

1 **PROPOSAL 2-5 (2009)**
2
3
4

5 **SCOPE: Chapter 16 of the 2009 Provisions**
6
7

8 **Reason:**

- 9 1. When NLRH analyses are used, they are commonly used as an MCE verification after a design at the code
10 level has already been done by linear static or linear dynamic methods. This code change adds a number of
11 important requirements for NLRH analyses, to be conducted at the MCE level.
- 12 2. The code change also revises requirements to provide a better overview and organization to the chapter,
13 provide consistency with and remove duplication of analysis requirements in Chapter 12, and avoid
14 repeated language within Chapter 16
- 15 3. Delete the requirements for the linear response-history procedure

16 The proposal extensively modifies and reorganizes Chapter 16. The entire chapter as proposed is shown here.
17 Language from ASCE 7-05 that has been moved or rearranged but not changed is not shown as a ~~deletion~~ or
18 addition. Section number changes are also not shown with ~~deletion~~ or addition formatting. Text that was deleted for
19 being a duplication of Chapter 12 requirements that are now referenced is not shown.
20

21 **TS 2 VOTE:**

22
23 YES = 6

Yes with Reservations = 0

No = 0

Not Voting = 3
24
25

CHAPTER 16
SEISMIC NONLINEAR RESPONSE-HISTORY (NLRH)
PROCEDURES ANALYSIS

16.1 GENERAL REQUIREMENTS

A nonlinear response-history (NLRH) analysis shall consist of an analysis of a mathematical model of the structure to determine its response, through methods of numerical integration, to suites of ground motion acceleration histories compatible with the design MCE response spectrum for the site. The analysis shall be performed in accordance with the requirements of this chapter.

16.1.1 Use of Analysis. NLRH analysis is permitted to be used to validate or supplement a seismic design that is based on the linear static or linear dynamic analysis procedure. NLRH analysis is permitted to be used to verify the governing mechanism of nonlinear lateral response for a structure, to provide part of the substantiation required in Paragraph 3 of Section 12.2.1 for undefined seismic force-resisting systems, or to provide part of the substantiation of an alternative design according to the requirements of the general building code.

NLRH analysis is permitted to be used as part of a capacity design approach, in which a linear analysis is used to determine the required strength of yielding actions and the NLRH analysis is used to determine deformation demands and the required strength of elements designed to remain elastic.

16.1.2 Linear Analysis Requirements. The design of the structure shall meet all requirements of the equivalent lateral force procedure or modal response spectrum analysis in accordance with Section 12.6, except that specific exceptions to such requirements are permitted to be taken, provided the exceptions are:

1. clearly identified in the documentation submitted for Design Review, and
2. justified through rational application of the NLRH analysis.

16.1.3 Occupancy Categories I and II. For Occupancy Category I and II, the analysis shall be based on the MCE ground motions, defined in Section 11.4.

16.1.4 Occupancy Categories III and IV. For Occupancy Categories III and IV, the requirements of this section shall be applied. The level of earthquake ground motion per Section 16.1.3 and/or the acceptance criteria per Section 16.4.3 shall be made more restrictive compared to values applicable to Occupancy Categories I and II.

In cases where a smaller probability of collapse is the objective, the ground motion level shall be appropriately increased.

In cases where more serviceable or repairable performance is the objective, the deformation acceptability criteria shall be appropriately decreased.

It is permitted to adjust both sets of quantities, or to demonstrate that objectives are met by carrying out the NLRH analysis at more than one ground motion and acceptability level.

The increase in ground motion, decrease in deformation acceptability, or the combined effect shall be demonstrated to be consistent with the importance factor *I* per Section 11.5.

Nonstructural elements shall be designed per Chapter 13 using *I* per Section 11.5.

16.2 GROUND MOTION

A suite of not less than ~~three~~ seven appropriate ground motions shall be used in the analysis.

Appropriate ground motion acceleration histories shall be obtained from records of events having magnitudes, fault distance, and source mechanisms that are consistent with those that control the maximum considered earthquake. Where the required number of appropriate recorded ground motion records are not available, appropriate simulated or modified ground motion records ~~shall~~ are permitted to be used to make up the total number required.

Where applicable, an appropriate number of the ground motion acceleration histories shall include near fault and directivity effects such as velocity pulses producing relatively large spectral ordinates at relatively long periods.

16.2.1 Duration. Each response-history analysis shall be run for a duration that includes all ground motion acceleration pulses with magnitude greater than 0.05g, unless it is demonstrated that shorter durations do not change the response.

16.2.3 Two-Dimensional Analysis. Where two-dimensional analyses are performed, each ground motion shall consist of a horizontal acceleration history. The ground motions shall be scaled such that the average value, over all ground motions, of the 5 percent damped response spectra for the suite of motions is not less than the ~~design~~ MCE response spectrum for the site for periods ranging from 0.2*T* to 1.5 *T* where *T* is the natural period of the structure in

1 the fundamental mode for the direction of response
 2 being analyzed.

