Evaluation of In Situ Effective Shear Modulus from Dispersion Measurements[a]

Discussion by George Gazetas[3]

This paper addressed the issue of properly interpreting the results of steady-state (Rayleigh wave) surface vibration tests. For soil profiles in which the shear modulus increases monotonically and continuously with depth, such as the Karlsruhe campus site examined in the paper, the measured "dispersion" relationship of the associated Rayleigh waves [$C_R = C_R(\lambda_R)$] is in essence least-squares fitted with theoretical parametric dispersion curves to backfigure $G(z)$. It is concluded that for each frequency the Rayleigh-wave velocity C_R measured at the surface represents the soil stiffness "at [a] . . . depth of 0.3 λ_R, which is shallower than [the] $0.5\lambda_R$ hitherto used" (page 1585).

Clearly, this is a valid procedure for such soil profiles; and the authors are commended for a very informative presentation. In general, however, a more cumbersome iterative numerical-inversion scheme would be necessary for deposits consisting of several different soil layers, as is presently done in the so-called spectral analysis of surface waves method (e.g., Stokoe et al. 1989). This is especially true for deposits containing stiff upper layers underlain by softer soils (e.g. weathered-clay crust).

With this discussion I would like to bring to the attention of the authors the findings of two earlier publications, one theoretical and one experimental, that also recommended using an "equivalent" depth of about 1/3 rather than 1/2 wavelengths for Rayleigh waves in nonhomogeneous soils.

Specifically, Gazetas (1982) performed a numerical study of the dispersion relations of Rayleigh waves in a deep soil stratum with S-wave velocity increasing with depth in the form

$$V_s(z) = V_s(0)\left(1 + b\frac{z}{H}\right)^m \quad \text{(9)}$$

where the exponent m and the factor b were varied parametrically

$$m = 0, \frac{1}{4}, \frac{1}{2}, \frac{2}{3}, 1 \quad \text{(10)}$$

and

$$0 < b < 5 \quad \text{(11)}$$

Fig. 5 shows the variations of V_s with depth corresponding to the foregoing five values of m for $b = 3$.

For each frequency, the depth z_{eq} at which the S-wave velocity is equal to the corresponding velocity of the Rayleigh waves was determined and is plotted in Fig. 6 for the four nonhomogeneous profiles of Fig. 5. It is seen that the ratio of equivalent depth to wavelength, being a slightly decreasing function of frequency

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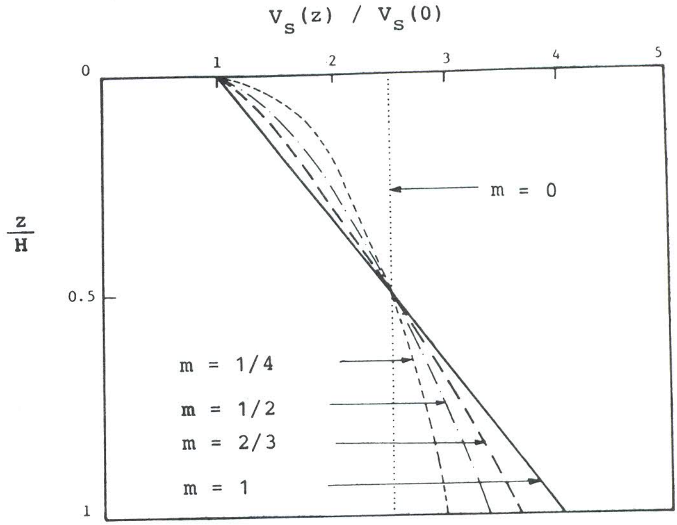

FIG. 5. Nonhomogeneous Soil Profiles Studied in Gazetas (1982)

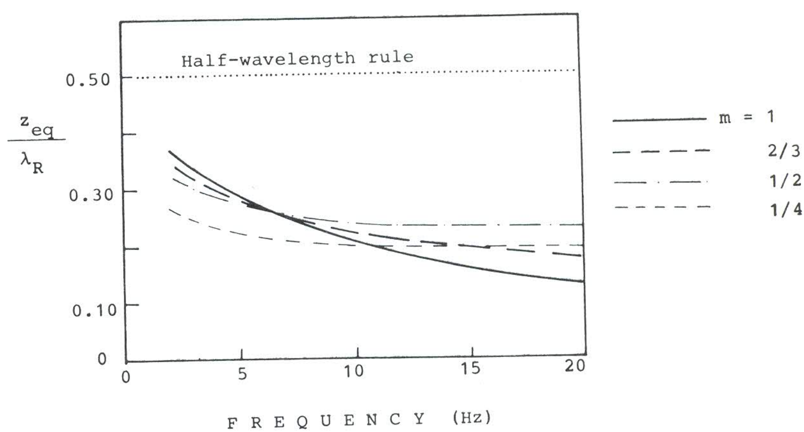

FIG. 6. Computed "Effective" Length over Raleigh Wavelength Ratio for Nonhomogeneous Profiles of Fig. 5, with $V_s(0)$ = 100 m/s; b = 3; and H = 100 m [from Gazetas (1982)]

