Shear Modulus and Damping Relationships for Dynamic Analysis of Structures with Backfill Effect

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INTRODUCTION
Seismic events, as well as other types of dynamic loading, cause shear strain in the soil surrounding and supporting structures. Therefore the strain-dependent shear stiffness and shear damping of the soil are the required dynamic properties for dynamic analyses of structures that consider the Soil-Structure interaction effect. The dynamic properties of soil are often represented by the shear modulus, \( G \), and the damping ratio \( D \), which are related to spring stiffness and damper relationships used by some structural finite element programs. Many buildings include a substructure, which requires excavation and backfill to construct. A realistic soil interaction model may need to consider the backfill zone around the substructure as shown in Fig. 1.

OBJECTIVE
1) Summarize past research on the dynamic properties (particularly shear modulus and damping) of coarse-grained soils.
2) Develop a simple set of typical properties for coarse-backfill zone around the substructure as shown in Fig. 1.

METHODOLOGY
1) The results of many investigations of compacted or reconstituted coarse-grained soils were collected, including sand, gravel, and barrier soils with gravel contents ranged from 0 to 60%.
2) The tests results were collected with the primary purpose of finding the relationship between \( G_{\text{max}} \) and \( D_r \) over a range of different confining pressures. The relative density was provided directly by some of the studies or calculated based on the reported void ratios or dry unit weights. From the data reported by the studies, the relative density of the tested soils ranged from 5 to 100%.

RESULTS AND DISCUSSION
CORRELATION BETWEEN \( G_{\text{max}} \) AND \( D_r \)
An empirical correlation was developed to estimate the value of \( G_{\text{max}} \) in situations where more detailed properties of the soil are not available. A simple linear functional form was selected to represent the dependence of the normalized \( G_{\text{max}} \) on \( D_r \) as:

\[
\frac{G_{\text{max}}}{G_{\text{max}}^0} = (A D_r + B)\left(\frac{\rho}{\rho^0}\right)^{0.5} (1)
\]

where \( G_{\text{max}} \) is the maximum shear modulus, \( D_r \) is the relative density in percent, and \( P \) is the atmospheric pressure. Using linear regression, the constants \( A=4.932 \) and \( B=615.23 \) were fitted to the sand data in Fig. 2(a) and \( A=12.22 \) and \( B=633.08 \) were fitted to the gravel data in Fig. 2(b). The new regression curves have been proposed by others (e.g., [13],[14],[6]) as shown in Fig. 4, 5, and 6. Best-fit equations Eqn. 2, 3 and 4 were found by the regression to represent the change of the shear modulus for gravelly, sandy soils and the damping ratio respectively with the strain amplitude. These equations could be used for the numerical analysis of the structures with the effect of SSI.

\[
\frac{G}{G_{\text{max}}} = \frac{1}{1+1.6\gamma_{\text{ref}}} (\text{Gravel}) (2)
\]

\[
\frac{G}{G_{\text{max}}} = \frac{1}{1+0.6\gamma_{\text{ref}}} (\text{Sand}) (3)
\]

\[
D = 0.9 + 24(0.92 + 0.15\gamma_{\text{ref}}^{0.85})^{-0.95} (4)
\]

Where \( \gamma \) is the strain and \( \gamma_{\text{ref}} \) is the value of \( \gamma \) when \( G/G_{\text{max}} = 0.5 \).

CONCLUSION
1. Two simple linear correlations have been formed to distinguish between the typical behavior of the sand and the gravel using \( G \), as input data.
2. A modified hyperbolic equation is presented to represent the average curve of the nonlinear shear-stress-shear strain behavior of coarse-grained soil for use in the dynamic analysis of structures.
3. A modified form of the damping vs. shear strain curve is proposed for reconstituted sand and gravel that better fits the available data.

REFERENCES

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