PROPOSAL 3-121 (2009)

SCOPE: Part 2, Commentary Chapter 21

PROPOSAL FOR CHANGE:

Add Chapter 21 to Part 2, of the 2009 Commentary:

Proposed Chapter is attached. Text is not underlined to allow easier review.

REASON FOR PROPOSAL:

One of the basic tasks of the 2009 NEHRP *Provisions* update is to develop a viable commentary to Part 1. Since Part 1 adopts ASCE 7-05 and lists any exceptions to it, the Commentary is developed in accordance with the format and sections of ASCE 7-05.

TS 3 VOTE:

YES ☐ *Yes with Reservations* *No ☐* *Not Voting ☐*

TS 3 developed this commentary chapter and approved for submission. The chapter was edited and is being reviewed by TS 3. No comments have been received as of issue of this ballot.

Chapter 21
SITE-SPECIFIC GROUND MOTION PROCEDURES FOR SEISMIC DESIGN

GENERAL

Site-specific procedures for computing earthquake ground motions include (1) dynamic site response analyses, and (2) probabilistic and deterministic seismic hazard analyses (PSHA and DSHA). Use of one or both procedures may be required in lieu of the general procedure in Sections 11.4.1 through 11.4.6. Section C11.4.7 explains why use of these procedures is required. Such studies must be comprehensive and incorporate current scientific interpretations. Because there is typically more than one scientifically credible alternative for models and parameter values used to characterize seismic sources and ground motions, it is important to formally incorporate these uncertainties in a site-specific analysis. For example, uncertainties may exist in seismic source location, extent and geometry; maximum earthquake magnitude; earthquake recurrence rate; ground-motion attenuation; local site conditions, including soil layering and dynamic soil properties; and possible two- or three-dimensional wave-propagation effects. The use of peer review for a site-specific ground-motion analysis is encouraged.

Where the intent is to perform both site response analysis and ground motion hazard analysis, two approaches are possible: separate two-step analysis, or direct analysis in one step.

In the first approach, a PSHA, and possibly a DSHA if the site is near an active fault, is used to compute a 5% damped response spectrum, which is taken as the outcrop bedrock motion. A representative set of acceleration time histories are then selected and scaled to be compatible with the bedrock response spectrum. Dynamic site-response analyses of these input time histories are used to compute motions at the ground surface. The response spectra of these surface motions are used to define an MCE response spectrum.

In the second approach, PSHA methods (and DSHA methods where required) are used to compute directly the ground-surface response spectrum. In this case, attenuation equations for computing soil-site response spectra (instead of bedrock response spectra) are input to the PSHA/DSHA.

Both of the approaches described above have advantages and disadvantages. In many cases, user preference governs the selection, but geotechnical conditions at the site may dictate the use of one approach over the other. On the one hand, if bedrock is at a depth much greater than the extent of the site geotechnical investigations, the one-step approach of computing the ground-surface motion in the PSHA/DSHA may be more reasonable. On the other hand, if bedrock is shallow and a large impedance contrast exists between it and the overlying soil (that is, density times shear-wave velocity of bedrock is much greater than that of the soil), the two-step approach might be more appropriate.

Use of peak ground acceleration as the anchor for a generalized site-dependent response spectrum is discouraged because sufficiently robust ground-motion attenuation relations are available for response spectra in western U.S. and eastern U.S. tectonic environments.

C21.1 SITE RESPONSE ANALYSIS

C21.1.1 Base Ground Motions. Acceleration time histories that are representative of horizontal rock motions at the site are required as input to the soil model. Where a site-specific ground motion hazard analysis is not performed the maximum considered earthquake (MCE) response spectrum for Site Class B (rock) is defined using the general procedure described in Section 11.4.1. If the model is terminated at material of Site Class A, C, or D, the input MCE response spectrum is adjusted in accordance with Section 11.4.3. The U.S. Geological Survey national seismic hazard mapping project website (http://geohazards.cr.usgs.gov/eq/) includes hazard deaggregation options that can be used to evaluate the predominant types of earthquake sources, magnitudes, and distances contributing to the probabilistic ground-motion hazard. Sources of recorded acceleration time histories include the databases of the Consortium of Organizations for Strong Motion Observation Systems (COSMOS) Virtual Data Center web site (db.cosmos-eq.org) and the Pacific Earthquake Engineering Research Center (PEER) Strong Motion Data Base website (http://peer.berkeley.edu/smcat/). Because the input response spectra are defined at the ground surface rather than at depth below a soil deposit, the time histories should be input in the analysis as outcropping motions rather than at the base of the soil model.

C21.1.2 Site Condition Modeling. Modeling criteria are established by site-specific geotechnical investigations that should include borings with sampling; standard penetration tests (SPTs), cone penetrometer tests (CPTs), and/or other subsurface investigative techniques; and laboratory testing to establish the soil types, properties, and layering. The depth to rock or stiff soil material should be established from these investigations. Investigation should extend to bedrock or, for very deep soil profiles, to material in which the model will be terminated While it is desirable to measure shear wave velocities in all soil layers, it is also possible to estimate shear wave velocities based on measurements available for similar soils in the local area or through correlations with soil types and properties. A number of such correlations are summarized by Kramer (1996).

