South Carolina
Department of Transportation

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U.S. Department
of Transportation

Federal Highway
Administration

PROJECT SUMMARY

Report No. FHWA–SC–03–07
November 2003

South Carolina
Department of Transportation
P. O. Box 191
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Guide for Estimating the Dynamic Properties of South Carolina Soils for Ground Response Analysis

Overview

South Carolina is the second most seismically active region in the eastern U.S. The 1886 Charleston earthquake caused about 60 deaths and an estimated $23 million (1886 dollars) in damage. Future large earthquakes in the state are expected, and property damage during these events will likely exceed several billion dollars (FEMA, 2000).

An important step in the engineering design of new and the retrofit of existing structures in earthquake-prone regions is the prediction of strong ground motions. Required inputs for ground response analysis include the small-strain shear-wave velocity, the variation of normalized shear modulus with shear strain, and the variation of material damping ratio with shear strain for each soil layer beneath the site in question. Collectively, these inputs are known as the dynamic soil properties.

The guide addresses the need for procedures for estimating the dynamic properties of soils in South Carolina that can be used to improve current earthquake ground motion and site response maps of the state, as well as for site-specific response analysis. The procedures recommended in the guide were based on a review of earlier general procedures proposed for soils worldwide and a statistical analysis of existing data from South Carolina and surrounding states.

Estimating Small-Strain Shear-Wave Velocity

Empirical equations for estimating the small-strain shear-wave velocity, V_S, from the Cone Penetration Test (CPT) and the Standard Penetration Test (SPT) results were developed based on findings in earlier studies and 123 penetration-V_S data pairs from soil deposits in the South Carolina Coastal Plain. The recommended CPT-V_S equation for all soil types was expressed as:

$$V_S = 4.63 q_c^{0.342} I_c^{0.688} Z^{0.092} ASF$$

where q_c = the measured CPT tip resistance in kPa, I_c = the soil behavior type index, Z = the depth in meters, and ASF = an age scaling factor to account for higher V_S in older soil deposits. The recommended SPT-V_S equation for soils with fines content < 40 % was expressed as:

$$V_S = 72.9(N_{60})^{0.224} Z^{0.130} ASF$$

where N_{60} = the equipment-corrected SPT blow count. Both equations provide values of V_S in m/s.

Average values of *ASF* were determined to be 1.00 for Holocene-age (< 10,000 years) soils, 1.23 for Pleistocene-age (10,000 to 1.8 million years) soils, 1.38 for soils of the Dry Branch Formation, 1.65 for soils of the Tobacco Road Formation, and 2.29 for soils of the Ashley Formation. These *ASF* values indicated that V_S measurements in Pleistocene soils were on average 23 % higher than V_S measurements in Holocene soils with the same penetration resistances. For the three formations, which are 25-36 million years in age, V_S measurements were 38 % to 129 % greater than V_S measurements in Holocene soils with the same penetration resistances, and appeared to depend on the amount of carbonate in the soils.

Estimating Normalized Shear Modulus and Material Damping Ratio

Predictive equations for estimating normalized shear modulus, G/G_{max}, and material damping ratio, *D*, were developed using a modified hyperbolic model and results from Resonant Column and Torsional Shear tests on 122 samples from South Carolina, North Carolina and Alabama. The modified hyperbolic model was expressed as (Stokoe et al., 1999):

$$G / G_{\max} = 1/[1 + (g / g_r)^a]$$

where g = the shear strain, g_r = the reference shear strain, and a = an exponent called the curvature coefficient. The *D* curves were expressed by:

$$D = 12.2(G / G_{\max})^2 - 34.2(G / G_{\max}) + 22.0 + D_{\min}$$

where D_{min} = the minimum material damping ratio. The recommended values of g_r, a, and D_{min} depended on confining stress, plasticity index, and geology (see Table 3.3). The recommended values of D_{min} were developed using only Torsional Shear test data.

In general, the recommended G/G_{max} curve for Holocene soils with plasticity index (*PI*) = 0 followed the Seed et al. (1986) upper range curve for sand. The recommended G/G_{max} curves for older soils with *PI* = 0 generally followed the Seed et al. mean or lower range curves for sand. The recommended *D* curve for Holocene soils with *PI* = 0 followed the Seed et al. lower range curve for sand; and the recommended *D* curves for older soils with *PI* = 0 generally followed the Seed et al. mean curve for sand.

Recommendations for Future Studies

The database of dynamic soil properties compiled for the guide should be updated and expanded to include significant new data that are being generated each day. In particular, additional penetration-V_S data are critically needed for the residual soils and saprolites in the Piedmont, and the sediments in the Middle/Upper Coastal Plain. Also, more G/G_{max} and *D* data are critically needed from the sediments in the Lower Coastal Plain. Such a database would be a useful resource for SCDOT and other organizations working to reduce seismic hazards and improve construction practices in the State of South Carolina.

Ronald D. Andrus, Jianfeng Zhang, Brian S. Ellis, and C. Hsein Juang of Clemson University were the authors of the guide. Many organizations generously provided data considered during the development of the guide, in particular, SCDOT, S&ME, WPC, Gregg In Situ, Bechtel Savannah River, Georgia Tech, LawGibbs, NC State Univ., Parsons-Brinckerhoff, Santee Cooper, SC State Ports Authority, Trigon Engrg. Consultants, U.S. Army Corps of Engineers – Savannah District, Univ. of SC, and Wilbur Smith Associates. For further information, contact Terry Swygert at SCDOT: 803.737.6652; swygerttl@dot.state.sc.us