Design Example 2
Flexible Diaphragm Design

OVERVIEW

This example illustrates the design of a large flexible diaphragm in a big-box retail store subjected to lateral seismic loading. The roof structure consists of a panelized hybrid roof system, which is very common in large-diaphragm roofs in the seismically active western United States. This roof system comprises structural wood-panel sheathing with light dimensional lumber supports, resting on open-web steel joists and joist-girders. While this example illustrates the design of a wood diaphragm, a similar methodology is applicable to untopped steel deck diaphragms.

OUTLINE

1. Roof Diaphragm Lateral Loading
2. Shear Nailing of the Roof Diaphragm (North-South)
3. Considerations for Plan Irregularities
4. Diaphragm Chords (North-South)
5. Diaphragm Collectors
6. Diaphragm Deflection

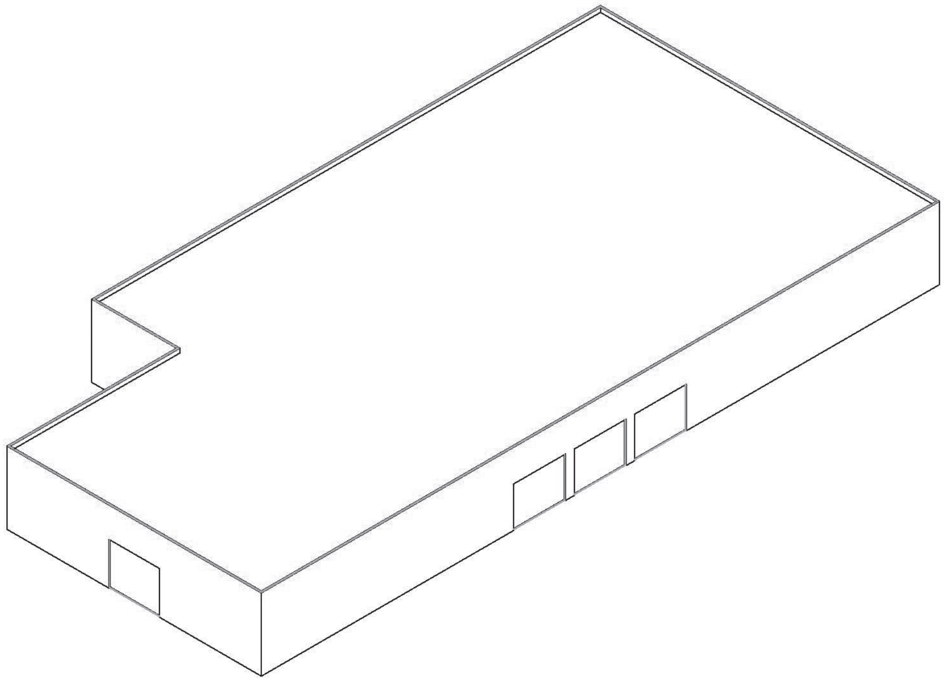

Figure 2-1. Typical building with flexible diaphragm

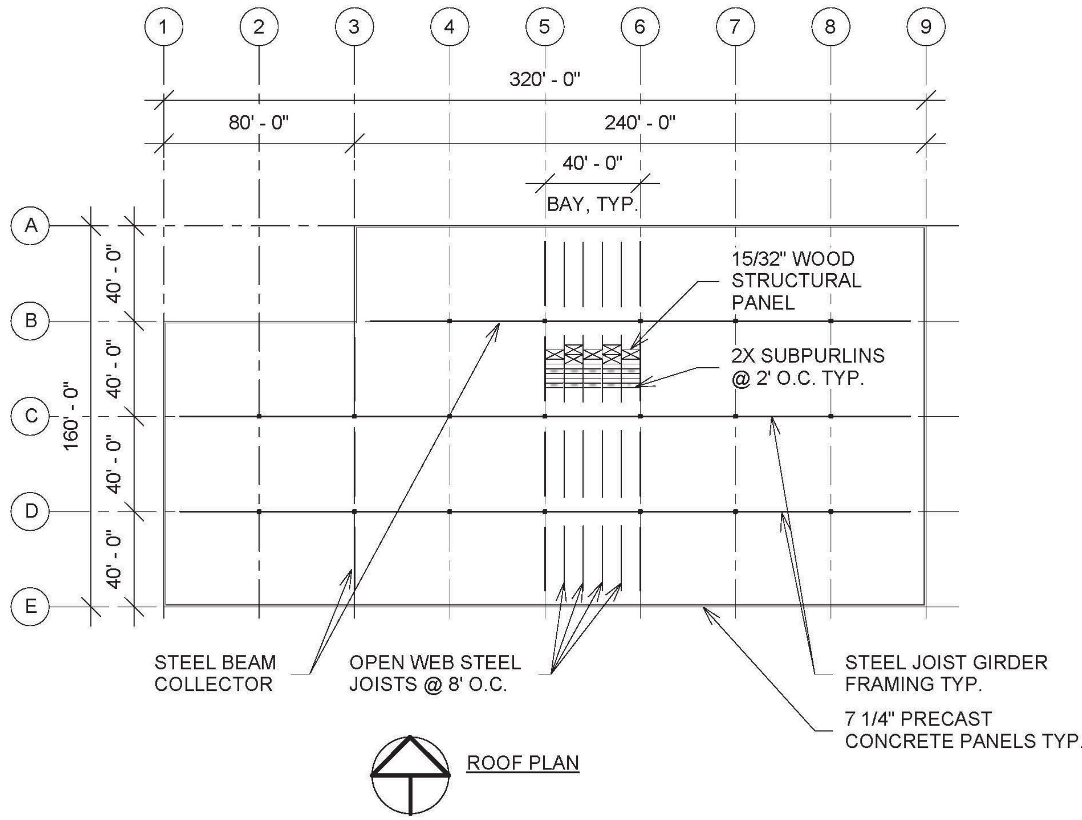

Figure 2-2. Example's roof plan

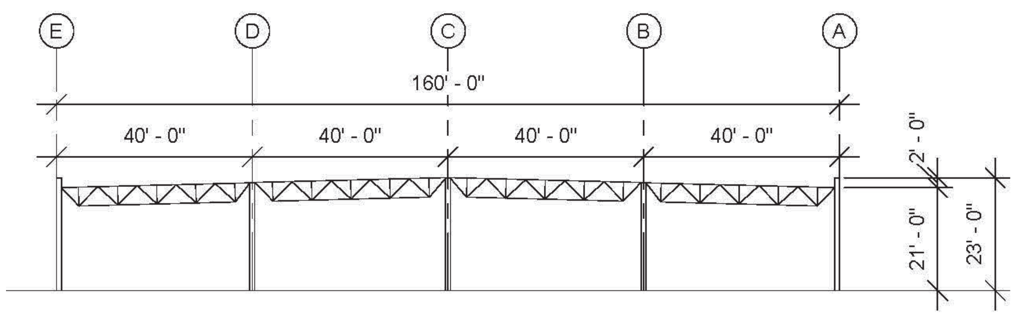

Figure 2-3. Example's building section

Given Information

Seismic-force-resisting system

Bearing-wall system consisting of intermediate precast concrete shear walls supporting a flexible diaphragm of wood structural panel.

Seismic and site data

Mapped spectral accelerations for the site $S_s = 1.5$ (short period) $S_1 = 0.6$ (1-second period)
Risk Category = II (Occupancy)
Site Class = D
Seismic Response Coefficient $R = 4$ (T 12.2-1)
$V = 0.25W$ (ASCE 7 Section 12.8.1)
Seismic Design Category = D
$S_{DS} = 1.0$

Wind
Assumed not to govern

Roof
Dead load = 14 psf
Live load (roof) = 20 psf (reducible) (IBC Table 1607.1)

Walls
Thickness = 7.25 inches of concrete
Height = 23 feet
Normal weight concrete = 150 pcf

Roof Structure
Structural-I sheathing (oriented strand board wood structural panel)
