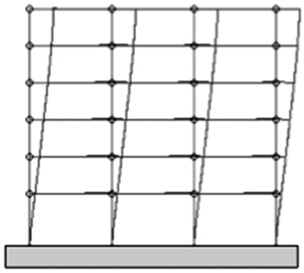

Example 15

Load Combinations

This example explores the use of the strength design load combinations that include earthquake load effects. These load combinations, numbered 5 and 7 in Section 2.3.2 of ASCE 7, are then discussed in context with the requirements of Section 12.4. Also discussed in this example are requirements for including direction of loading (Section 12.5), accidental torsion (Section 12.8.4.2), and amplification of accidental torsion (Section 12.8.4.3).

Chapter 2 of ASCE 7 provides the required load combinations for both strength-based and allowable stress-based designs. This example covers only the use of the strength-based load combinations. There are seven basic load combinations provided in Section 2.3.2. Each member and connection of the structure must be designed for the maximum force or interaction of forces (e.g., axial force plus bending) produced by any one of these basic combinations. For any given member, such as a reinforced concrete girder, it might be found that different combinations control different aspects of the design. For example, load combination 2 in Section 2.3.2 might control the requirements for bottom reinforcement at midspan, whereas combination 5 controls requirements for top reinforcement at the ends of the member. A specific example of this circumstance is provided later. The remainder of this example concentrates on combinations 5 and 7, which are shown below:

Combination 5: $1.2D + 1.0E + 1.0L + 0.2S$
Combination 7: $0.9D + 1.0E + 1.6H$

In each of these combinations, the factor on earthquake load effects, E, is 1.0. This is due to the fact that the spectral design accelerations S_{DS} and S_{D1}, produced from the requirements of Chapter 11, are calibrated to be consistent with an ultimate load. Wind loads, on the other hand, are nominal, and when used in strength design, must be multiplied by a factor greater than 1.0 (in combinations 4 and 6 of Section 2.3.2) to elevate them to the ultimate load level. Also, the factor on live load in combination 5 may be reduced to 0.5 in most cases (See Exception 1 in Section 2.3.2). The adopted building code may provide load combinations that are different than those specified in ASCE 7 (e.g., the alternate basic combinations of ICC 2006). If so, these combinations must be used in lieu of the ASCE 7 requirements.

The snow load in combination 5 is always included when $S > 0$. There might also be a snow load effect in E in both combinations because the effective seismic weight, W, is required to include 20 percent of the design snow load when the flat roof snow load exceeds 30 lb/ft^2 (Section 12.7.2). See Exception 2 in Section 2.3.2 for comments related to the use of the pressure load H.

There are two ways in which the combinations are used. The first, covered in Section 12.4.2, is applicable to all elements and connections in the structure and may be considered the standard load combinations. The second, covered in Section 12.4.3, is for those special elements or connections that must be designed with the overstrength factor, Ω_o. Where required, the special load combinations supersede the standard combinations (item 6 in Section 12.3.4.1).

ASCE 7 provides several specific cases where the overstrength load combination must be used. For example:

- Section 12.2.5.2, which requires that the overturning resistance of a cantilever structure be designed with the overstrength factor.
- Section 12.3.3.3, which pertains to elements supporting discontinuous walls or frames.
- Section 12.10.2.1, which pertains to collector elements, their splices, and their connections to resisting elements.

Section 12.4.2 of ASCE 7 provides details on the standard seismic load effect. For use in load combination 5, the seismic load effect E is given as

$$E = E_h + E_v \tag{12.4-1}$$

and for use in load combination 7,

$$E = E_h - E_v \tag{12.4-2}$$

where

$$E_h = \rho Q_E \tag{12.4-3}$$

and

$$E_v = 0.2S_{DS}D \tag{12.4-4}$$

The term E_h represents the horizontal seismic load effect. The term ρ in Eq. 12.4-3 is the redundancy factor, computed in accordance with Section 12.3.4. This value is 1.0 for all buildings assigned to Seismic Design Category (SDC) B or C and is either 1.0 or 1.3 in SDC D through F. This factor applies to the entire structure but may be different in the two orthogonal directions. See Example 13 in this guide for details on determination of the redundancy factor.

The term E_v represents the effect of vertical ground acceleration, which is not considered explicitly elsewhere, with the exception of Section 12.4.4, which provides requirements for minimum upward forces in horizontal cantilevers for buildings in SDC D through F.

