STRUCTURAL PERFORMANCE

performance issues relative to extreme events

The Most Common Errors in Seismic Design

… & How to Avoid Them

By Thomas F. Heausler, P.E., S.E.

*Thomas F. Heausler, P.E., S.E. (**TFHSE@aol.com**), has 33 years of experience in structural and seismic engineering and has been a voting member of ASCE/SEI 7 Seismic Provisions since 2006. He provides seismic expertise and senior review to engineering firms for building and industrial projects.*

This article identifies common errors that structural engineers make when performing seismic design and calculations. The intent is to help engineers avoid those errors and misapplications. This article is written in checklist format such that an engineer can verify adequate self-knowledge, as well as review the work of others on a project. It is based upon the 2012 *International Building Code* (IBC), the American Society of Civil Engineers' ASCE/SEI 7-10, the American Concrete Institute's ACI 318-11, the American Institute of Steel Construction's AISC 360-10, AISC 341-10, and other current standards. For ease of identification, referenced sections are noted in brackets and refer to ASCE/SEI 7-10 section numbers, unless otherwise noted.

1) Seismic Design Category A

When in seismic design category (SDC) A, it is not necessary to use any of the provisions of Chapter 12. Instead, the general structural integrity provisions of Section 1.4 apply. Note that these provisions include some loads that may often be erroneously neglected. The required lateral forces include 1% of dead load, 5% of dead plus live load for beam (axial load) connections, and 20% of wall weight for wall connections. Non-structural components in SDC A are exempt from seismic design requirements. *See [1.4], [11.4.1], and [11.7].*

2) Importance Factor

The importance factor is based upon the risk category and the associated life safety, hazard or essential nature of the structure. Both [*Table 1.5-1*] and [*IBC Table 1604.5*] should be reviewed. A typical building can sometimes evolve into an I_e equal to 1.25 or 1.5 when occupancy or use expands. Examples include relatively small churches (expanding to an occupancy greater than 300) or a building where hazardous materials are stored. It should be noted that for building design, I_e = 1.0, 1.25, or 1.5; but for non-structural components, I_p = 1.0 or 1.5 only [*13.1.3*], such that I_p may not equal I_e, and in some instances I_p may be less than I_e. *See [11.5.1] and [Table 1.5-2].*

3) Continuous Load Path

ASCE/SEI 7-10 has very specific provisions for many elements such as collectors, connections, diaphragms, walls, etc. However, in addition to those specifics, the engineer is required to provide a continuous load path for all inertial forces from their origin to the foundation. Such load paths must conform to the relative stiffness and strength of the elements that exist in the structure. *See* [*12.1.3*].

> *… a checklist to verify self-knowledge as well as check the work of others on a project.*

4) R Factor

The response modification coefficient, R, is part of a concept where an elastic design may be performed, but with due consideration of the overstrength and ductility inherent in the lateral force resisting system. In order to ensure reliability, many requirements are triggered with each R factor. The "R" Tables, [*Table 12.2-1*] and [*Table 15.4-1, 2*], list the corresponding detailing requirements. The "strings attached" can be extremely significant, especially for concrete structures that fall under ACI 318-11 Chapter 21 and steel structures with R greater than 3 (AISC 341 *Seismic*).

5) Irregularity Triggers

[*Table 12.3-1*] and [*Table 12.3-2*] describe various horizontal and vertical irregularities, respectively, which trigger specific provisions. Each referenced section must be reviewed. Triggered provisions include modal analysis, three-dimensional analysis, redundancy factor, force amplification, torsion amplification, and collector force increases. *See [12.3.2.1] and [12.3.2.2].*

6) Overstrength – Ω_o

The variable Ω_o is an amplification factor applied to the forces in certain elements in the seismic load path. It is required so as to prevent a weak link from occurring prior to the full energy dissipation and ductility potential of the primary lateral-force-resisting system. For example, in a steel braced frame, in order for the diagonal brace to yield and dissipate energy in a controlled and reliable manner, all other portions of the load path (e.g., connections,

