South Carolina
Department of Transportation

GLENN DEPARTMENT OF CIVIL ENGINEERING

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PROJECT SUMMARY

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Seismic Site Coefficients and Acceleration Design Response Spectra Based on Conditions in South Carolina

Overview

The State of South Carolina is vulnerable to earthquake disasters. Several major earthquakes have occurred in the South Carolina Coastal Plain during the past 6,000 years, including the 1886 Charleston earthquake with magnitude of ~7.0. Several moderate to light earthquakes have occurred in the South Carolina Piedmont, including the 1913 Union County and the 2014 Edgefield County earthquakes with magnitudes of ~5.2 and 4.1, respectively.

The simplified procedure in design codes for determining seismic loading on structures involves estimating site coefficients and using them to adjust available rock accelerations to local conditions. Several investigators have noted concerns with the site coefficients recommended in current codes, herein called the 1994 National Earthquake Hazard Reduction Program (NEHRP) site coefficients, including (1) the suitability of the 1994 NEHRP coefficients for conditions different from the Western United States; (2) the appropriateness of using a single coefficient for a wide range of soil stiffnesses; and (3) the suitability of using coefficients that are independent of depth to top of rock.

A systematic ground response study was conducted to determined seismic site coefficients appropriate for South Carolina. Over 60,000 total stress, one-dimensional equivalent linear and nonlinear ground response simulations were performed using a suite of over 130 synthetic rock outcrop motions and numerous shear wave velocity profiles representative of conditions at seven locations in the Coastal Plain and four locations in the Piedmont.

Findings

Results of the ground response analyses are compiled into over 400 plots of computed seismic site coefficients (F) versus average shear wave velocity in the top 100 ft (V_{S100ft}) grouped by site location, depth to top of soft rock ($H_{B\text{-}C}$) or top of hard rock (H_{HR}), spectral period (T), and spectral acceleration of the rock input motion ($S_{outcrop}$). In nearly all the plots, the following three distinct features can be seen—(1) an increasing trend in F as V_{S100ft} increases from zero; (2) a zone of peak values of F; and (3) a decreasing trend in F as V_{S100ft} increases to the velocity of the reference rock.

A new mathematical model for F that captures these three features is developed from the results of the ground response analyses. Development of the model starts by estimating the peak site coefficient (F_P) and the corresponding average shear wave velocity ($V_{S100ftP}$) for each plot. Next, the values of F_P and $V_{S100ftP}$ are studied to determine the most significant influencing variables. In addition to V_{S100ft}, $H_{B\text{-}C}$, H_{HR}, $S_{outcrop}$, mean predominant period of the rock input motion (T_m), and average shear wave velocity in the top 330 ft (V_{S330ft}) are found to be significant influential variables. Lastly, overall median relationships of F that are functions of F_P, $V_{S100ftP}$ and the most influential variables are derived from regression analysis.

Computed median relationships of F are found to be generally higher for the Piedmont than for the Coastal Plain. This difference can be explained by the fact that the Piedmont coefficients are referenced to hard rock (instead of soft rock) and because of the higher impedance contrasts between soil and hard rock.

Computed median relationships of F for spectral periods of 0.0, 0.2 and 1.0 s and soft rock conditions are compared with the 1994 NEHRP coefficients, which are also based on median values. The 1994 NEHRP coefficients are found to be often over conservative for NEHRP Site Class E sites; and sometimes un-conservative for NEHRP Site Class C and D sites, particularly where the top of rock lies at shallow depths. Based on the comparison, the median relationships of F developed in this study are recommended for seismic design in South Carolina.

Because the new site coefficient model is based on a very broad range of soil/rock conditions and general rock motion properties, it can be applied to other areas with similar geologic and seismic conditions. In areas outside of South Carolina, calibration or modification of model variables may be required.

The simplified procedure for determining acceleration design response spectrum (ADRS), sometimes called the 3-point ADRS method, is found to be generally valid when V_{S100ft} > 650 ft/s. However, when $V_{S100ft} \leq$ 650 ft/s, the results of this and other studies indicate that significant spectral peaks may occur at periods greater than 1.0 s. For this reason, it is recommended that a multi-point ADRS curve be plotted based on the results of this study with the 3-point ADRS to check if long-period spectral accelerations are under predicted. The objective of the multi-point ADRS is not to replace the design code philosophy, but to present an option for the designer to check that longer period accelerations are not under-predicted by the 3-point ADRS.

It is also found that 3-point ADRS curves predicted by the site coefficients for the Coastal Plain and the Piedmont are in good agreement when applied to sites near the boundary between the two regions (called the Fall Line), but can exhibit some differences. It is recommended that ADRS curves based on the Piedmont site coefficients be used at sites in the Piedmont and in the Coastal Plain near the Fall Line where H_{HR} < 330 ft; and the Coastal Plain site coefficients be used at sites in the Coastal Plain where $H_{HR} \geq$ 330 ft.

Finally, based on the analysis results of two sample bridges using the computer program SAP2000 or CSiBridge, both increases and decreases in structural demand with respect to the current practice (i.e., 1994 NEHRP coefficients) are observed when the site coefficients of this study are applied in the seismic loading inputs.

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