Q_E in Eq. 12.4-3 is the seismic effect on an individual member or connection. This value is produced by the seismic analysis of the structure and includes direct loading (e.g., application of equivalent lateral forces), accidental torsion and torsional amplification (if applicable), and orthogonal loading effects (if applicable). Q_E might represent, for example, a bending moment at a column support, an axial force in a bracing member, or a stress in a weld. In some cases, Q_E might represent an interaction effect, such as an axial-force bending moment combination in a beam column. In such cases, both the axial force and bending moment occur concurrently and should be taken from the same load combination.

When Eqs. 12.4-1 through 12.4-4 are substituted into the basic load combinations, the following detailed combinations for strength design are obtained:

Combination 5: $(1.2 + 0.2S_{DS})D + \rho Q_E + 1.0L + 0.2S$
Combination 7: $(0.9 - 0.2S_{DS})D + \rho Q_E + 1.6H$

The use of these load combinations is illustrated in **Fig. G15–1** and **Fig. G15–2**. Each figure shows a simple frame with gravity and seismic loading. Snow and hydrostatic pressure loading are not present.

The top of **Fig. G15–1** shows only the gravity portion of the load, with the heavy gravity case shown at the upper left and the light gravity case shown at the upper right. At the bottom of the figure, the loading is shown for seismic effect acting to the east or to the west. Moment diagrams are

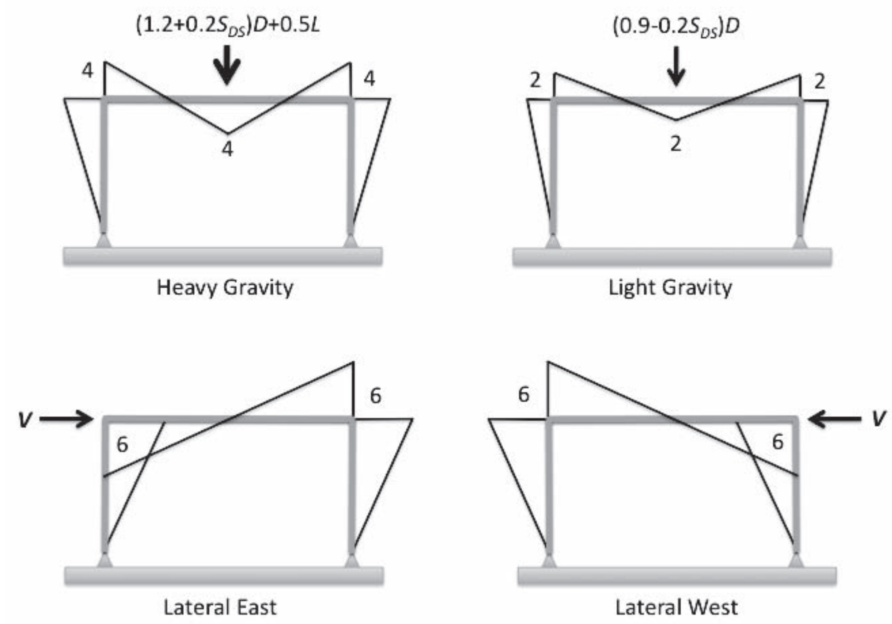

Figure G15–1 Basic Load Combinations for Simple Frame.

