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 2021 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.

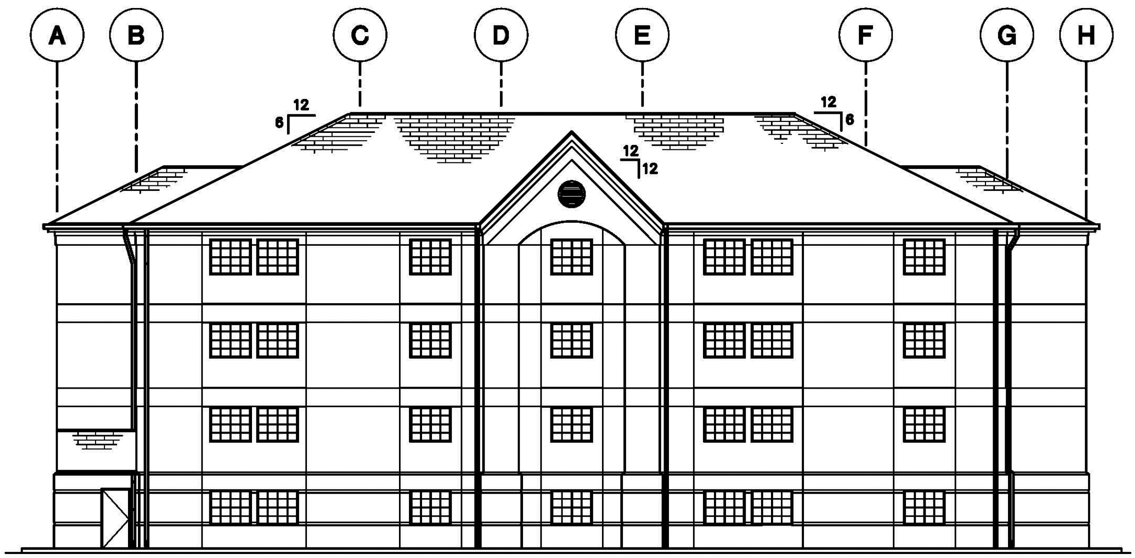

Figure 1-1. Building elevation

