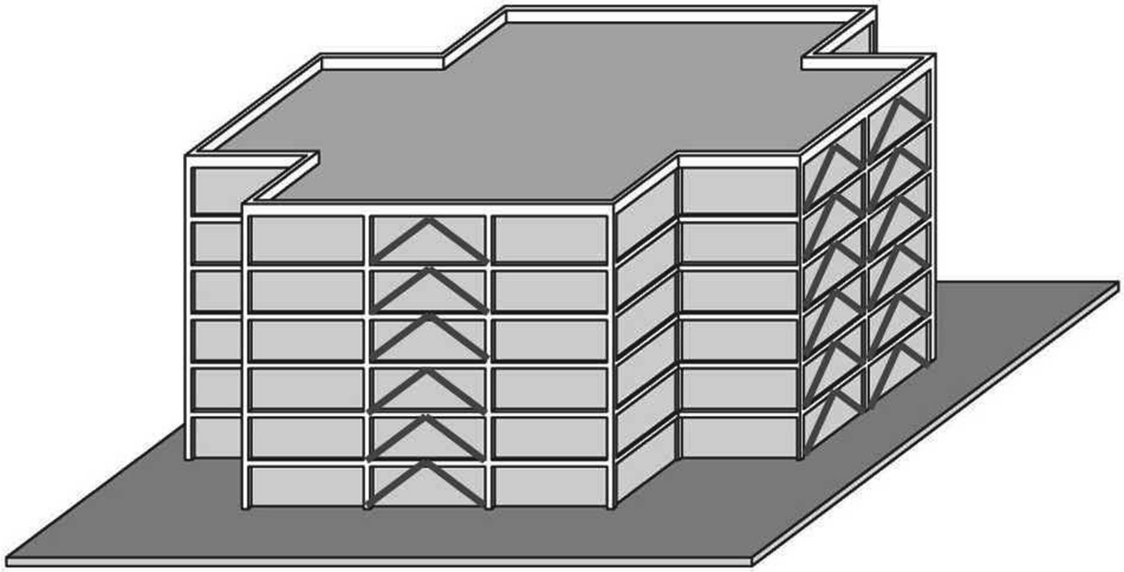
Design Example 3
Buckling-Restrained Braced Frame



OVERVIEW

Buckling-restrained braced frame (BRBF) is a relatively new system. It was developed in the late 1990s and has since gained acceptance in the United States as engineers look for a system with high ductility and energy dissipation. Unlike conventional steel braces, buckling-restrained braces consist of a steel core that is restrained from buckling by outer casing of concrete, steel, or both. As a result, the steel core will yield in tension as well as compression. The purpose of the outer casing is to prevent global buckling of the core only, and it must be kept free of axial forces. The methods to prevent transfer of axial forces to the casing as well as to provide confinement to the core are fairly specialized. As a result, BRBF in the United States consists of proprietary braces provided by a steel fabricator or a specialty manufacturer.

The 2005 edition of AISC 341 and ASCE 7 contained the first US code provisions for the design as well as testing requirements for BRBF. Subsequent editions of ASCE 7 (2010 edition) and AISC 341 (2010 edition) introduced additional updates. For example, the 2010 edition of ASCE 7 added provisions to estimate period (Method A) for BRBFs. In addition, the differentiation between BRBFs where beam-column joints are fixed or pinned has been eliminated and replaced by a single value of $R = 8$. AISC 341 included updates of beam-column joint requirements where the connection must either be able to allow rotation (0.025 radians) or to be designed to resist expected flexural strength of the beams or sum of the columns.

AISC 341-22 has only modest changes for BRBF. Column compactness requirements were increased from “moderately ductile” to “highly ductile.”