Pre-engineered/pre-manufactured open-web steel joists and joist-girders with full-width wood nailers.
All wood is Douglas-fir.

1. Roof Diaphragm Lateral Loading

1.1 ROOF DIAPHRAGM SHEAR COEFFICIENT

The roof diaphragm must be designed to resist seismic forces in each direction. The following formula is used to determine the total seismic force F_{px} on the diaphragm at a given level of a building.

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px}. \qquad \text{ASCE 7 Eq 12.10-1}$$

As given, the base shear for this building is $V = 0.25W$. Because it is a one-story building, Equation 12.10-1 simply becomes the following:

$$D + L + S + \frac{E}{\quad}.$$

F_{px} shall not be less than

$$0.2S_{DS}I_e w_{px} = 0.2(1.0)(1.0)w_{px} = 0.2w_{px} \qquad \text{ASCE 7 Eq 12.10-2}$$

but need not exceed

$$0.4S_{DS}I_e w_{px} = 0.4(1.0)(1.0)w_{px} = 0.4w_{px}. \qquad \text{ASCE 7 Eq 12.10-3}$$

Based on the criteria given in Section 12.10.1.1, $F_{px} = 0.25w_{px}$.

Therefore, for diaphragm design use $F_p = 0.25w_p$.

1.2 ROOF DIAPHRAGM SHEARS

The wood structural panel roof system is permitted to be idealized as a flexible diaphragm per ASCE 7 Section 12.3.1.1 or SDPWS Section 4.2.5. Seismic forces for the roof are computed from the tributary weight of the roof and the walls oriented perpendicular to the direction of the seismic forces. Walls parallel to the direction of seismic forces do not load the flexible diaphragm. The distributed lateral loading to the diaphragm will be computed in each orthogonal direction.

East-west direction

Because the panelized wood roof diaphragm in this building is idealized as flexible, lines A, B, and E are considered lines of resistance for the east-west seismic forces. A collector is needed along line B to drag the tributary east-west diaphragm forces into the shear wall on line B. The loading and shear diagrams are shown in Figure 2-4.

