

PROPOSAL 2-2 Revision 1(2009)

SCOPE: Sec. 12.6 of the 2009 Provisions

- 1 **PROPOSAL FOR CHANGE:**
- 2 **Change Table 12.6-1 to read as follows:**
- 3 **Table 12.6-1 Permitted Analytical Procedures**

| Seismic Design Category | Structural Characteristics | Equivalent Lateral Force Analysis Section 12.8 | Modal Response Spectrum Analysis Section 12.9 | Seismic Response History Procedures Section Chapter 16 |
|-------------------------|--|--|---|--|
| B, C | Occupancy Category I or II buildings of light framed construction not exceeding 3 stories in height | P | P | P |
| | Other Occupancy Category I or II buildings not exceeding 2 stories in height | P | P | P |
| | All other structures | P | P | P |
| D, E, F | Occupancy Category I or II buildings of light framed construction not exceeding 3 stories in height | P | P | P |
| | Other Occupancy Category I or II buildings not exceeding 2 stories in height | P | P | P |
| | Regular structures not exceeding with $T < 3.5 T_s$ and all structures of light frame construction | P | P | P |
| | Regular structures exceeding 160 feet in height with $T < 3.5 T_s$ | P | P | P |
| | Irregular structures not exceeding with $T < 3.5 T_s$ and having only horizontal irregularities type 2, 3, 4, or 5 of Table 12.3-1 or vertical irregularities type 4, 5a or 5b of Table 12.3-2 | P | P | P |
| | All other structures | NP | P | P |

Note: P – Permitted NP – Not Permitted

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1 **COMMENTARY**

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3 **C12.6 Analysis Selection Procedure**

4 Table 12.6-1 provides the permitted analysis procedures for all seismic design categories.
5 The table is applicable only to buildings without seismic isolation (Chapter 17) or passive
6 energy devices (Chapter 18).

7
8 The three basic procedures provided in Table 12.6-1 are Equivalent Lateral Force (ELF)
9 analysis (Section 12.8), modal response spectrum (MRS) analysis (Section 12.9), linear
10 response history analysis (LRH) and nonlinear response history (NRH) analysis.
11 Requirements for performing response history analysis are provided in Chapter 16 of the
12 standard. Nonlinear static pushover analysis is not provided as an "approved" analysis
13 procedure in *ASCE 7-05*.

14
15 The ELF Method is allowed for all SDC B and C buildings, and for all SDC D, E, and F
16 buildings, with the following two exceptions:

- 17
18 1. Regular structures with height > 160 feet and $T > 3.5 T_s$
19 2. Structures with height < 160 feet and with one or more of the following
20 irregularities; torsion, extreme torsion, soft story, extreme soft story, weight
21 (mass), or vertical geometric.

22
23 $T_s = S_{D1}/S_{DS}$ is the period at which the horizontal and descending parts of the response
24 spectrum intersect (see Figure 11.4-1). Note that the value of T_s will depend on the Site
25 Class because S_{DS} and S_{D1} include such effects. When ELF is not allowed, the analysis
26 must be performed using modal response spectrum or response history analysis.

27
28 ELF is not allowed for buildings with the listed irregularities because the procedure is
29 based on an assumption of a gradually varying distribution of mass and stiffness along
30 the height, and negligible torsional response. The basis for the $3.5 T_s$ limitation is that the
31 higher modes become more dominant in taller buildings (Lopez and Cruz, 1996; Chopra,
32 2007), and as a result, the ELF method may underestimate the design base shear and may
33 not correctly predict the vertical distribution of seismic forces in taller buildings.

34
35 **References:**

- 36
37 Lopez, O.A., and Cruz, M., (1996). "Number of Modes for the Seismic Design of Buildings",
38 *Earthquake Engineering and Structural Dynamics*, Vol 25, N0. 8, pp 837-856.
39
40 Chopra, A.K. (2007). *Structural Dynamics*, Prentice Hall.

