Dynamic Response of Foundation on Finite Stratum — an Experimental Investigation.' *Indian Geotechnical Journal*, vol 30, no 4, 2000, pp 327-350.
14. D K Baidya and G Muralikrishna. 'Investigation of Resonant Frequency and Amplitude of Vibrating Footing Resting on a Layered Soil System.' *Geotechnical Testing Journal, ASTM*, vol 24, no 4, 2001, pp 409-417.
15. D K Baidya and A Sridharan. 'Foundation Vibration on Layered Soil System.' *Indian Geotechnical Journal*, vol 32, no 2, 2002, pp 235-257.
16. G Ehlers. 'The Effect of Soil Flexibility on Vibrating Systems.' *Beton and Eisen*, vol 41, nos 21/22, 1942, pp 197-203.
17. J W Meek and A S Veletsos. 'Simple Models for Foundations in Lateral an Rocking Motions.' *Proceedings of Fifth World Congress on Earthquake Engineering, Rome*, vol 2, 1974, pp 2610-2613.
18. A S Veletsos and V D Nair. 'Response of Torsionally Excited Foundations.' *Journal of Geotechnical Engineering Division, ASCE*, vol 100, 1974, pp 476-482.

19. J W Meek and J P Wolf. 'Cone Models for Homogeneous Soil.' *Journal of Geotechnical Engineering Division, ASCE*, vol 118, no 5, 1992a, pp 667-685.
20. J W Meek and J P Wolf. 'Cone Models for Soil Layer on Rigid Rock.' *Journal of Geotechnical Engineering Division, ASCE*, vol 118, no 5, 1992b, pp 686-703.
21. J P Wolf and J W Meek. 'Cone Models for a Soil Layer on Flexible Rock Half-space.' *Earthquake Engineering and Structural Dynamics*, vol 22, 1993, pp 185-193.
22. J P Wolf and J W Meek. 'Dynamic Stiffness of Foundation on or Embedded in Layered Soil using Cone Frustums.' *Earthquake Engineering and Structural Dynamics*, vol 23, 1994, pp 1079-1095.
23. K P Jaya and A M Prasad. 'Embedded Foundation in Layered Soil under Dynamic Excitations.' *Journal of Soil Dynamics and Earthquake Engineering*, vol 22, no 6, 2002, pp 485-498.
24. P K Pradhan, D K Baidya and D P Ghosh. 'Impedance Functions of Circular Foundation Resting on Layered Soil using Cone Model.' *Electronic Journal of Geotechnical Engineering*, vol 8, part B, 2003.
25. J P Wolf. 'Foundation Vibration Analysis using Simple Physical Models.' *Englewood Cliffs, NJ: Prentice-Hall*, 1994.

Submission of Manuscripts for IEI Journals

Authors desirous to publish technical papers in the Journal of the Institution under various engineering disciplines are requested to send the manuscript in quadruplicate accompanied by one soft copy in CD or floppy disk (text in MS-Word and figures in JPG or TIFF format) along with original illustrations/photographs. It may be noted that the evaluation process will not be initiated unless these requirements are fulfilled.