3 **16.2.4 Three-dimensional Analysis.** Where three-
 4 dimensional analysis is performed, ground motions
 5 shall consist of pairs of appropriate horizontal ground
 6 motion acceleration components. For each pair of
 7 horizontal ground motion components, an SRSS
 8 spectrum shall be constructed by taking the square
 9 root of the sum of the squares of the five-percent-
 10 damped response spectra for the scaled components
 11 (where an identical scale factor is applied to both
 12 components of a pair). Each pair of motions shall be
 13 scaled such that for each period between $0.2T$ and
 14 $1.5T$, the average, over all component pairs, of the
 15 SRSS spectra ~~from all horizontal component pairs~~
 16 does not fall below 1.3 times the corresponding
 17 ordinate of the design MCE response spectrum;
 18 ~~determined in accordance with Section 11.4.5 or~~
 19 ~~21.2~~, by more than 10 percent.

20 **16.3 MODELING AND ANALYSIS**

21 Mathematical models shall conform to the
 22 requirements of Section 12.7.

23 **16.3.1 Interaction of Elements.** The analysis shall
 24 consider the interaction of all structural and
 25 nonstructural elements that can adversely affect the
 26 response of the structure to earthquake motions,
 27 including elements not designated as part of the
 28 seismic-force-resisting system.

29 **16.3.2 Identification of Nonlinear Actions.**
 30 Documentation submitted for Design Review shall
 31 identify the structural elements or actions that are
 32 designed for nonlinear seismic response. All other
 33 elements and actions shall be demonstrated by
 34 analysis to remain essentially elastic.

35 **16.3.3 Two-Dimensional Analysis.** A 2-D analysis
 36 model is permitted to be used if Section 12.7.3 does
 37 not require a 3-D model, or if documentation
 38 submitted for Design Review demonstrates that the
 39 2-D analysis captures all significant 3-D effects,
 40 including plan torsion, non-orthogonal earthquake
 41 response, engagement of overturning resistance
 42 through flange effects or transverse coupling, and
 43 non-orthogonal effects on strong-column weak-beam
 44 behavior.

45 **16.3.4. Direction of Loading.** Two-dimensional
 46 modeling shall account for direction of loading
 47 effects in accordance with Section 12.5

48 **16.3.5 Diaphragm Modeling.** Floor and roof
 49 diaphragms shall be modeled as semi-rigid unless
 50 either:

- 51 1. Section 12.3.1 permits modeling as flexible or
 52 rigid, or

- 53 2. A consideration of diaphragm stiffness,
 54 configuration of vertical elements, and force
 55 transfer through the diaphragm indicates that a
 56 flexible or rigid diaphragm assumption
 57 adequately represents the seismic behavior of the
 58 structure and the distribution of forces to the
 59 vertical resisting elements.

60 Diaphragms shall be modeled as nonlinear if required
 61 by Section 16.3.12

62 **16.3.6 Number of Modes.** The analysis shall
 63 conform to Section 12.9.1.

64 **16.3.7 Seismic Mass.** The effective seismic mass
 65 used in the analysis shall be per Section 12.7.2.

66 **16.3.8 Gravity Load.** The modeling of and
 67 demands on elements in the analysis model shall be
 68 determined considering earthquake effects acting in
 69 the presence of expected gravity loads. Expected
 70 gravity loads shall be taken as:

71
$$1.0D + L_{exp};$$

72 where D is the dead load and L_{exp} is the expected live
 73 load. For non-storage live loads, it is permitted to
 74 take L_{exp} equal to 10 psf. For storage live loads it is
 75 permitted to take L_{exp} equal to 0.25 times the code-
 76 prescribed live load without live load reduction.

77 **16.3.9 P-delta effects.** P-delta effects that include
 78 all the building dead load plus L_{exp} shall be included
 79 explicitly in the analyses.

80 **16.3.10 Inherent Plan Torsion.** Inherent plan
 81 torsion shall be included per Section 12.8.4.1.

82 **16.3.11 Accidental Plan Torsion.** If the accidental
 83 torsion requirements of Section 12.8.4.2 are included
 84 in the determination of the strength of the nonlinear
 85 elements of the structure and in the linear analysis
 86 used to meet the requirements of Section 16.1.2,
 87 inclusion of accidental torsion in the NLRH analysis
 88 is not required.

89 **16.3.12 Nonlinear Modeling.** The mathematical
 90 model shall directly account for the nonlinear
 91 hysteretic behavior of the structural components.