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43 **REASON FOR PROPOSAL:**

44 For clarity, the revised table (without the markup) is shown below:
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46

1 **Table 12.6-2 Permitted Analytical Procedures**

| Seismic Design Category | Structural Characteristics | Equivalent Lateral Force Analysis Section 12.8 | Modal Response Spectrum Analysis Section 12.9 | Seismic Response History Procedures Chapter 16 |
|-------------------------|--|--|---|--|
| B, C | All systems | P | P | P |
| D, E, F | Regular structures not exceeding 160 feet in height and all structures of light frame construction | P | P | P |
| | Regular structures exceeding 160 feet in height and with $T < 3.5T_s$ | P | P | P |
| | Irregular structures not exceeding 160 feet in height and having only horizontal irregularities type 2, 3, 4, or 5 of Table 12.3-1 or vertical irregularities type 4, 5a or 5b of Table 12.3-2 | P | P | P |
| | All other structures | NP | P | P |

2 **Note:** P – Permitted NP – Not Permitted

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5 This change fulfills two purposes:

- 6 1. Simplifies the analysis selection procedure
- 7 2. Eliminates certain illogical aspects of using the $3.5T_s$ trigger for disallowing ELF
- 8 analysis.
- 9

10 The first purpose eliminates unnecessary complexity in existing Table 12.6-1, which

11 allows ELF in all situations with a few exceptions. The proposed revisions provide the

12 following simplification:

- 13
- 14 • For SDC B and C buildings, the original table allowed all analysis procedures all
 - 15 the time. Hence, there is no need for three rows in the upper portion of the table.
 - 16 One row is sufficient.
 - 17
 - 18 • For SDC D, E and F Buildings, the language in the original table regarding
 - 19 Occupancy I and II buildings is confusing. The way the original table is written,
 - 20 it appears that ELF would not be allowed for a one story Occupancy III building.
 - 21 Is this the intent? The revised table removes this ambiguity by eliminating all
 - 22 reference to Occupancy Category.
 - 23

24 The second significant change in the table is the use of height, instead of T_s , as a trigger

25 for not allowing ELF in some cases. In the revised table, ELF is allowed for regular

1 buildings less than 160 feet in height, and is not allowed for irregular buildings above 160
2 feet in height. In the revised table, ELF would be allowed for regular buildings greater
3 than 160 feet in height, but only if $T < 3.5 T_s$. This protects certain buildings, such a tall
4 braced frames or dual systems that may be vulnerable to the original intent of the $3.5 T_s$
5 limit. The $3.5 T_s$ limit is not applicable to moment frames less than 160 ft in height
6 because the higher modes for such systems are relatively insignificant. For braced frames
7 less than 160 feet in height, higher mode effects may be significant, but it is unlikely that
8 T will be greater than $3.5 T_s$ for even a 160 foot tall building.

9
10 **Background**

11 Some background is now presented on the use of $3.5T_s$ as a trigger. This trigger is based
12 on the results of modal response spectrum analysis of moment frames systems with a
13 variety of first mode shapes. While the mass and stiffness of the frames is constant with
14 height, the stiffness of the columns relative to the beams has been varied. When columns
15 are very stiff relative to the beams, the first mode shape is similar to curve "A" in Figure
16 1. When the beams are very stiff relative to the column, the first mode shape is as shown
17 by curve "C". A straight line mode shape is represented by curve "B".

18
19 When the first mode shape is similar to that given by shapes "B" and "C", the Modal
20 Response Spectrum (MRS) method will always give base shears less than that given by
21 the ELF method. When the first mode shape is like that of curve "A", it is possible that
22 the base shear from the MRS method will exceed that computed by the ELF method.
23 Chopra¹ has shown that the MRS base shear will exceed the ELF base shear when the
24 system period exceeds about 3.5 times T_s . ($T_s = S_{ds}/S_{d1}$ is the period at which the constant
25 acceleration and constant velocity branches of the spectrum meet.) This writer has
26 independently verified that Chopra's findings are correct.

27
28 Consider, for example, a 10 story frame in Seattle on site class B with $S_{ds}=1.02$ and
29 $S_{d1}=0.34$. If the building period is 6.0 times T_s , the ratios of MRS to ELF base shears are
30 as shown for various first mode shapes in Figure 2a. In this figure, the horizontal axis
31 represents the number of modes used in the SRSS combination that produced the MRS
32 base shear. Curves are presented for column to beam stiffness ratios (ρ) of 0.1, 1.0, 10,
33 100, and 1000. When $\rho=0.1$ the deflected shape is similar to curve "C" of Figure 1, and
34 when $\rho=1000$ the first mode shape is as shown by Curve "A". The actual first mode
35 shapes (normalized to a maximum value of 1.0) are shown in Figure 3. Also shown in
36 this figure are three reference geometric shapes.