OUTLINE

1. Building Geometry and Loads

2. Calculation of the Design Base Shear and Load Combinations

3. Vertical and Horizontal Distribution of Load

4. Preliminary Sizing

5. Preliminary Analysis and Brace Deformations

6. Iteration and Final Design

7. Detailing and Design of Connections

8. Items Not Addressed in This Example

1. Building Geometry and Loads

1.1 GIVEN INFORMATION

- Per Appendix A:
  - Office occupancy on all floors
  - Site Class D
  - 120 feet × 150 feet in plan with typical floor and roof framing shown in Figure 3-1
  - Six stories as shown in Figure 3-2

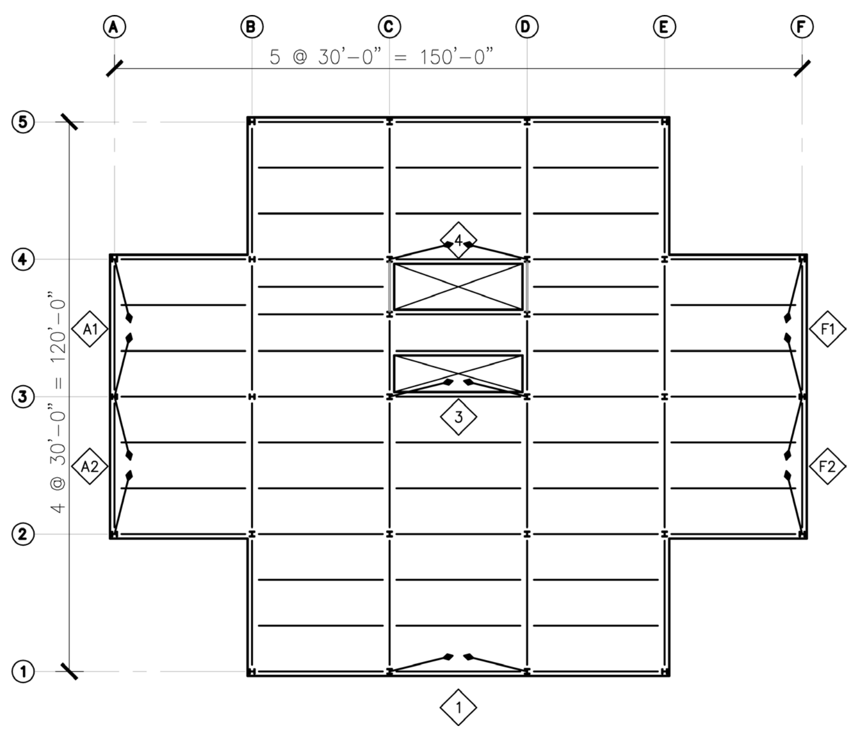


Figure 3-1. Typical floor and roof framing plan

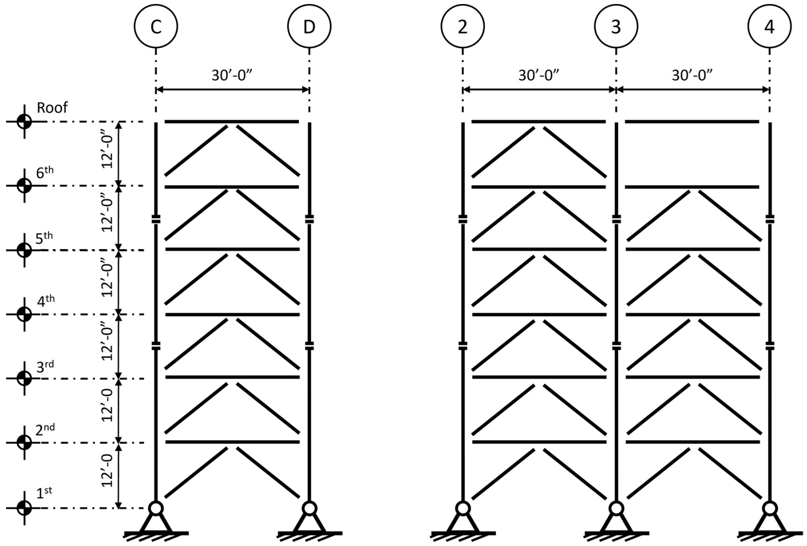


Figure 3-2. Braced-frame elevations

1.2 FLOOR WEIGHTS

Per Appendix A:

Table 3-1. Floor weights per Appendix A

Level	Assembly	Unit Weight (psf)	Area (ft^2)	Weight (kips)	Floor Weight (kips)
Typical floor	Floor	77.7	15,220	1183	1315
	Ext wall	19	6990	133	
Roof	Roof	36	15,220	548	656
	Ext wall/parapet	19	5700	108	

