MODULUS AND DAMPING OF SOILS DUE TO CYCLIC SHEAR[1]

by
B. O. Hardin
Professor of Civil Engineering
and
V. P. Drnevich
Assistant Professor of Civil Engineering
University of Kentucky

The aims of this research are to determine the shear modulus and damping of soils as functions of ambient confining stresses, soil type, void ratio, cycles of loading, strain amplitude, and frequency. Both undisturbed and disturbed samples are being tested. Soils range from the sensitive Leda clay of Canada to San Francisco sand.

Three different test apparatus were used. The first applied a pseudo-static cyclic shear stress (1/12 cycle per second) to a hollow cylindrical soil specimen. The second applied dynamic cyclic shear stress (30 to 100 cycles per second) to a hollow cylindrical specimen. The third applied dynamic cyclic shear stress (200 to 300 cycles per second) to triaxial type specimens.

As shearing strain amplitude approaches zero, the shear modulus approaches a maximum value which is given by

$$G_{max} = 1230\,(OCR)^{K}\,F(e)\;\bar{\sigma}_o^{\,1/2}$$

where: G_{max} is shear modulus at strains approaching zero, OCR is the over-consolidation ratio, K is a parameter related to the plasticity index, F(e) is given by $(2.973\text{-}e)^2 / (1 + e)$, e is the void ratio, and $\bar{\sigma}_o$ is the mean effective principal stress.

The shear moduli at larger strain amplitudes are related to G_{max}, the shearing strain amplitude, and the shear strength of the soil. The relationship is in the modified hyperbolic form.

For damping, a term D_{max}, the maximum damping ratio for a given soil can be determined. Because damping increases with shearing strain amplitude, D_{max} occurs at large amplitudes. The empirical equation for D_{max} is in the process of final preparation.

Based on data from many soils, it appears that damping and modulus for a soil can be related by the simple expression

$$G / G_{max} = 1 - (D / D_{max})$$

where G and D are the shear modulus at a given strain amplitude.

The more sophisticated analytical techniques such as viscoelasticity, finite elements, etc. are limited by the soil data used. With accurate modulus and damping data, these techniques can become useful for such soil-structure interaction problems as earthquake response, machine foundations, pavement behavior, and vibration isolation.