37
38 As shown in Figure 2a, the MRS base shear exceeds the ELF base shear only when more
39 than two modes are included and when ρ is greater than or equal to 100. In all other
40 cases, the ratio is less than 1.

Reference:

Chopra, A., *Earthquake Dynamics of Structures, a Primer, 2nd Edition*. EERI, 2005.

1 Figures 2b through 2e present similar results for $T = 5.0T_s, 4.0T_s, 3.0T_s,$ and $2.0T_s,$
2 respectively. As may be observed, the MRS base shear exceeds the ELF base shear when
3 $T=5.0$ and $4.0 T_s,$ but not when $T=3.0$ and $2.0 T_s.$ Also, the ratio of MRS base shear to
4 ELF base shear reduces to about 0.8. (This justifies the scaling of MRS base shear to 0.85
5 times the ELF base shear).

6
7 The maximum MRS to ELF bases shear ratios are shown for various T/T_s ratios in Figure
8 4. As may be seen, the ratio exceeds 1.0 at a period of approximately 3.5 $T_s.$

9
10 While all of Chopra's analysis used systems with uniform stiffness along the height, the
11 analysis performed by the writer also considered systems with reducing stiffness with
12 height. It was found that the same general trends occur, but that the peak ratios of MRS
13 base shear to ELF base shear are slightly reduced.

14
15 The current analysis also considered the systems on site classes C, D, and E.
16 Interestingly, the results did not vary with site class (when presented in terms of systems
17 with periods with multiples of T_s).

18
19 Based on the analysis described above, it appears that the $3.5T_s$ trigger is rational.
20 However, when applied as in the current ASCE-7, the results may appear illogical. For
21 example:

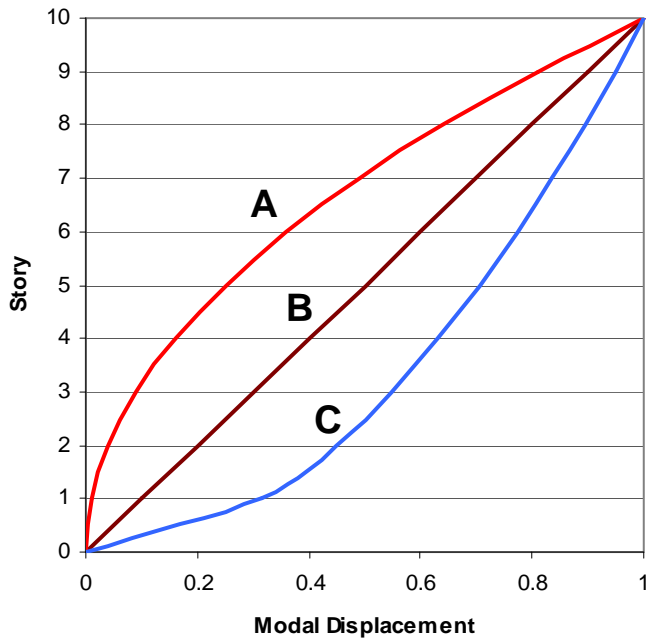
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23 1. The trigger requires modal analysis for very short buildings in some cases. For
24 example, in Memphis, site class B, a moment frame of greater than 4 stories
25 would need to be analyzed by modal analysis.
- 26
27 2. The trigger allows ELF analysis for taller braced frames than moment frames.
28 For example, in Memphis, site class C, ELF analysis can be used for moment
29 frames only up to about 7 stories, while it allows ELF analysis for braced frames
30 up to 15 stories (which is essentially all braced frames because of height limit of
31 160 ft = 12 to 13 stories). The problem that the $3.5T_s$ trigger addresses is most
32 significant for braced frames that have a cantilever type first mode shape. The
33 problem should not exist for moment frames that (presumably) have a linear first
34 mode shape.
- 35
36 3. The 3.5 trigger allows ELF analysis for taller buildings in higher seismic hazard
37 areas than in buildings of same site class and SDC in lower hazard areas. For
38 example, for a SDC D building on site class E, ELF may be used for moment
39 frames up to about 22 stories in Portland OR, but only up to about 9 stories in
40 Charlotte, NC.