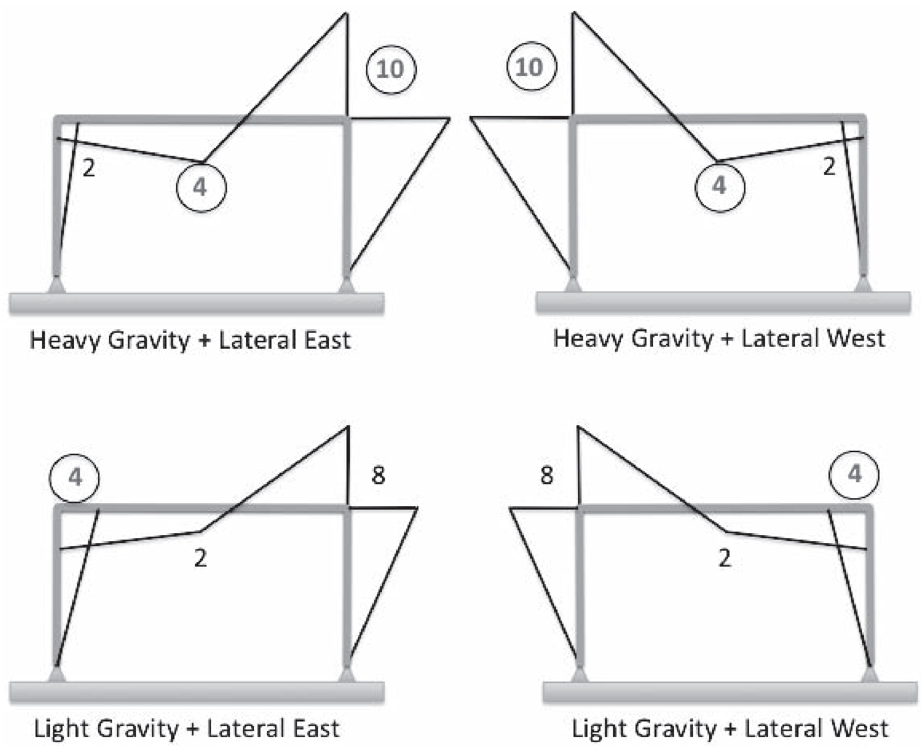

Figure G15–2 Combinations of Basic Combinations for Worst Effect.

drawn for each loading, and these diagrams are presented on the tension side. The moment values (units not important) are shown for each loading.

Fig. G15–2 shows the combination of gravity and earthquake load. The top of the figure gives the total moments for load combination 5, with heavy gravity plus seismic acting to the east on the left side of the figure and heavy gravity plus seismic acting to the west on the right side of the figure. The bottom of the figure is for combination 7 with light gravity and seismic acting to the east or west. Controlling moments are circled.

As may be seen in **Fig. G15–2**, each load combination must be exercised twice, once for positive seismic and once for negative seismic to produce the controlling effect in each member or connection. For the given example, the controlling tension on the top moment is 10 at both ends of the beam, and the controlling tension on the bottom moment is 4 for the full beam span. Of course, other load combinations (without seismic) provided in Chapter 2 of ASCE 7 must also be exercised to determine if they control. It is important to recognize, however, that the seismic detailing requirements associated with any system must be provided, regardless of the loading combination that controls the strength of the member or connection. For example, a member in an intermediate moment frame that has a wind-based design force twice as high as the seismic design force may be sized on the basis of the wind forces but must be detailed according to the requirements for intermediate moment frames.

The lateral forces shown in **Fig. G15–1** and **Fig. G15–2** include the effects of accidental torsion, as well as the effect of seismic loads acting simultaneously in orthogonal directions. Accidental torsion must be considered for any building with a nonflexible diaphragm, and torsionally irregular buildings in SDC C through F are subject to requirements for amplifying accidental torsion. Direction of load effects is covered in Section 12.5. For structures in SDC B, the analysis (including accidental torsion effects) may be performed independently in each direction and the structure may be designed on that basis. For structures in higher SDCs, the direction of load effects must be explicitly considered wherever a Type 5 horizontal nonparallel systems irregularity occurs (Table 12.3-1). Because such irregularities are common, many buildings must be designed for a complicated combination of loads that include gravity, lateral loads acting from any direction, simultaneous application of lateral loads acting in orthogonal directions, and accidental torsion with or without amplification.

The manner in which the different load effects are considered depends on whether the analysis is being performed using the equivalent lateral force (ELF) method or the modal response spectrum (MRS) method. Procedures used in association with response history analysis are beyond the scope of this guide.

Before illustrating the procedures used in association with ELF or MRS analysis, it is important to note that these procedures, as presented herein, depend on the analysis being performed in three dimensions. Section

12.7.3 requires 3D modeling for structures with horizontal structural irregularities of Type 1a, 1b, 4, or 5 of Table 12.3-1. Additionally, a 3D analysis is required for structures with semirigid diaphragms. Even where 3D analysis is not required by ASCE 7, it is advisable to use such analysis because the requirements for accidental torsion and loading direction are easier to apply than would be the case if the structure were to be decomposed into a number of 2D models.

15.1 Load Combination Procedures Used in ELF Analysis

In ELF analysis, as many as 16 seismic lateral load cases may be required. The generation of the 16 lateral load cases is shown in **Table G15–1** and in accompanying **Fig. G15–3**.