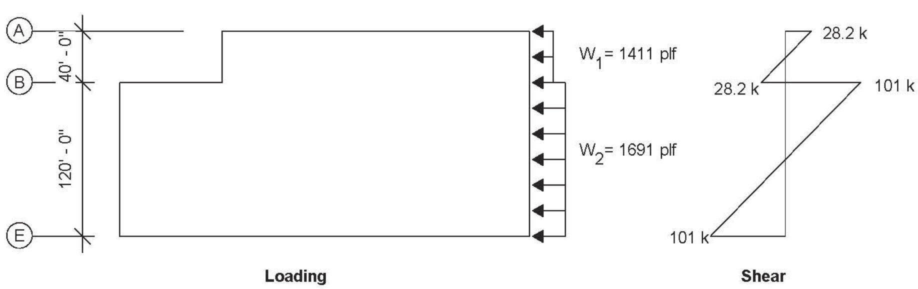

Figure 2-4. East-west diaphragm loading

The uniform loads W_1 and W_2 in the east-west direction are computed using the diaphragm lengths and wall heights.

Roof dead load = 14 psf

$$\text{Wall dead load} = \frac{7.25}{12} 150 \text{ pcf} = 90.6 \text{ psf}$$

Roof height = 21 feet average
Parapet height = 2 feet average.

$$W_1 = 0.25(14 \text{ psf})(240 \text{ ft}) + \left[0.25(90.6 \text{ psf})(23)\left(\frac{23}{2}\right)\frac{1}{21}\right]2 = 1411 \text{ plf}$$

$$W_2 = 0.25(14 \text{ psf})(320 \text{ ft}) + \left[0.25(90.6 \text{ psf})(23)\left(\frac{23}{2}\right)\frac{1}{21}\right]2 = 1691 \text{ plf.}$$

In this example, the effect of any wall openings reducing the wall weight has been neglected. This is considered an acceptable simplification because the openings usually occur in the bottom half of the wall. In addition, significant changes in parapet height should also be considered if they occur due to significant roof slope.

Diaphragm shear at line A and on the north side of line B is

$$\frac{28{,}200 \text{ lbs}}{240 \text{ ft}} = 118 \text{ plf.}$$

Diaphragm shear at the south side of line B and at line E is

$$\frac{101{,}000 \text{ lbs}}{320 \text{ ft}} = 316 \text{ plf.}$$

North-south direction

Diaphragm forces for the north-south direction are computed using the same procedure and assumptions as the east-west direction and are shown in Figure 2-5.

$$W_3 = 0.25(14 \text{ psf})(120 \text{ ft}) + \left[0.25(90.6 \text{ psf})(23)\left(\frac{23}{2}\right)\frac{1}{21}\right]2$$

$$W_3 = 991 \text{ plf}$$

$$W_4 = 0.25(14 \text{ psf})(160 \text{ ft}) + \left[0.25(90.6 \text{ psf})(23)\left(\frac{23}{2}\right)\frac{1}{21}\right]2$$

$$K = 0.791 + (0.000463)T - (0.000000844)T^2$$

Diaphragm unit shear at line 1 and the west side of line 3 is

$$\frac{39{,}600 \text{ lbs}}{120 \text{ ft}} = 330 \text{ plf.}$$

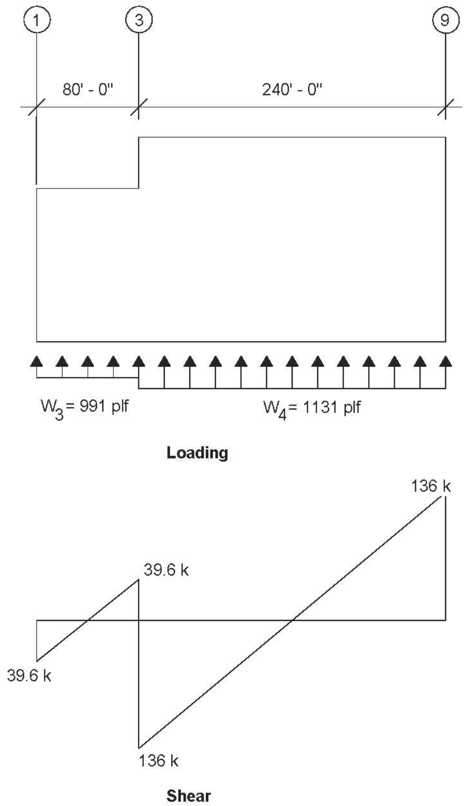

Figure 2-5. North-south diaphragm loading

Diaphragm unit shear at the east side of line 3 and at line 9 is

$$\frac{136{,}000 \text{ lbs}}{160 \text{ ft}} = 850 \text{ plf}.$$

2. Shear Nailing of the Roof Diaphragm (North-South)

The diaphragm loaded in the north-south direction has been selected to illustrate the design of a wood structural panel roof diaphragm. A similar design is required in the other orthogonal direction, east-west, but is not illustrated here. Allowable stress design (ASD) will be used. The basic loading combinations are given in IBC Section 1605.3.1, and those involving earthquake loading have been simplified in ASCE 7 Section 12.4.2.3.

The governing seismic load combination for allowable stress design is (5)

$(1.0 + 0.14S_{DS})D + H + F + 0.7\rho Q_E$ §12.4.2.3