$W = 5(1315 \text{ kips}) + 656 \text{ kips} = 7231 \text{ kips}$

2. Calculation of the Design Base Shear and Load Combinations ASCE 7

2.1 CLASSIFY THE STRUCTURAL SYSTEM AND DETERMINE SPECTRAL ACCELERATIONS

Per ASCE 7 Table 12.2-1 for steel buckling-restrained braced frame:

$$\boxed{R = 8.0 \quad \Omega_0 = 2.5 \quad C_d = 5.0}$$

2.2 APPROXIMATE PERIOD

Determine the approximate fundamental building period using Section 12.8.2.1:

$C_t = 0.03$ and $x = 0.75$ T 12.8-2

$T_a = C_t h_n^x = 0.03 \times 72^{0.75} = 0.74$ sec (see the following discussion) Eq 12.8-7

$$\boxed{T_a = 0.74 \text{ sec}}$$

2.3 DESIGN SPECTRAL ACCELERATIONS

As discussed in Appendix A, because this value is greater than the limiting period T_{DS}, Method 1 will be used to determine the design base shear.

For $C_u T_a = 0.74$ seconds, the value of S_a is interpolated between the values at 0.5 and 0.75 seconds; this results in:

$$S_a = 0.78$$

$$C_s = \frac{S_a}{R/I_e} = 0.097$$

This exceeds the Section 12.8.1 minima presented in Appendix A.

The spectrum is shown in Figure 3-3.

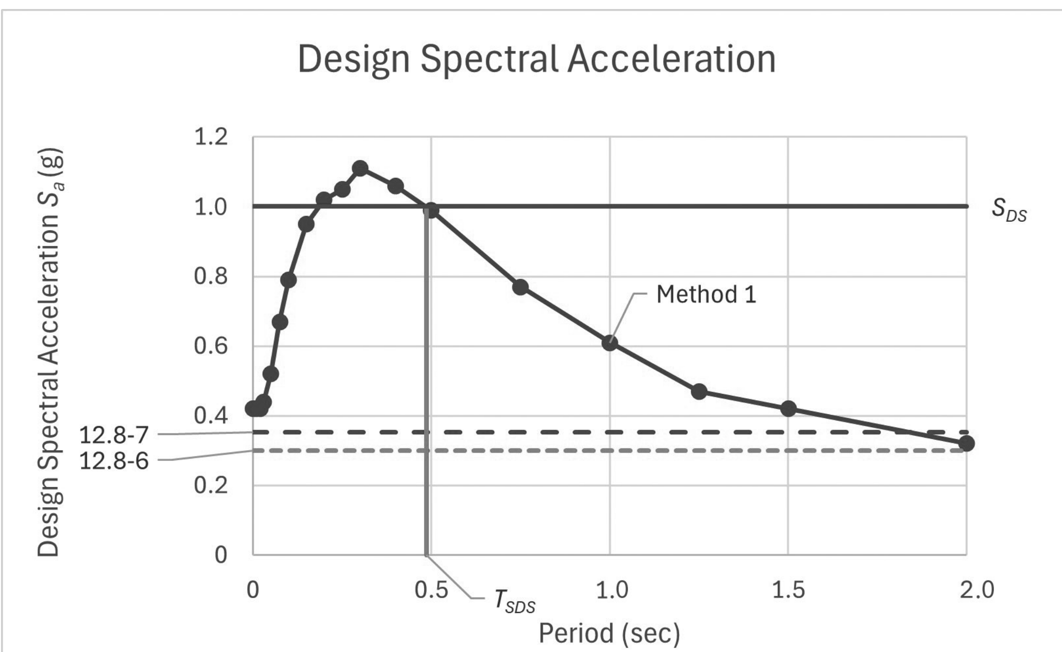


Figure 3-3. Design response spectrum for the example building

The response spectrum demonstrates the effect of the assumptions used in the calculation of the building period. Values of $C_t = 0.03$ and $x = 0.75$ were selected as specified for steel buckling-restrained braced frames, which result in an approximate period $T_a = 0.74$ sec. As shown later in this example, drifts are close to, if not at, the story drift limits of Section 12.12.