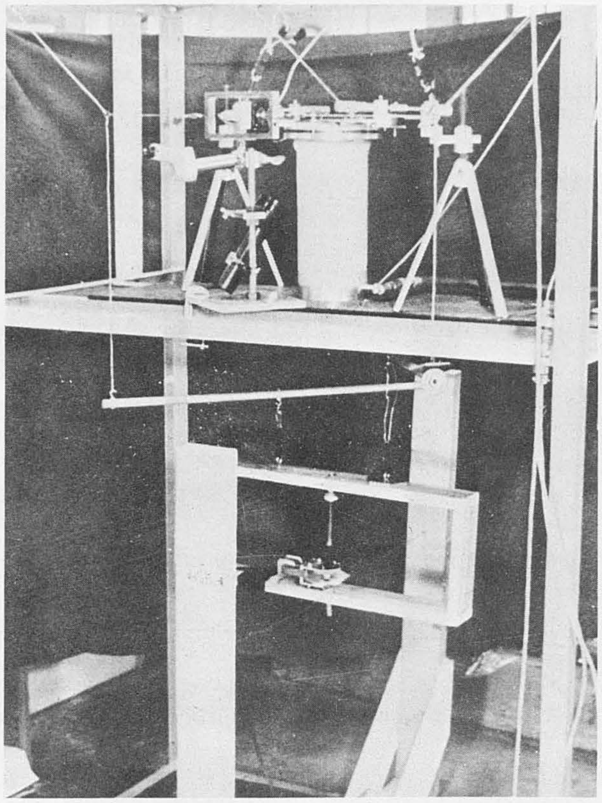


Figure 3. Static Hollow-Cylinder Shear Apparatus

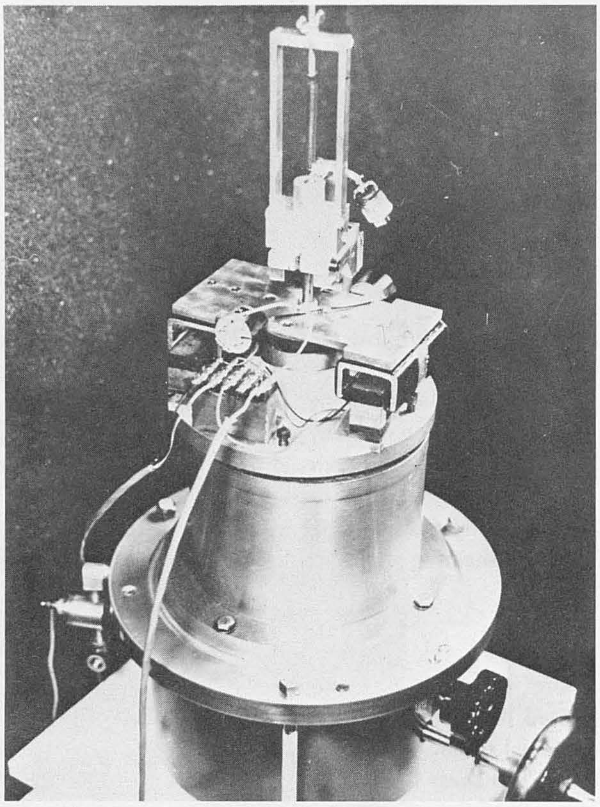
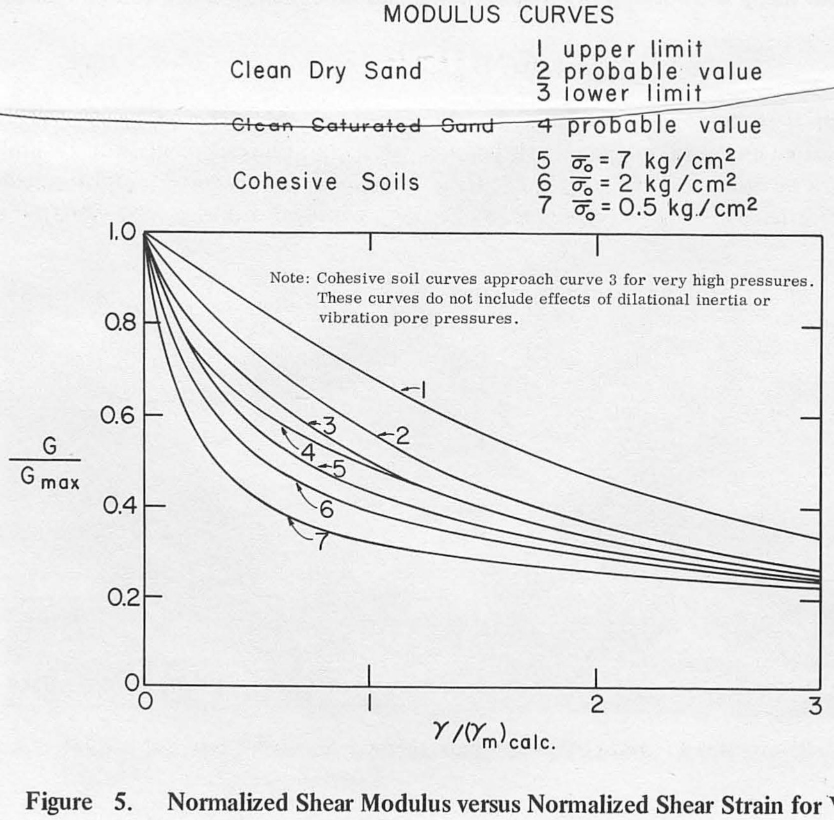
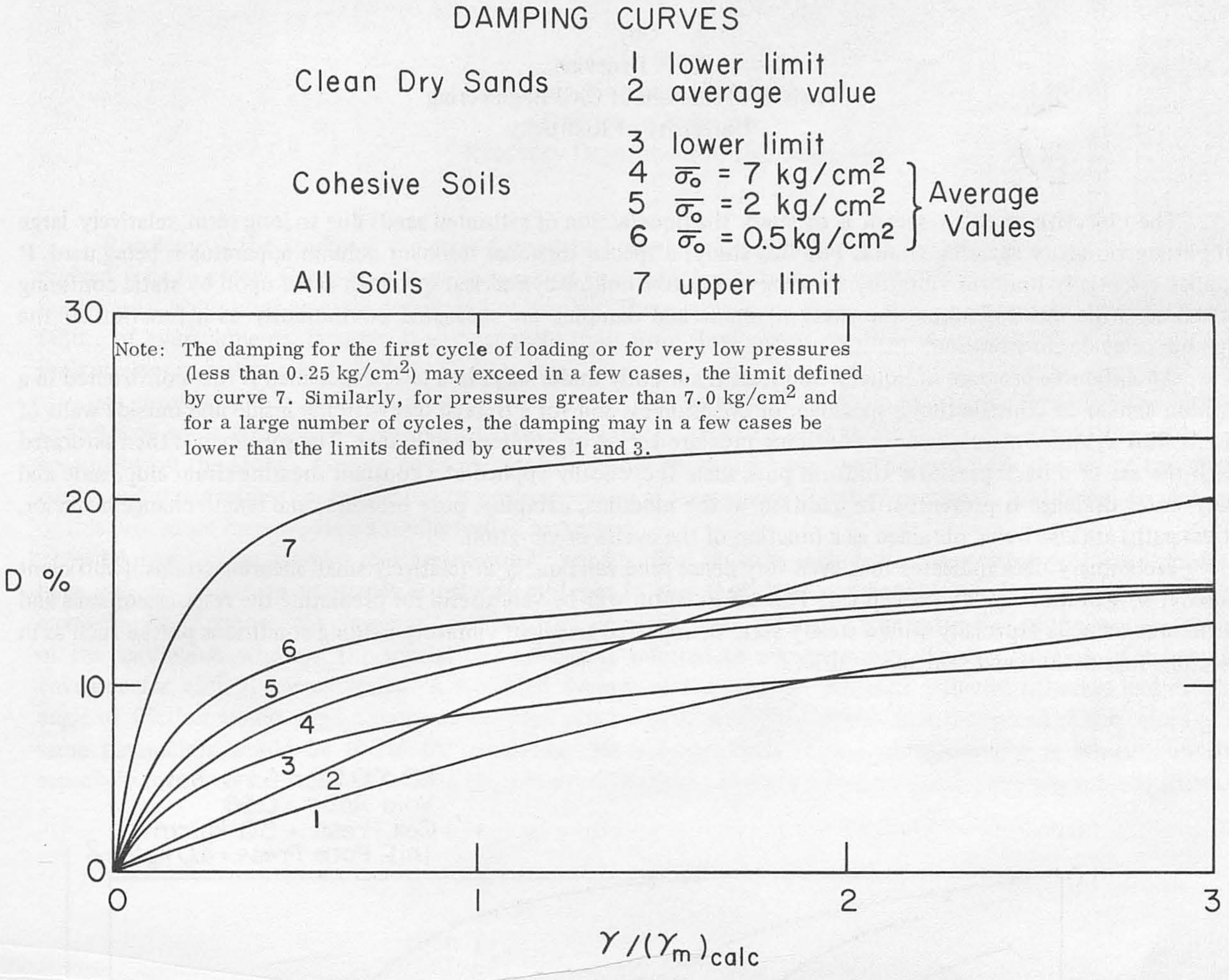