attains an average value of about 0.25, essentially independent of the exact type of nonhomogeneity. This value is only half the usually recommended value (0.50). However, milder rates of heterogeneity lead to larger average values of the z_{eq}/λ_R ratio, closer to 0.50 . . . Therefore, one must be careful in deciding to what depth each value of C_R corresponds . . . It appears that a shallower depth than $z_{eq} = 0.5\lambda_R$ is more appropriate. For a realistic range of values of the rate of nonhomogeneity ($1 < b < 3$) an average value of $\lambda_R/3$ is recommended (Gazetas 1982).

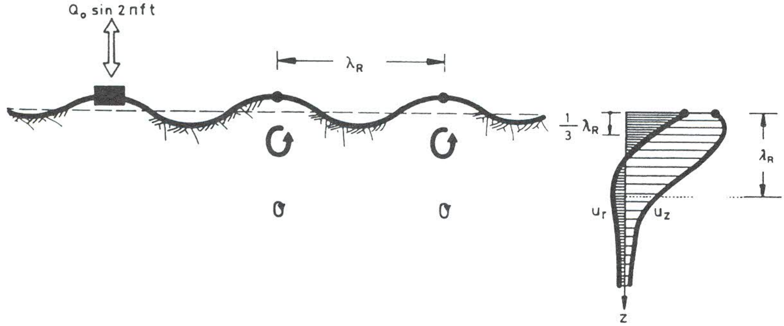

FIG. 7. Rayleigh Waves Generated during Steady-State Surface Vibration Testing Induce Nearly Triangularly Distributed Displacements (Gazetas 1987, 1991)

Based on several field experiments by Heisey et al. (1982), Stokoe and Nazarian (1985) also recommended a depth of 1/3 of the wavelength as the "effective depth of sampling" of the Rayleigh waves.

The foregoing recommendations, which are in qualitative accord with the conclusion of the discussed paper, have also found their way in textbooks [e.g., Gazetas (1987, 1991)]. In the classroom, the writer has found rather convincing the argument that for the nearly triangular R-wave displacement distribution (Fig. 7) the "effective" depth should equal the depth of the centroid ($\lambda_R/3$)—although with an arbitrarily layered soil profile this depth may attain a somewhat different value.

Appendix. References

Gazetas, G. (1982). "Vibrational characteristics of soil deposits with variable wave velocity." *Int. J. for Num. and Anal. Methods in Geomech.*, 6(1), 1–20.

Gazetas, G. (1987). *Soil dynamics notes* (in Greek). Nat. Tech. Univ., Athens, Greece.

Gazetas, G. (1991). "Foundation vibrations." *Foundation engineering handbook*, 2nd Ed., H. Y. Fang, ed., Van Nostrand Reinhold, New York, N.Y., 553–593.

Heisey, J. S., Stokoe, K. H., and Meyer, A. H. (1982). "Moduli of pavement systems from spectral analysis of surface waves." *Transp. Res. Record 852*, 22–31.

Stokoe, K. H. II, Rix, G. J., and Nazarian, S. (1989). "In situ seismic testing with surface waves." *Proc., 12th Int. Conf. Soil Mech. and Found. Engrg.*, A. A. Balkema, Rotterdam, The Netherlands 1, 331–334.

Stokoe, K. H., II, and Nazarian, S. (1985). "Use of Rayleigh waves in liquefaction studies." *Measurement and use of shear wave velocity*, R. D. Woods, ed., ASCE, New York, N. Y., 1–17.

Discussion by Glenn J. Rix,[4] Associate Member, ASCE

The authors presented a simplified method of inverting surface-wave dispersion data to obtain the initial tangent shear modulus profile. The method is based on the idea that the velocity of a surface wave with wavelength λ is related to the soil modulus at an equivalent depth, z_{eq}, equal to 0.3 λ. In developing the relationship between z_{eq} and λ, the authors assumed

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