> **When you select an R factor from the Table, you are obliged to implement the associated "strings attached."**

bolts, welds, gusset plates, anchor bolts, columns and collectors) need to be stronger than the maximum anticipated strength or force in the brace. Therefore, Ω_o amplification and load combinations are specifically triggered for those elements, in the sections mentioned below and in Material Standards such as AISC 341-10 and ACI 318-11. For example, AISC 341-10 states that anchor bolt forces must be amplified by Ω_o, which is typically 2.0 or greater. This applies to all steel buildings where R is greater than 3, unless you can prove otherwise via an advanced and rigorous analysis. *See [12.4], [12.2.5.2], [12.10.2.1], [12.3.3.3], [12.13.6.5], and [AISC 341 when R>3, ACI Chapter 21, Appendix D, etc.].*

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7) Redundancy – Rho

Rho is a factor that penalizes structures that do not have redundancy. Rho is equal to either 1.0 or 1.3. Rho is equal to 1.0 for SDC B and C, for drift calculations, non-structural component forces, collectors, Ω_o load combinations, and diaphragms. *See [12.3.4].*

8) Vertical Seismic Load Effect – E_v

[*12.4.2.2*] requires that a vertical load effect equal to 0.2 S_{DS} be applied to dead load. It is applied as a dead load factor adjustment and may act downward or upward. It is at the strength design level, so it may be multiplied by 0.7 for allowable stress design (ASD). The values of I_e, I_p, Rho and R are not applied to E_v.

9) Load Combinations and Allowable Stress Design – 0.7 E

For ASD load combinations [*12.4.2.3*], [*12.4.2*] shall be used in lieu of [*2.3.2*] and [*2.4.1*]. Earthquake forces are at strength level, so for the ASD combinations, use 0.7 E. The 0.7 E applies to non-structural component forces (F_p). *See* [*13.3.1*].

10) Orthogonal Effects

Earthquake forces must be calculated for each of the two primary orthogonal directions. In order to consider the effects of earthquake forces at some angle other than those two directions, "orthogonal effects" must be considered. [*12.5*] requires that irregular buildings in SDC C and corner columns in SDC D, E, and F be considered with 100% of forces in one direction plus 30% in the other. It should be noted that IEEE 693 (Electrical Equipment) applies orthogonal effects to all elements, including corner anchor bolts.

11) Effective Seismic Weight

[*12.7.2*] defines the effective seismic weight, W. Except for as mentioned below, live load is not included in the inertial force; however, the seismic force is later combined with dead and live loads in the load combinations. [*12.7.2*] stipulates that W must include the following masses: 25% of storage live load, partition load of 10 psf [*4.3.2*], industrial operating weight and unbalanced conditions, 20% of snow if greater than 30 psf, and weight of roof gardens.

12) Distribute Base Shear over Height

Once the base shear, V, is calculated, it must be distributed over the height of the structure. For a one-story building, all of the base shear would be applied at the roof. For multi-story structures, the base shear must be distributed to each floor, not only in proportion to each floor's mass, but also in proportion to the distance of the floor from the base. A triangular distribution of force results for regular multi-story buildings. For distributed-mass structures like stacks and masonry fences, the centroid of the load should result at ⅔ of the height above the base, not at ½ the height or at the center of gravity. *See [12.8.3].*

13) Modal Response Spectrum Analysis

When a structure has significant vertical or horizontal irregularities, the equation [*12.8-12*] (triangular force distribution) becomes inaccurate, and therefore a modal response spectrum analysis is required. *See [12.6], [Table 12.6-1] and [12.9].* The purpose is not to refine the magnitude of the base shear, but to perform the following more accurately:

1) Distribute base shear over height.
2) Quantify horizontal torsional effects.
3) Account for higher mode effects.

Note that the "NP" entry in [*Table 12.6-1*] includes many common irregularities, including horizontal type 1a, 1b and vertical type 1a, 1b, 2 and 3, and thus a modal analysis is triggered for those structures.

14) Accidental Torsion

In addition to inherent torsion, accidental torsion must be applied. This is to prevent weak torsional resisting arrangements, as well as account for unexpected distribution of live load and unexpected stiffness of structural and non-structural elements. This provision applies to non-building structures, as well as buildings. For torsionally irregular buildings, amplification of the accidental torsion may be required as per [*12.8.4.3*]. *See* [*12.8.4.2*].

