Design Example 1
Four-Story Wood Light-Frame Structure

OVERVIEW

This design example illustrates the seismic design of selected elements for a four-story wood-frame hotel structure. The gravity-load framing system consists of wood-frame bearing walls. The lateral-load-resisting system consists of wood-frame bearing shear walls (common box-type system). A typical building elevation and floor plan of the structure are shown in Figures 1-1 and 1-2, respectively. A typical section showing the heights of the structure is shown in Figure 1-3. The wood roof is framed with pre-manufactured wood trusses. The floor is framed with prefabricated wood I-joists. The floors have a 1½-inch lightweight concrete topping. The roofing is composition shingles.

When designing this type of mid-rise wood-frame structure, there are several unique design elements to consider. The following steps provide a detailed analysis of some of the important seismic requirements of the shear walls per the 2018 IBC. This design example represents a very simple wood-frame wood structure; most wood-frame structures have several unique features requiring engineering design and detailing not shown in this design example.

This design example is not a complete building design. Many aspects have not been included, specifically the gravity-load framing system, and only certain steps of the seismic design related to portions of a selected shear wall have been illustrated. In addition, the lateral requirements for wind design related to the selected shear wall have not been illustrated (only seismic). The steps that have been illustrated may be more detailed than what is necessary for an actual building design but are presented in this manner to help the design engineer understand the process. For a more detailed listing of the items not addressed, see Section 10.

OUTLINE

1. Building Geometry and Loads
2. Calculation of the Design Base Shear
3. Location of Shear Walls and Horizontal Distribution of Shear
4. Mechanics of Multistory Segmented Shear Walls and Load Combinations
5. Mechanics of Multistory Shear Walls with Force Transfer around Openings
6. The Envelope Process
7. Design and Detailing of Shear Wall at Line C
8. Diaphragm Deflections to Determine if the Diaphragm Is Flexible
9. Discontinuous System Considerations and the Overstrength Factor
10. Special Inspection and Structural Observation
11. Items Not Addressed in This Example

1. Building Geometry and Loads — ASCE 7

1.1 GIVEN INFORMATION

The roof is $^{15}/_{32}$-inch-thick DOC PS 1- or DOC PS 2-rated wood structural panel (WSP) sheathing, with a 32/16 span rating and Exposure I adhesive or waterproof adhesive.

The floor is $^{23}/_{32}$-inch-thick DOC PS 1- or DOC PS 2-rated Sturd-I-Floor 24 inches o.c. rating, with a 48/24 span rating (40/20 span rating with topping is also acceptable) and Exposure I adhesive or waterproof adhesive.

DOC PS 1 and DOC PS 2 are the US Department of Commerce (DOC) prescriptive and performance-based standards for plywood and oriented strand board (OSB), respectively.

Wall framing is a "modified balloon framing" where the joists hang from the walls in joist hangers. (See Figure 1-7 detail of this and an explanation of other common framing conditions.)

Framing lumber for studs and posts — NDS T 4A

Douglas Fir-Larch-No. 1 Grade unadjusted design values:

F_b = 1,000 psi
F_c = 1,500 psi
$F_{c\perp}$ = 625 psi
F_t = 675 psi
E = 1,700,000 psi
$E_{\min}$ = 620,000 psi
C_M = 1.0 dry in-service conditions assumed
C_t = 1.0 normal temperature conditions assumed

Framing lumber used for studs and posts is designed per the National Design Specification® (NDS®) for Wood Construction and NDS Supplement: Design Values for Wood Construction. Only two end-use adjustment factors are shown here. Others will be defined and shown later in the design example.

Common wire nails are used for shear walls, diaphragms, and straps. When specifying nails on a project, specification of the penny weight, type, diameter, and length (example 10d common = 0.148 inch × 3 inches) are recommended.