Typically, a one-dimensional soil column extending from the ground surface to bedrock is adequate to capture first-order site response characteristics. For very deep soils, the model of the soil columns may extend to very stiff or very dense soils at depth in the column. Two- or three-dimensional models should be considered for critical projects when two or three-dimensional wave propagation effects may be significant (for example, in basins). The soil layers in a one-dimensional model are characterized by their total unit weights and shear wave velocities from which low-strain (maximum) shear moduli may be obtained, and by relationships defining the nonlinear shear stress-strain behavior of the soils. The required relationships for analysis are often in the form of curves that describe the variation of soil shear modulus with shear strain (modulus reduction curves) and by curves that describe the variation of soil damping with shear strain (damping curves). In a two- or three-dimensional model, compression wave velocities or moduli or Poisson ratios also are required. In an analysis to estimate the effects of liquefaction on soil site response, the nonlinear soil model also must incorporate the buildup of soil pore water pressures and the consequent reductions of soil stiffness and strength. Typically, modulus reduction curves and damping curves are selected on the basis of published relationships for similar soils (for example, Seed and Idriss, 1970; Seed et al., 1986; Sun et al., 1988; Vucetic and Dobry, 1991; Electric Power Research Institute, 1993; Kramer, 1996). Site-specific laboratory dynamic tests on soil samples to establish nonlinear soil characteristics can be considered where published relationships are judged to be inadequate for the types of soils present at the site. Shear and compression wave velocities and associated maximum moduli should be selected based on field tests to determine these parameters or on published relationships and experience for similar soils in the local area. The uncertainty in the selected maximum shear moduli, modulus reduction and damping curves, and other soil properties should be estimated.

C21.1.3 Site Response Analysis and Computed Results. Analytical methods may be equivalent linear or nonlinear. Frequently used computer programs for one-dimensional analysis include the equivalent linear program SHAKE (Schnabel et al., 1972; Idriss and Sun, 1992) and the nonlinear programs FLAC (Itasca, 1995), DESRA-2 (Lee and Finn, 1978), MARDES (Chang et al., 1991), SUMDES (Li et al., 1992), D-MOD (Matasovic, 1993), TESS (Pyke, 1992), and DESRAMUSC (Qiu, 1998). If the soil response is highly nonlinear (such as for high acceleration levels and soft soils), nonlinear programs may be preferable to equivalent linear programs. For analysis of liquefaction effects on site response, computer programs incorporating pore water pressure development (effective stress analyses) must be used (for example, FLAC, DESRA-2, SUMDES, D-MOD, TESS, and DESRAMUSC). Response spectra of output motions at the ground surface are calculated as are the ratios of response spectra of ground surface motions to input outcropping rock motions. Typically, an average of the response spectral ratio curves is obtained and multiplied by the input MCE response spectrum to obtain the MCE ground-surface response spectrum. Sensitivity analyses to evaluate effects of soil property uncertainties should be conducted and considered in developing the final MCE response spectrum.

C21.2 GROUND MOTION HAZARD ANALYSIS

Uncertainties in the characterizations of the key seismic sources (tectonic provinces, zones of seismicity, and active faults) with respect to location, earthquake recurrence, and maximum earthquake magnitude, must be considered in the ground motion hazard analysis. Uncertainties in the ground-motion models are typically included by incorporating more than one ground-motion attenuation equation. However, these equations may underestimate the intermediate- and long-period motion from large earthquakes on nearby active faults due to directivity and directionality effects mentioned in C11.4.7. The probabilistic seismic hazard analysis code can be modified to account for these effects in a consistent probabilistic manner, or a deterministic adjustment can be made to the probabilistic MCE response spectrum using methods in Somerville et al. (1997) or Abrahamson (2000). If the deterministic adjustment is used, then judgment must be exercised in selecting the parameters comprising these methods. The worst-case scenario yielding the maximum possible increase in motion from directivity/directionality effects is acknowledged to be conservative, but it offers an upper bound solution to help gauge the appropriate level for the MCE response spectrum.

Where site response analysis is not required, bedrock motions may be computed with a site-specific PSHA/DSHA, and then modified using the general procedure of Sections 11.4.2 through 11.4.6 to account for the effects of the local soil conditions.

C21.2.1 Probabilistic MCE

Probabilistic seismic hazard analysis (PSHA) methods are sufficient to define the probabilistic MCE ground motion at all locations except those near highly active faults. Descriptions of current PSHA methods can be found in McGuire (2004).

C21.2.2 Deterministic MCE

Ground motions for the deterministic MCE shall be based on characteristic earthquakes on all known active faults in a region. The magnitude of a characteristic earthquake on a given fault should be a best estimate of the maximum magnitude capable for that fault but not less than the largest magnitude that has occurred historically on the fault. The maximum magnitude should be estimated considering all seismic-geologic evidence for the fault, including fault length and paleoseismic observations. For faults characterized as having more than a single segment, the potential for rupture of multiple segments in a single earthquake should be considered in assessing the characteristic maximum magnitude for the fault.

For consistency, the same attenuation equations used in the PSHA should be used in the deterministic seismic hazard analysis (DSHA). Adjustments for directivity/directional effects should also be made, when appropriate. In some cases, ground-motion simulation methods may be appropriate for the estimation of long-period motions at sites in deep sedimentary basins or from great ($M \geq 8$) or giant ($M \geq 9$) earthquakes, for which recorded ground-motion data are lacking.

C21.2.3 Site-Specific MCE.

C21.3 DESIGN RESPONSE SPECTRUM

C21.4 DESIGN ACCELERATION PARAMETERS

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