Table G15–1 Generation of ELF Load Cases

Major Load Direction	*Major Load Applied at Eccentricity*[a]	*Orthogonal Load (applied at zero eccentricity)*[b]	*Load Case Number*
$+V_{EW}$	$0.05A_xB$	$+0.3\ V_{NS}$	1
		$-0.3\ V_{NS}$	2
	$-0.05A_xB$	$+0.3\ V_{NS}$	3
		$-0.3\ V_{NS}$	4
$-V_{EW}$	$0.05A_xB$	$+0.3\ V_{NS}$	5
		$-0.3\ V_{NS}$	6
	$-0.05A_xB$	$+0.3\ V_{NS}$	7
		$-0.3\ V_{NS}$	8
$+V_{NS}$	$0.05A_xL$	$+0.3\ V_{EW}$	9
		$-0.3\ V_{EW}$	10
	$-0.05A_xL$	$+0.3\ V_{EW}$	11
		$-0.3\ V_{EW}$	12
$-V_{NS}$	$0.05A_xL$	$+0.3\ V_{EW}$	13
		$-0.3\ V_{EW}$	14
	$-0.05A_xL$	$+0.3\ V_{EW}$	15
		$-0.3\ V_{EW}$	16

a. A_x is the torsional amplification factor.
b. Not always required. See Section 12.5

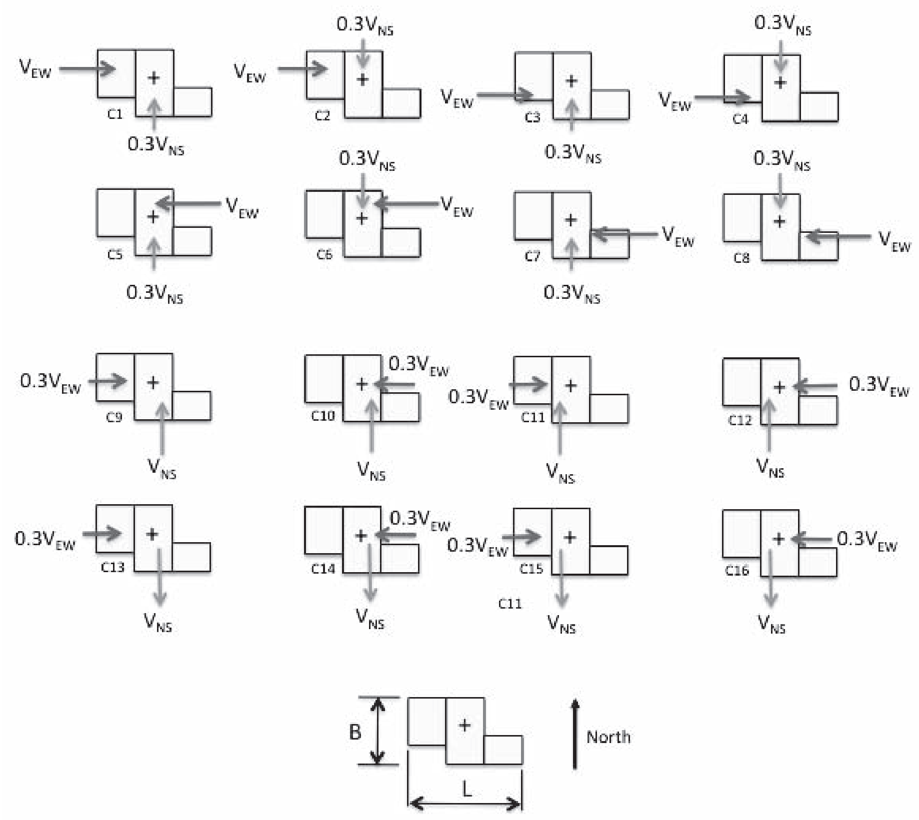

Figure G15–3 Sixteen Basic Lateral Load Cases Used in ELF Analysis.

The first column of **Table G15–1** represents the direct lateral load without accidental eccentricity. These forces would come from Eqs. 12.8-1, 12.8-11, and 12.8-12. The second column provides the eccentricity at which the lateral loads must be applied. As described in Section 12.8.4.2, this eccentricity is equal to at least 0.05 times the dimension of the building perpendicular to the direction of the applied loads. Both positive and negative eccentricities must be considered for each direction of lateral load. If the building is in SDC C or higher and has a torsional or extreme torsional irregularity, the accidental torsion must be amplified per Section 12.8.4.3. It is possible that the torsion amplifier, given by Eq. 12.8-14, may be different at each level of the structure.