15) Drift Check

Results from the elastic analysis must be amplified by C_d to render expected deflections. Note that C_d is a very large value, typically a factor of about 4 or 5. The drift is then divided by I_e, because the allowable drifts are organized into a table that considers risk category. One should be careful when using ASD load combinations not to apply the 0.7E to drift calculations. *See [12.8.6], [12.12], and [Table 12.12-1].*

16) Diaphragm Forces

Forces at lower floor diaphragms may be higher than those used for the lateral force resisting system [*Equation 12.8-12*]. This is due to higher mode effects (i.e., modes higher than the first mode) where the lower floors may be accelerating higher than calculated. Note that Fpx minimums of [*Equation 12.10-2*] often govern for the lower floors. *See [12.10.1.1].*

17) Non-structural Components

Non-structural components may also experience higher local accelerations due to higher mode effects, as well as amplification of the force within the non-structural element itself. *See [Equation 13.3.1].* Industrial structures often feature very large forces. It is unlikely that the forces on two different floors would occur at the same point in time. Therefore, one method of accounting for the forces in a computer model is to evaluate two conditions.

1) Run a load case with the weight of the equipment included in the seismic weight of the floor and the base shear, V, distributed over the height as per [*Equation 12.8-12*].
2) Run a load case with only the non-structural component force for one piece of equipment, so as to verify an adequate load path to the vertical system and/or foundation.
   Note that it is necessary to apply E_v to load combinations with non-structural component forces. The factor Ω_o does not apply to such load combinations, except in some ACI 318-11 Appendix D calculations. Note also that when non-structural components get very large – i.e., 25% or more of total structure mass – then [*15.3*] provisions apply. For these heavy components, the stiffness and design coefficients of both the component and the primary structure must be considered together in a computer model.

18) Wall Design

Connections to wall panels made of concrete and concrete masonry units (CMU) have performed poorly in past earthquakes. The equations of [*12.11.1*] and [*12.11.2.1*] should be implemented, as well as ACI 318-11 Appendix D for anchorage.

19) Foundation Ties

Foundation ties are required as per [*12.13.6.2*] in order to ensure that the foundation system acts as an integral unit, not permitting one column or wall to move appreciably relative to another. This applies to pile caps in SDC C, D,E and F, and spread footings for SDC E and F.

20) Reduction of Foundation Overturning

[*12.13.4*] allows for a reduction of the bearing pressures at the soil-foundation interface. Forces may be reduced by 25% in recognition that the first mode triangular force distribution will likely not occur without higher mode effects occurring and negating the direction of the first mode, resulting in reduced maximum overturning moments.

21) Errata

The ASCE/SEI 7-10 and IBC 2012 websites have the latest errata for those documents. Significant entries due to typographical mistakes or unintended consequences of revisions are corrected in the errata.

22) IBC Overrides

IBC 2012 contains amendments to ASCE/SEI 7-10. *See [IBC 1613], [IBC 1613.5], and [IBC Chapters 18 through 23].* ASCE/SEI 7 is on a six-year update cycle, and IBC is on a three-year cycle. Technical changes to IBC often have to be approved well before the issue date. Inevitably, coordination between ASCE 7, IBC and referenced material standards (e.g. ACI, AISC, etc.) often occur through errata, supplements or IBC-published amendments. It is essential to check for these changes periodically. Individual state and local governments may also adopt amendments that affect projects located within their jurisdiction.

23) ASCE/SEI 7-10 Third Printing

It is recommended that the user make use of the ASCE/SEI 7-10 *Expanded Seismic Commentary*, which provides 135 pages of valuable background information. It is incorporated in the third printing of ASCE/SEI 7-10 only. For those who own a first or second printing, you may download a PDF file of the commentary for free from the ASCE website. This Commentary was developed by the National Earthquake Hazard Reduction Program/Building Seismic Safety Council/Provisions Update Committee (NEHRP/BSSC/PUC) and describes the reasons for the individual provisions of ASCE/SEI 7-10.

Conclusion

A concerted effort to avoid errors is essential. Errors can be minimized by applying knowledge and experience. This article is intended to assist in that effort. The above listing of common errors was developed by the author during frequent reviews of other engineers' work. It is based upon the author's experience and should not be construed as a consensus document prepared or endorsed by the ASCE/SEI 7-10 or NCSEA Seismic Committees.■