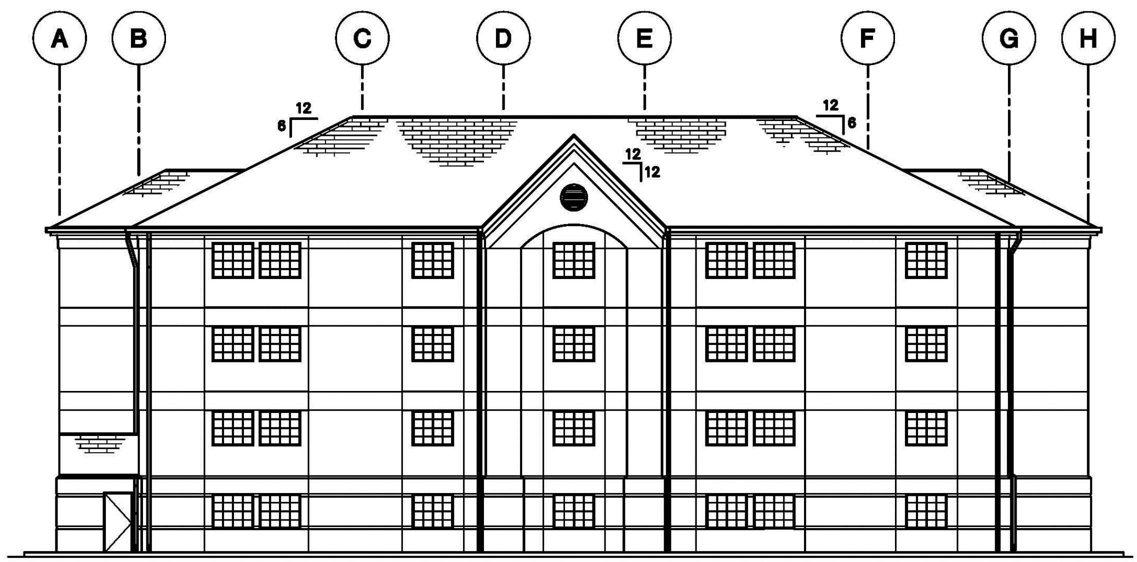

Figure 1-1. Building elevation

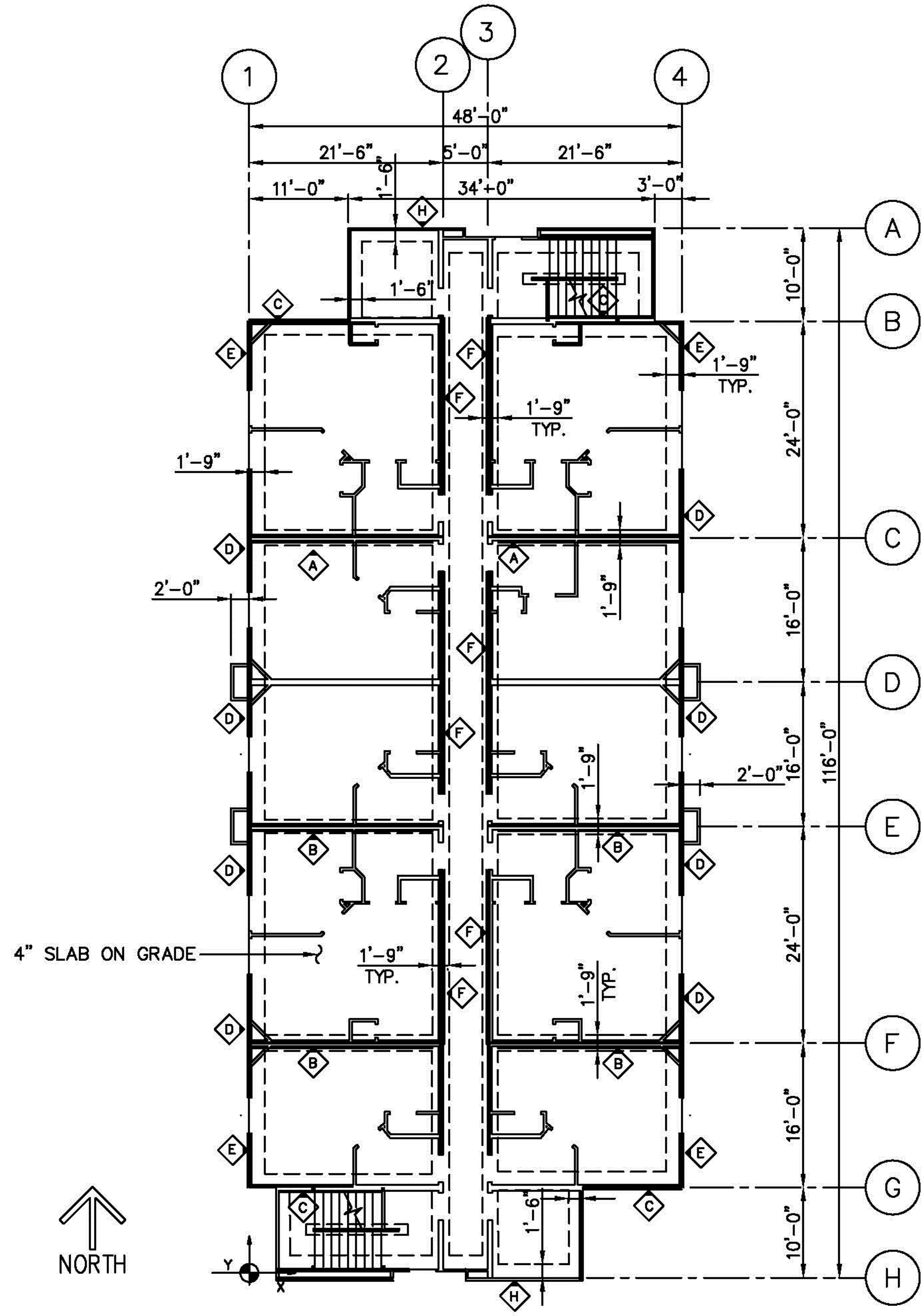

Figure 1-2. Typical foundation plan

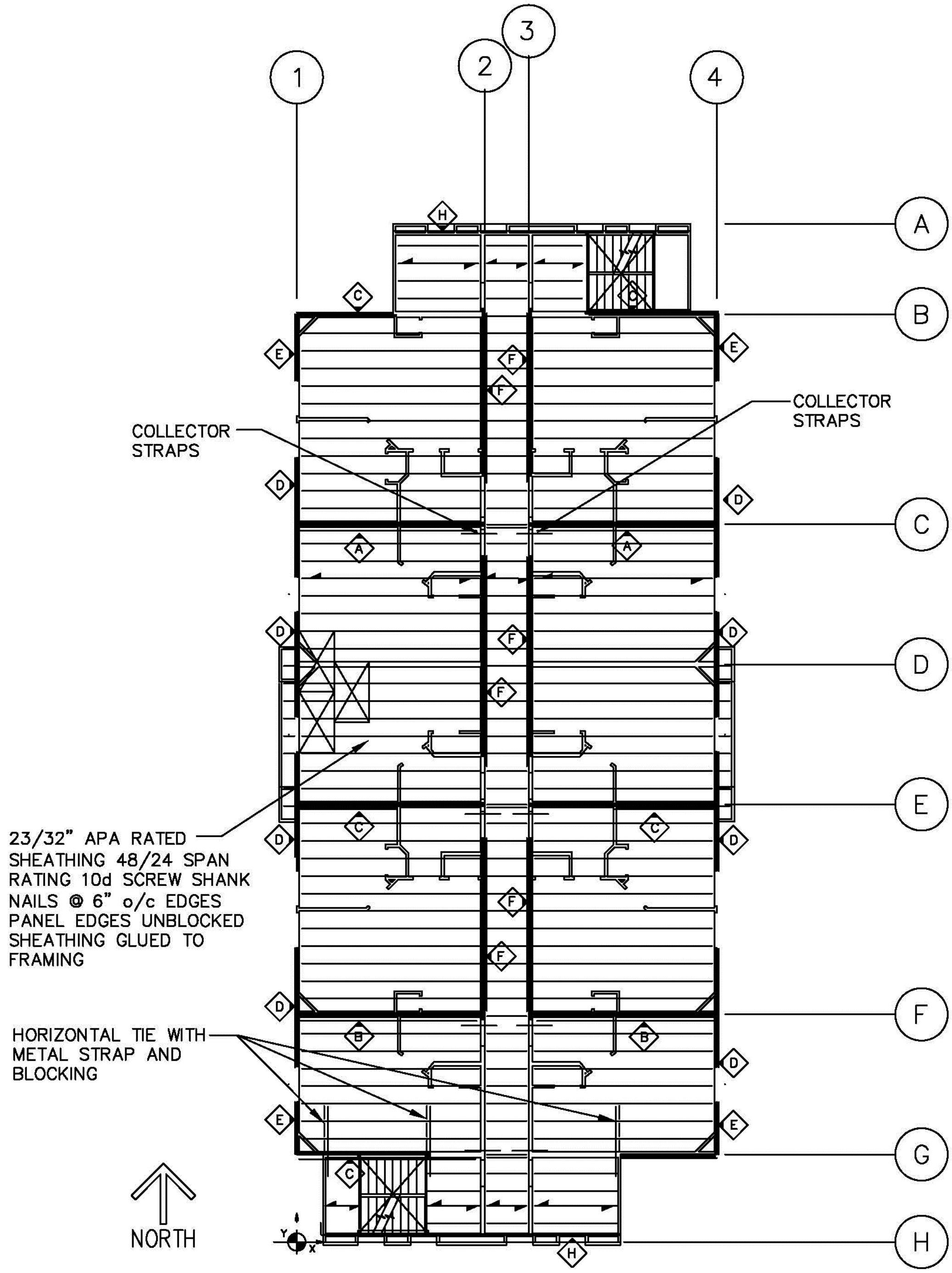