Figure 4. Hollow-Cylinder Resonant Shear Apparatus



Note: Cohesive soil curves approach curve 3 for very high pressures. These curves do not include effects of dilational inertia or vibration pore pressures.

Figure 5. Normalized Shear Modulus versus Normalized Shear Strain for Various Soils



Note: The damping for the first cycle of loading or for very low pressures (less than 0.25 kg/cm^2) may exceed in a few cases, the limit defined by curve 7. Similarly, for pressures greater than 7.0 kg/cm^2 and for a large number of cycles, the damping may in a few cases be lower than the limits defined by curves 1 and 3.

Figure 6. Damping Ratio versus Normalized Strain

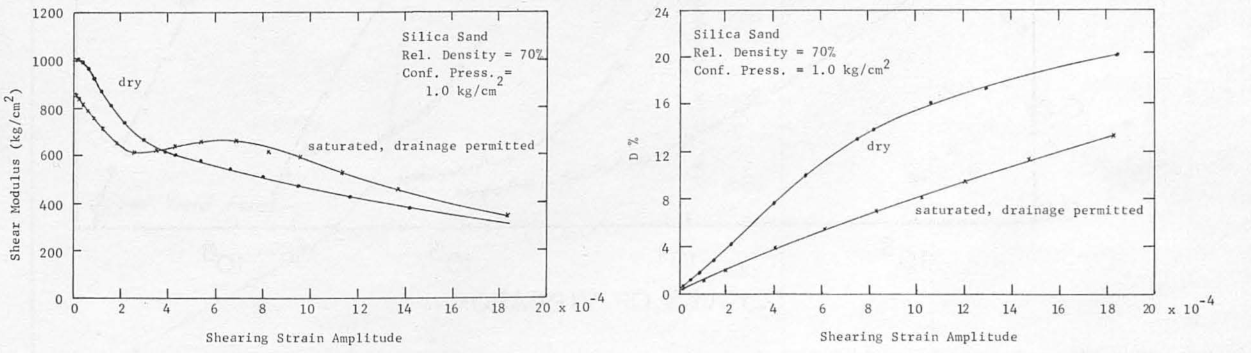


Figure 7. Shear Modulus and Damping versus Shearing Strain for Dry and Saturated Sands