The period of the structure can be established through structural analysis of the BRBF. Section 12.8.2, however, limits the period that can be used to calculate spectral acceleration to a value of $T_{\max} = C_u \times T_a$, where C_u is a factor found in Table 12.8-1. In this case, $T_{\max} = 1.4 \times 0.74 = 1.04$ sec. For preliminary design, the approximate period, T_a, will be used to design the BRBF, and the period of the building will be verified later in the design process. The first mode period of the final design shown in Figure 4-14 was calculated to be 0.97 second and 0.87 second in the longitudinal and transverse directions, respectively; therefore, the initial assumption of $T = 0.74$ sec is shown to not only be valid, but still quite conservative.

2.4 HORIZONTAL IRREGULARITIES — T12.3-1

1. Torsional Irregularity—A torsional irregularity exists when the maximum story drift computed, including accidental torsion, is more than 1.2 times the average story drift. The 3D computer analysis later in this example provides the displacement at the corners of the building. The following shows the calculation for earthquake load case in X-direction with positive accidental eccentricity:

Table 3-2. Story displacements, line 1 and line 5, torsional irregularity check

Story	δ_x @ Line 5	δ_x @ Line 1	δ_{avg}	$\delta_{max}/\delta_{avg}$
Roof	1.35	1.10	1.22	1.10
6th	1.19	0.97	1.08	1.10
5th	0.94	0.76	0.85	1.10
4th	0.68	0.55	0.62	1.11
3rd	0.44	0.36	0.40	1.11
2nd	0.22	0.18	0.20	1.11

$\boxed{\text{NO TORSIONAL IRREGULARITY: } \delta_{max}/\delta_{avg} < 1.2}$

2. Reentrant corner irregularity exists where both plan projections of the structure beyond a reentrant corner are greater than 20 percent of the plan dimension of the structure in the given direction. The plan projections in longitudinal and transverse directions are 30 feet. The plan dimensions are 150 feet and 120 feet in the longitudinal and transverse direction respectively:

   30 ft/150 ft = 20% in the longitudinal direction → NO REENTRANT CORNER IRREGULARITY EXISTS

   30 ft/120 ft = 25% in the transverse direction → REENTRANT CORNER IRREGULARITY EXISTS

3. to 5. By inspection, the building does not qualify for any of these horizontal structural irregularities.

> REENTRANT CORNER IRREGULARITY EXISTS
>
> Per Section 12.3.3.4, forces for the connections of diaphragms to vertical elements and collectors and the design of collectors and their connections must be increased by 25 percent. If forces for the design of collectors and their connections are calculated using seismic-load effects including the overstrength factor, the 25 percent increase is not required.

2.5 VERTICAL IRREGULARITIES **T12.3-2**

1a. to 4b. By inspection, the building does not qualify for any of the vertical structural irregularities.

> NO VERTICAL STRUCTURAL IRREGULARITIES

2.6 LATERAL FORCE PROCEDURE **T12.6-1**

1. Simplified Alternative Structural Design Criteria—According to Section 12.14.1.1, this analysis procedure can be used for BRBF, but not for buildings over three stories—NOT PERMITTED
2. Equivalent Lateral Force Analysis—PERMITTED
3. Modal Response Spectrum Analysis—PERMITTED
4. Seismic Response History Procedures—PERMITTED

> USE EQUIVALENT LATERAL FORCE ANALYSIS

2.7 BASE SHEAR

$$V = C_s W = 0.097 \times 7231 = 704 \text{ kips} \qquad \text{Eq 12.8-1}$$

$$\boxed{V = 704 \text{ kips}}$$

2.8 REDUNDANCY FACTOR

According to Section 12.3.4, the redundancy factor should be calculated for each principal axis. The redundancy factor is 1.3 unless either Section 12.3.4.2(a) or Section 12.3.4.2(b) is shown to be true, in which case the redundancy factor can be taken as 1.0. Section 12.3.4.2(a) and Table 12.3-3 require that for each story resisting more than 35 percent of the base shear, removal of an individual brace or connection thereto would not result in more than a 33 percent reduction in story strength, nor does the resulting system have an extreme torsional irregularity.

Additionally, two frames must be present on each side of the center of mass. In this example, one of the east-west frames is on the center of mass, which is considered to meet this provision.

There are a total of six BRBs and eight BRBs at each level in the longitudinal and transverse directions, respectively; thus, by inspection, removal of an individual BRB would not result in more than a 33 percent