Figure 1-3. Typical floor framing plan

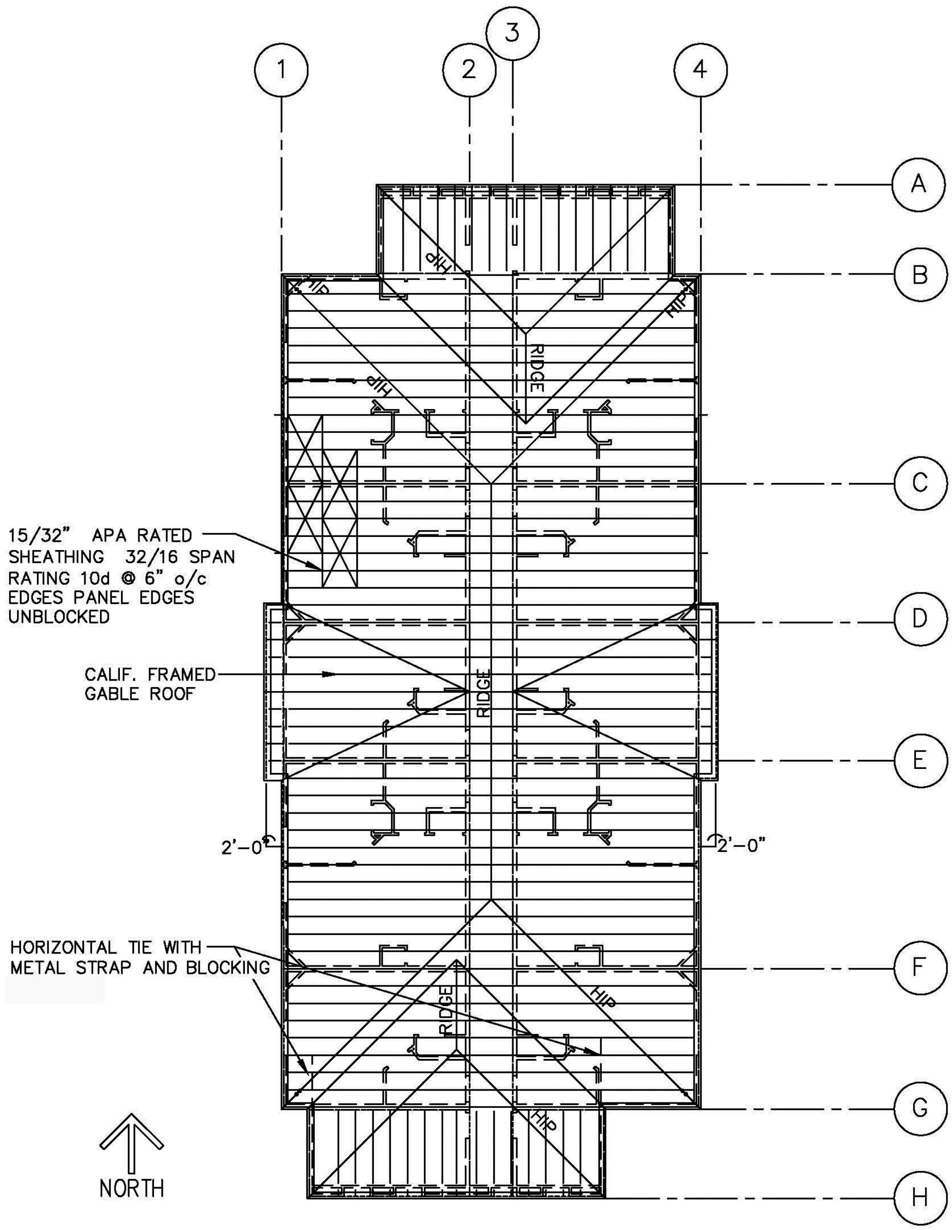

Figure 1-4. Typical roof framing plan

Notes for Figures 1-2 through 1-4:

1. Nonstructural "pop-outs" on the exterior walls at lines 1, 4 need special detailing showing the wood structural panel sheathing running continuous at lines 1, 4 and the pop-outs framed after the sheathing is installed.

2. All walls stack from the foundation to the fourth floor.

3. ◇ Designates sheathed wall per shear-wall schedule (see Table 1-35).