41
42 The recommended change to the provisions has the following effects:

- 43
44 1. It allows ELF analysis for all regular moment frames less than 160 feet in height
45 because moment frames less than this height are almost certainly going to have
46 first mode shapes that resemble curves B or C of Figure 1.

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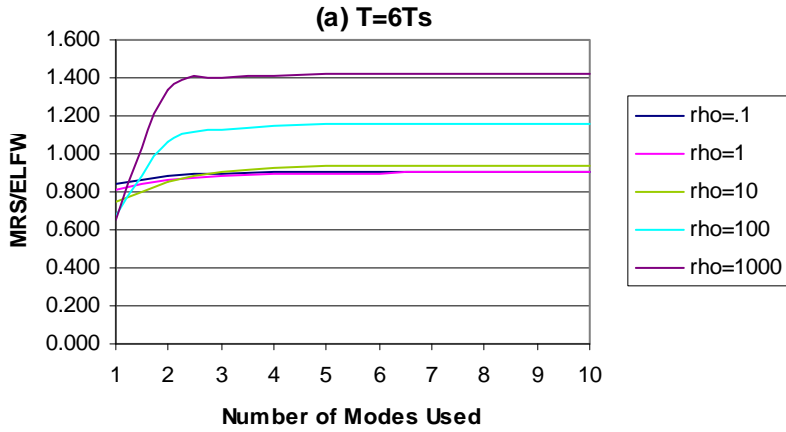
- 2. It allows ELF for most regular braced frames (and other similar systems) because it is highly unlikely that these structures have $T_1 > 3.5T_s$.



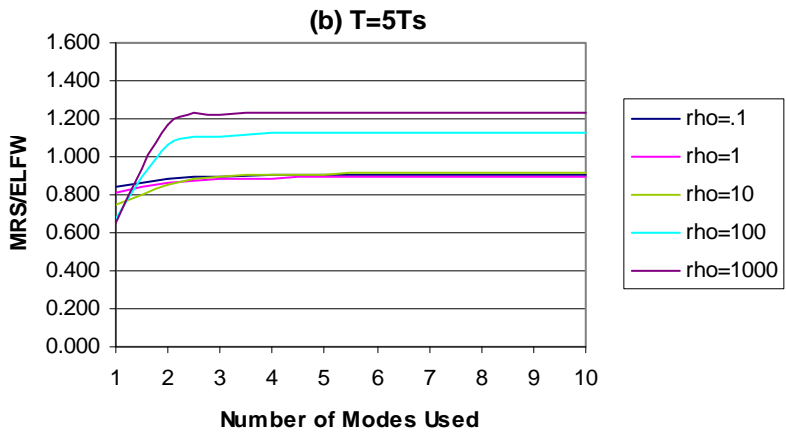
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Figure 1. Assumed First Mode Shapes

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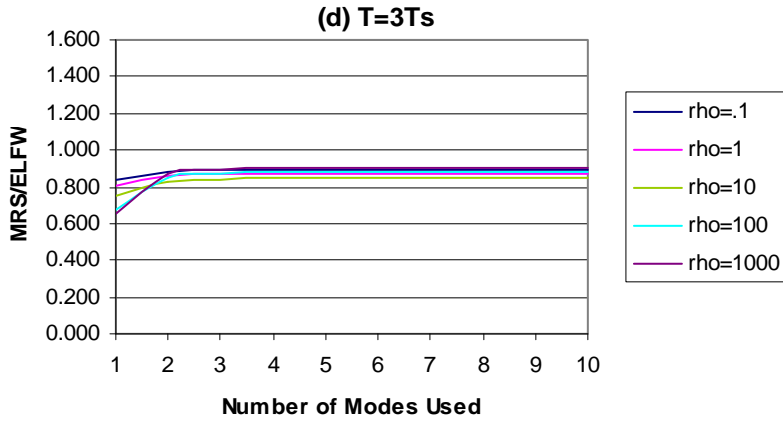
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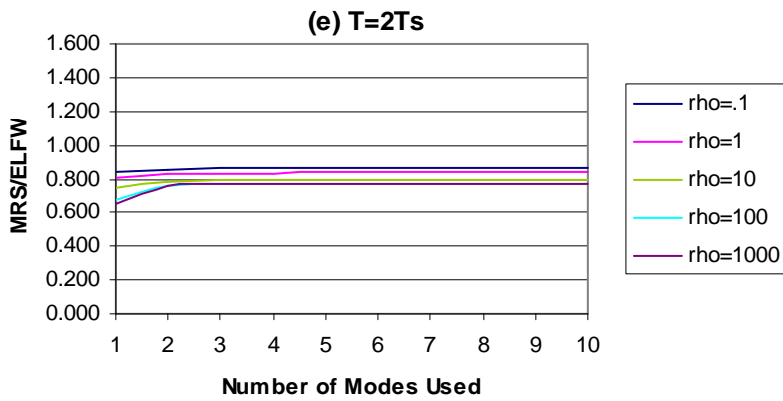
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Figure 2. MRS to ELF Base Shears Ratio for Various Ts.

