18.3 NONLINEAR PROCEDURES

The stiffness and damping properties of the damping devices used in the models shall be based on or verified by testing of the damping devices as specified in Section 18.9. The nonlinear force-deflection characteristics of damping devices shall be modeled, as required, to explicitly account for device dependence on frequency, amplitude, and duration of seismic loading.

18.3.1 Nonlinear Response-History Procedure

A nonlinear response-history analysis shall utilize a mathematical model of the structure and the damping system as provided in Section 16.2.2 and this section. The model shall directly account for the nonlinear hysteretic behavior of elements of the structure and the damping devices to determine its response.

The analysis shall be performed in accordance with Section 16.2 together with the requirements of this section. Inherent damping of the structure shall not be taken as greater than 5 percent of critical unless test data consistent with levels of deformation at or just below the effective yield displacement of the seismic force-resisting system support higher values.

If the calculated force in an element of the seismic force-resisting system does not exceed 1.5 times its nominal strength, that element is permitted to be modeled as linear.

18.3.1.1 Damping Device Modeling

Mathematical models of displacement-dependent damping devices shall include the hysteretic behavior of the devices consistent with test data and accounting for all significant changes in strength, stiffness, and hysteretic loop shape. Mathematical models of velocity-dependent damping devices shall include the velocity coefficient consistent with test data. If this coefficient changes with time and/or temperature, such behavior shall be modeled explicitly. The elements of damping devices connecting damper units to the structure shall be included in the model.

EXCEPTION: If the properties of the damping devices are expected to change during the duration of the time history analysis, the dynamic response is permitted to be enveloped by the upper and lower limits of device properties. All these limit cases for variable device properties must satisfy the same conditions as if the time-dependent behavior of the devices were explicitly modeled.

18.3.1.2 Response Parameters

In addition to the response parameters given in Section 16.2.4, for each ground motion used for response-history analysis, individual response parameters consisting of the maximum value of the discrete damping device forces, displacements, and velocities, in the case of velocity-dependent devices, shall be determined.

If at least seven pairs of ground motions are used for response-history analysis, the design values of the damping device forces, displacements, and velocities are permitted to be taken as the average of the values determined by the analyses. If less than seven pairs of ground motions are used for response-history analysis, the design damping device forces, displacements, and velocities shall be taken as the maximum value determined by the analyses. A minimum of three pairs of ground motions shall be used.

18.3.2 Nonlinear Static Procedure

The nonlinear modeling described in Section 16.2.2 and the lateral loads described in Section 16.2 shall be applied to the seismic force-resisting system. The resulting force-displacement curve shall be used in lieu of the assumed effective yield displacement, D_Y, of Eq. 18.6-10 to calculate the effective ductility demand due to the design earthquake ground motions, μ_D, and due to the maximum considered earthquake ground motions, μ_M, in Eqs. 18.6-8 and 18.6-9, respectively. The value of (R/C_d) shall be taken as 1.0 in Eqs. 18.4-4, 18.4-5, 18.4-8, and 18.4-9 for the response-spectrum procedure, and in Eqs. 18.5-6, 18.5-7, and 18.5-15 for the equivalent lateral force procedure.

18.4 RESPONSE-SPECTRUM PROCEDURE

Where the response-spectrum procedure is used to analyze a structure with a damping system, the requirements of this section shall apply.

18.4.1 Modeling

A mathematical model of the seismic force-resisting system and damping system shall be constructed that represents the spatial distribution of mass, stiffness, and damping throughout the structure. The model and analysis shall comply with the requirements of Section 12.9 for the seismic force-resisting system and to the requirements of this section for the