Appendix C
GUIDELINES FOR CONDUCTION OF SITE-SPECIFIC GEOTECHNICAL INVESTIGATIONS AND DYNAMIC SITE RESPONSE ANALYSES

C.1 INTRODUCTION

As indicated in Article 3.4.2.3 and Tables 3.4.2.3-1 and -2, site coefficients F_a and F_v are not provided for Site Class F soils and site-specific geotechnical investigations and dynamic site response analyses are required for these soils. Guidelines are provided below for conducting site-specific investigations and site response analyses for Site Class F soils. These guidelines are also applicable if it is desired to conduct dynamic site response analyses for other soil types. Additional guidance on the topics addressed below is presented in a report by the Caltrans Seismic Advisory Board Ad Hoc Committee on Soil-Foundation-Structure-Interaction (CSABAC, 1999).

C.2 SITE-SPECIFIC GEOTECHNICAL INVESTIGATION

For purposes of obtaining data to conduct a site response analysis, site-specific geotechnical investigations should include borings with sampling, standard penetration tests (SPTs), cone penetrometer tests (CPTs), and/or other subsurface investigative techniques and laboratory soil testing to establish the soil types, properties, and layering and the depth to rock or rock-like material. It is desirable to measure shear wave velocities in all soil layers. Alternatively, shear wave velocities may be estimated based on shear wave velocity data 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).

C.3 DYNAMIC SITE RESPONSE ANALYSIS

Components of a dynamic site response analysis include: (1) modeling the soil profile; (2) selecting rock motions to input into the soil profile; and (3) conducting a site response analysis and interpreting the results.

1. Modeling the soil profile: Typically, a one-dimensional soil column extending from the ground surface to bedrock is adequate to capture first-order site response characteristics. However, two- to three-dimensional models may be considered for critical projects when two or three-dimensional wave propagation effects may be significant (e.g., in basins). The soil layers in a one-dimensional model are characterized by their total unit weights, shear wave velocities from which low-strain (maximum) shear moduli may be obtained and by relationships defining the nonlinear shear stress-strain relationships of the soils. The required relationships for analysis are often in the form of curves that describe the variation of shear modulus with shear strain (modulus reduction curves) and by curves that describe the variation of damping with shear strain (damping curves). In a two- or three-dimensional model, compression wave velocities or moduli or Poissons ratios are also required. In an analysis to estimate the effects of liquefaction on soil site response, the nonlinear soil model must also incorporate the buildup of soil pore water pressures and the consequent effects on reducing soil stiffness and strength. Typically, modulus reduction curves and

damping curves are selected on the basis of published relationships for similar soils (e.g., 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. The uncertainty in soil properties should be estimated, especially the uncertainty in the selected maximum shear moduli and modulus reduction and damping curves.

2. Selecting input rock motions: Acceleration time histories that are representative of horizontal rock motions at the site are required as input to the soil model. Unless a site-specific analysis is carried out to develop the rock response spectrum at the site, the Maximum Credible Earthquake (MCE) rock spectrum for Site Class B rock can be defined using the general procedure described in Article 7.4.1 or 8.4.1. For hard rock (Site Class A), the spectrum may be adjusted using the site factors in Tables 3.4.2.3-1 and –2. For profiles having great depths of soil above Site Class A or B rock, consideration can be given to defining the base of the soil profile and the input rock motions at a depth at which soft rock or very stiff soil of Site Class C is encountered. In such cases, the design rock response spectrum may be taken as the spectrum for Site Class C defined using the site factors in Tables 3.4.2.3-1 and –2. Several acceleration time histories, typically at least four, recorded during earthquakes having magnitudes and distances that significantly contribute to the site seismic hazard should be selected for analysis. The U.S. Geological Survey results for deaggregation of seismic hazard (website address: http://geohazards.cr.usgs.gov/eq/) can be used to evaluate the dominant magnitudes and distances contributing to the hazard. Prior to analysis, each time history should be scaled so that its spectrum is at the approximate level of the design rock response spectrum in the period range of interest. It is desirable that the average of the response spectra of the suite of scaled input time histories be approximately at the level of the design rock response spectrum in the period range of interest. Because rock response spectra are defined at the ground surface rather than at depth below a soil deposit, the rock time histories should be input in the analysis as outcropping rock motions rather than at the soil-rock interface.

3. Site response analysis and results interpretation. 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 nonlinear programs DESRA-2 (Lee and Finn, 1978), MARDES (Chang et al., 1991), SUMDES (Li et al., 1992), D-MOD (Matasovic, 1993), TESS (Pyke, 1992), and DESRA-MUSC (Qiu, 1998). If the soil response is highly nonlinear (e.g. high acceleration levels and soft clay soils), nonlinear programs are generally 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 (e.g., DESRA-2, SUMDES, D-MOD, DESRA-MUSC and TESS). Response spectra of output motions at the ground surface should be calculated and the ratios of response spectra of ground surface motions to input outcropping rock motions should be calculated. Typically, an average of the response spectral ratio curves is obtained and multiplied by the design rock

response spectrum to obtain a soil response spectrum. This response spectrum is then typically adjusted to a smooth design soil response spectrum by slightly decreasing spectral peaks and slightly increasing spectral valleys. Sensitivity analyses to evaluate effects of soil property uncertainties should be conducted and considered in developing the design response spectrum.