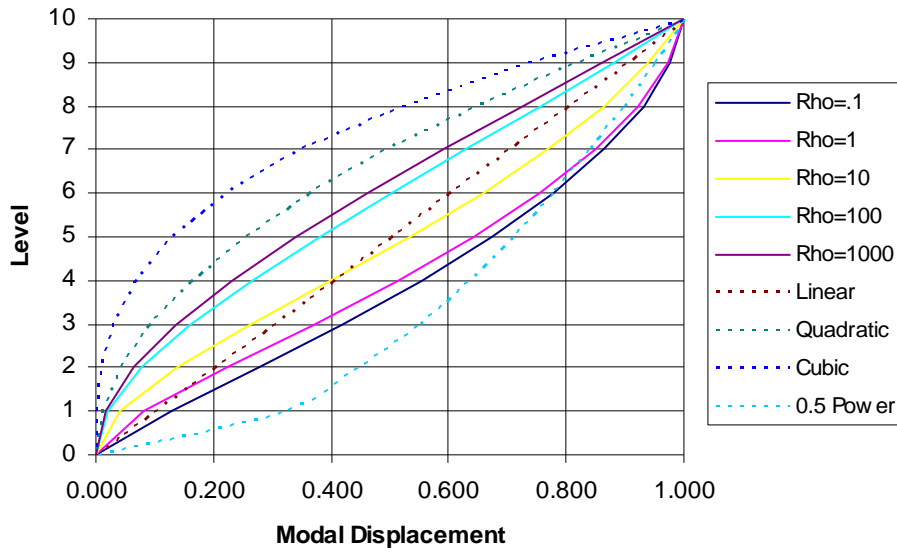


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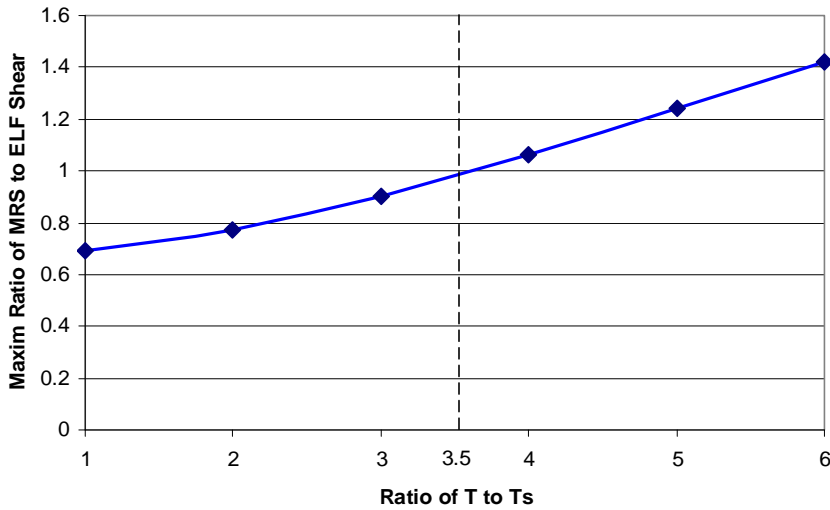
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Figure 2 (Continued). MRS to ELF Base Shears Ratio for Various Ts.



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Figure 3. First Mode Shapes used in Analysis



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Figure 4. Base Shear Ratios for Various T/Ts