The third column of **Table G15–1** represents the orthogonal loading requirements, which are specified in Section 12.5. When orthogonal loading is required in SDC C and higher, it is permitted to satisfy these requirements by simultaneously applying 100 percent of the load in one direction (with torsion and torsion amplification if necessary) and simultaneously applying 30 percent of the orthogonal direction loading. Section 12.5.4 provides additional orthogonal loading requirements for certain interacting structural components in structures that have been assigned to SDC D though F. According to Section 12.8.4.2, the orthogonal direction load need not be applied with an eccentricity.

15.2 Load Combination Procedures Used in MRS Analysis

Where the modal response spectrum method of analysis is used, all signs in the member forces are lost because of the square root of the sum of the squares (SRSS) or complete quadratic combination (CQC) modal combinations. Additionally, it is common to apply accidental torsion as a static load and then combine this load with the results of the modal analysis. Orthogonal load effects may be handled in one of two manners:

1. Apply 100 percent of the spectrum in one direction, and run a separate analysis with 30 percent of the spectrum in the orthogonal direction. Member forces and displacements are obtained by SRSS or CQC for each analysis. Combine the two sets of results by direct addition.
2. Apply 100 percent of the spectrum independently in each of two orthogonal directions. Member forces and displacements are found by CQC. Combine to two sets of results by taking the SRSS of results from the two separate analyses.

The first method gives different results for different angles of attack for the main component of loading. The main advantage of the second method is that it produces the same results regardless of the angle of attack of the seismic loads (Wilson 2004). From either of these approaches, only two dynamic load analyses are required.

The results from the gravity and response spectrum analysis are then combined algebraically with the results of static torsion analyses, where the accidental torsion, amplified if necessary, is applied. There are only four basic cases of accidental torsion loading. These cases are illustrated in **Fig. G15–4**.

15.3 Special Seismic Load Combinations, Including the Overstrength Factor

In some cases, it might be necessary to design members or connections for load effects, including the overstrength factor, Ω_o. This factor is listed for each viable system in Table 12.2-1. The requirement to use the overstrength factor may come directly from ASCE 7, or it may come from the specification used to proportion and detail the member or connection. Examples of ASCE 7 requiring the use of the overstrength factor include elements supporting discontinuous walls or frames (Section 12.3.3.3) and the design of diaphragm collector elements (Section 12.10.2.1). An example from a material specification, in this case the *Seismic Provisions for Structural Steel Buildings* (AISC 2005a), is the requirement that moment connections in intermediate

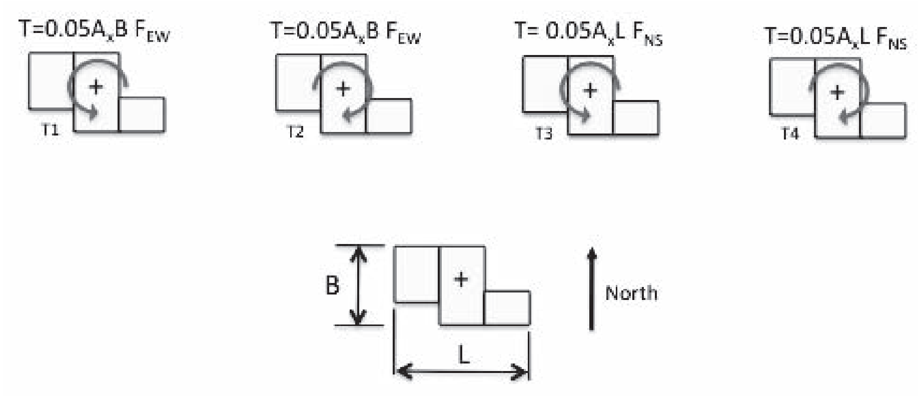

Figure G15–4 Static Load Cases for Torsion and MRS Analysis.

moment frames be designed for shear forces that are determined by "using load combinations stipulated by the applicable building code including the amplified seismic load." The amplified seismic load is defined as the "horizontal component of earthquake load E multiplied by Ω_o."

The special load combinations that include the overstrength factor are

Combination 5: $(1.2 + 0.2S_{DS})D + \Omega_o Q_E + 1.0L + 0.2S$
Combination 7: $(0.9 - 0.2S_{DS})D + \Omega_o Q^E + 1.6H$

where the only difference with respect to the standard load combination is that the term Ω_o replaces the redundancy factor ρ. Again, load combinations including the overstrength factor are required only for a few select members or connections. Most of the members and connections are designed using the standard load combination. There is no circumstance in which both the redundancy factor and the overstrength factor are used at the same time (for the same element or component).

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