92 The hysteretic force-deformation behavior of
 93 elements shall be modeled consistent with suitable
 94 applicable laboratory test data and shall account for
 95 all significant yielding, strength degradation, stiffness
 96 degradation, and hysteretic pinching indicated by
 97 such test data. Strength of elements shall be based on
 98 expected values considering material overstrength,
 99 strain hardening at the expected range of
 100 deformation, and hysteretic strength degradation.

101 Linear properties, consistent with the requirements of
 102 Section 12.7.3, are permitted to be used for those
 103 elements demonstrated by the analysis to remain
 104 within their linear range of response.

1 **16.3.13 Stiffness.** To the extent that such effects are
2 significant for the MCE response, element properties
3 shall account for the following:

4 Stiffness properties of reinforced concrete and
5 reinforced masonry shall account for cracking and
6 other phenomena that affect effective initial stiffness,
7 including strain penetration, bond slip, joint and
8 panel zone deformation, and tension shift associated
9 with shear cracking.

10 Stiffness properties of steel elements shall account
11 for connection stiffness, including for moment frames
12 the effect of panel zone (beam-column joint)
13 deformations.

14 Stiffness properties of steel elements embedded in
15 concrete shall account for the effect of the embedded
16 zone.

17 **16.3.14 Bracketing of Assumptions.** Gravity loads
18 and strength and stiffness properties that are
19 uncertain and have a large effect on the resulting
20 design shall be bracketed to consider properties both
21 above and below the expected values.

22 **16.3.15 Damping.** The equivalent viscous damping
23 level shall not exceed 5% of critical damping, unless
24 adequately substantiated. Documentation submitted
25 for Design Review shall identify how damping
26 effects are included in the NLRH analyses to account
27 for energy dissipation that is not considered directly
28 in the nonlinear analysis model, and shall report on
29 how viscous damping in the model affects higher
30 mode response.

31 **16.4 ANALYSIS RESULTS.**

32 **16.4.1 Design values.** The calculation of design
33 values shall account for the signs of actions and the
34 combinations of actions, such as axial force and
35 bending moment, that can govern the design.

36 **16.4.2 Analysis Results.** Demands for ductile
37 actions shall be taken not less than the mean value
38 obtained from the NLRH.

39 Demands for low-ductility actions (e.g., axial and
40 shear response of columns and shear response of
41 walls) shall account for the dispersion of the values
42 obtained from the NLRH. It is permitted to account
43 for dispersion by taking the mean plus one standard
44 deviation of the values from the NLRH analysis runs.

45 Alternatively, mean values are permitted to be used
46 for low-ductility actions, provided that associated
47 element capacities per Section 16.4.3 are reduced to
48 account for the dispersion in demands.

49 **16.4.3 Acceptance Criteria for Linear Actions.**
50 For structural elements or actions designed to remain
51 essentially elastic, calculated force demands shall not
52 exceed element capacities. This requirement applies

53 to those elements designated as part of the seismic
54 force-resisting system, as well as those elements not
55 designated as part of the seismic force-resisting
56 system but deemed to be materially affected.

57 **16.4.4 Overstrength Forces.** Forces calculated per
58 Section 16.4.2 and 16.4.3 shall be used in lieu of
59 using earthquake forces magnified by the
60 overstrength factor Ω_o .

61 **16.4.5 Acceptance Criteria for Nonlinear Actions.**
62 For structural elements or actions that undergo
63 nonlinear seismic response, documentation submitted
64 for design review shall indicate the adequacy of
65 individual elements and their connections to
66 withstand deformation demands. Deformation
67 capacities shall be based on laboratory test data for
68 similar elements. Member deformation shall not
69 result in deterioration of attainable member strength
70 to less than 80 percent of the peak value.

71 **16.4.6 Story Drift.** The average result, over the
72 NLRH analyses, of peak story drift ratio shall not
73 exceed 1.5 times the limits of Section 12.12.1 for any
74 story.

75 **16.4.7 Stability.** The structure shall be designed
76 such that none of the analysis results shall indicate
77 local or global instability of the structure.

78 **16.5 DESIGN REVIEW.** A design review of the
79 seismic force-resisting system and the structural
80 analysis shall be performed by an independent team
81 of registered design professionals in the appropriate
82 disciplines and others experienced in seismic analysis
83 methods and the theory and application of nonlinear
84 seismic analysis and structural behavior under
85 extreme cyclic loads. The design review shall
86 include, but need not be limited to, the following:

- 87 1. Review of any site-specific seismic criteria
88 employed in the analysis including the
89 development of site-specific spectra and
90 ground motion time histories.
- 91 2. Review of acceptance criteria used to
92 demonstrate the adequacy of structural
93 elements and systems to withstand the
94 calculated force and deformation demands,
95 together with that laboratory and other data
96 used to substantiate these criteria.
- 97 3. Review of the preliminary design including
98 the selection of structural system and the
99 configuration of structural elements.
- 100 4. Review of the final design of the entire
101 structural system and all supporting
102 analyses.