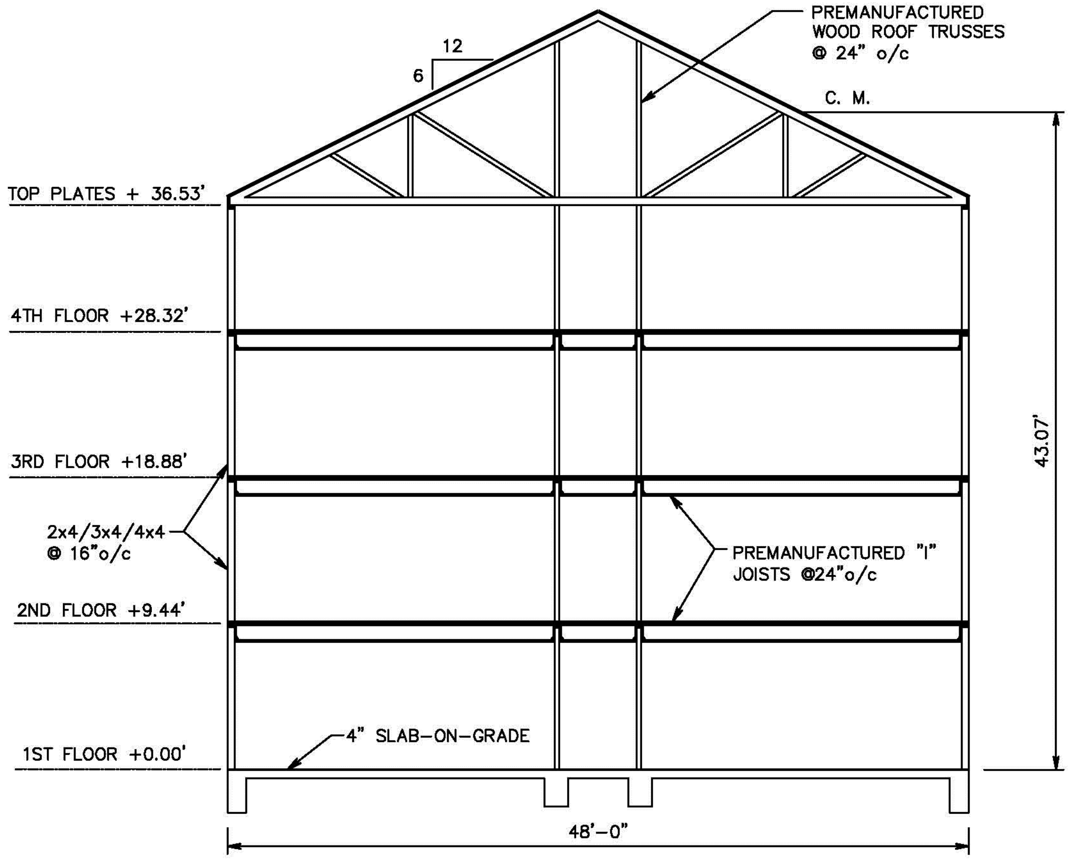

Figure 1-5. Typical building sections

Notes for Figure 1-5:

The center of mass of the roof is higher than one-third of the "triangle" shape plus the blocking height over the top plates due to the weight of the roofing re-roof, and sheathing is heavier than the weight of the ceiling. A conservative height equal to the center of the roof diaphragm (average height of the sloped roof) has been used in this design example.

1.2 FACTORS THAT INFLUENCE DESIGN

Prior to starting the seismic design of a structure, the following must be considered:

Good Shear-Wall Construction Detailing Guidance

Use oriented strand board (OSB) sheathing rather than plywood for improved stiffness.

Use distributed nailing to end studs and plates. This reduces the need to stitch multi-ply end studs and reduces potential framing split damage due to putting all nails in a single 2× end framing member. In a typical high-strength wall test, placing all the nails in the outermost stud tends to increase compression perpendicular to grain deformation in the bottom plate that is flush with the end stud.

Provide greater than minimum nail edge distance at OSB panel edges. Putting nails at ⅜ inch from the panel edge increases the potential for nonconforming construction, even in testing. Because some nails will be closer than ⅜ inch, it places panel edge fastening in the outermost stud of a multi-ply stud pack, which might lead to splitting damage even if the outermost row of nails is staggered (per above), and in some cases promotes earlier occurrence of panel edge tear out relative to distributed nailing.

Use concentric hold-downs or continuous tie-down systems rather than eccentric hold-downs. Data from both shear-wall testing with continuous rods and from prior wood shear-wall testing with conventional hold-down devices on both sides of a built-up 2 × 6 end stud performed better than tests with a single conventional hold-down on the inboard side of the wall.

Provide at least equivalent strength and stiffness (including the participation of finishes) at first-level lateral system elements as compared with the second level. Consider nonstructural walls (especially when such walls do not stack down to the building base) when evaluating lateral system layout for weak and/or soft story conditions.

Species of Lumber

The species of lumber used in this design example is Douglas Fir-Larch (DF-L), which is common on the west coast. The author does not intend to imply that this species can or should be used in all areas or for all markets. Species that are both appropriate for this type of construction and locally available vary by region and commonly include (among others) Southern Pine (SP) and Spruce Pine Fir (SPF).

Grade of Lumber

The lower two stories of the wood-frame structure carry higher gravity loads than the upper two stories. One approach is to use a higher grade of lumber for the lower two stories than the upper two stories. This approach can produce designs that yield a consistent wall construction over the height of the building. Another approach is to choose one grade of lumber for all four wood-frame stories. This approach produces the need to change the size and/or spacing of the studs based on the loading requirements. Sill-plate crushing may control stud sizing at lower levels. For simplicity, this design example illustrates the use of one lumber grade for all floor levels.

Figure 1-6. Typical grade stamp

Notes for Figure 1-6:

a. Certification Mark: Certifies association quality supervision

b. Mill Identification: Firm name, brand, or assigned mill number

c. Grade Designation: Grade name, number, or abbreviation

d. Species Identification: Indicates species by individual species or species combination

e. Condition of Seasoning: Indicates condition of seasoning at the time of surfacing