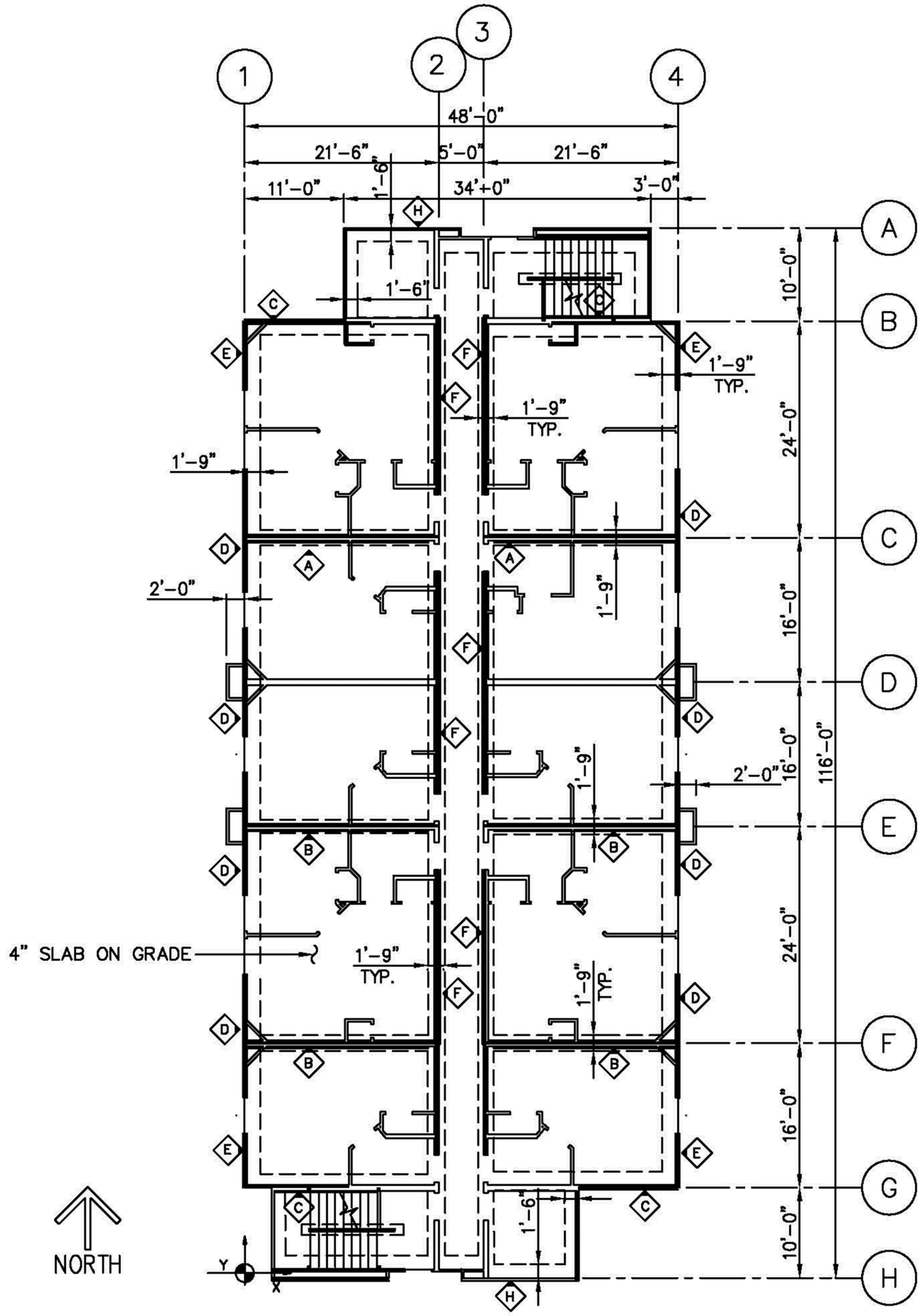

Figure 1-2. Typical foundation plan

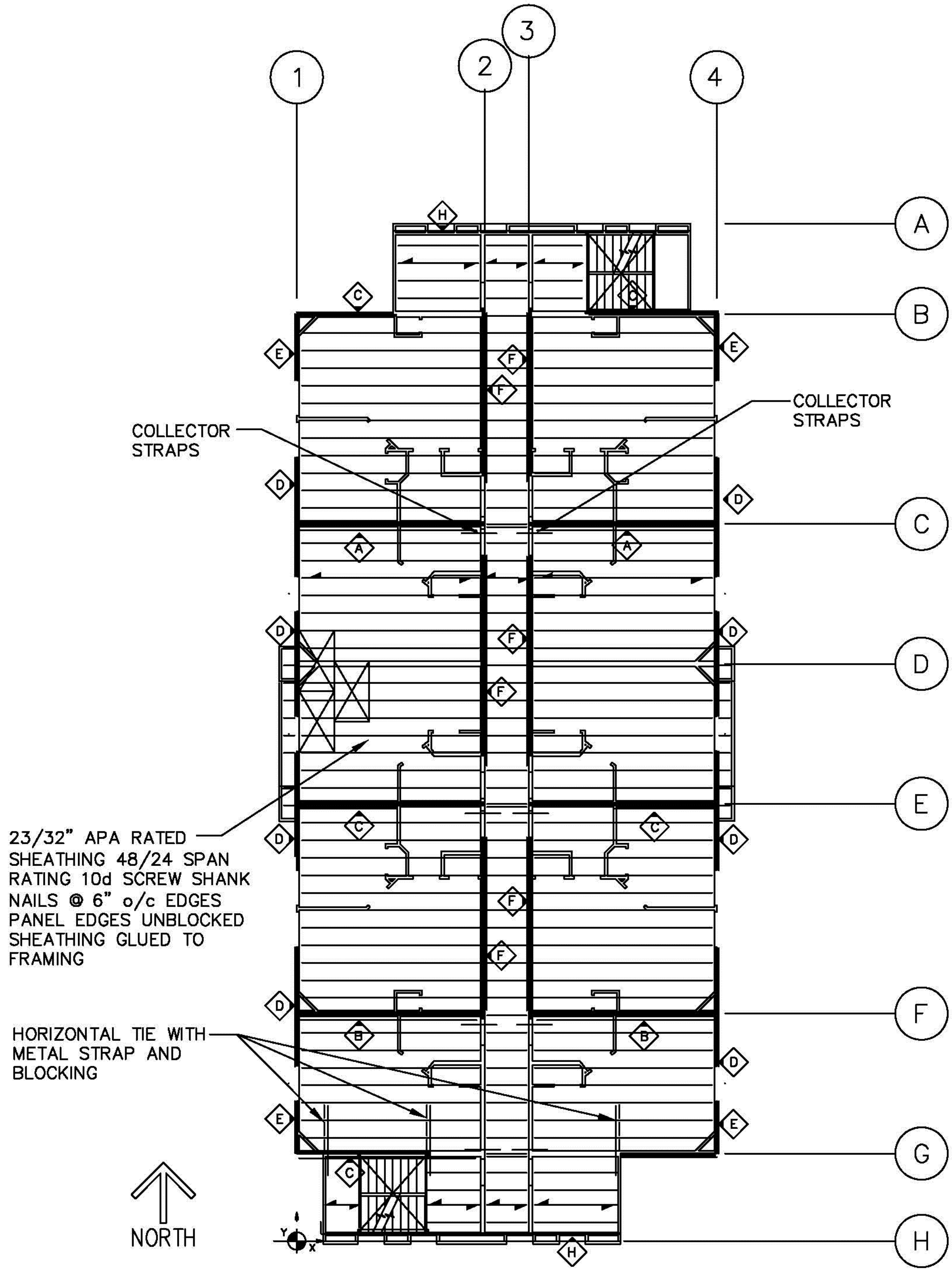

Figure 1-3. Typical floor framing plan

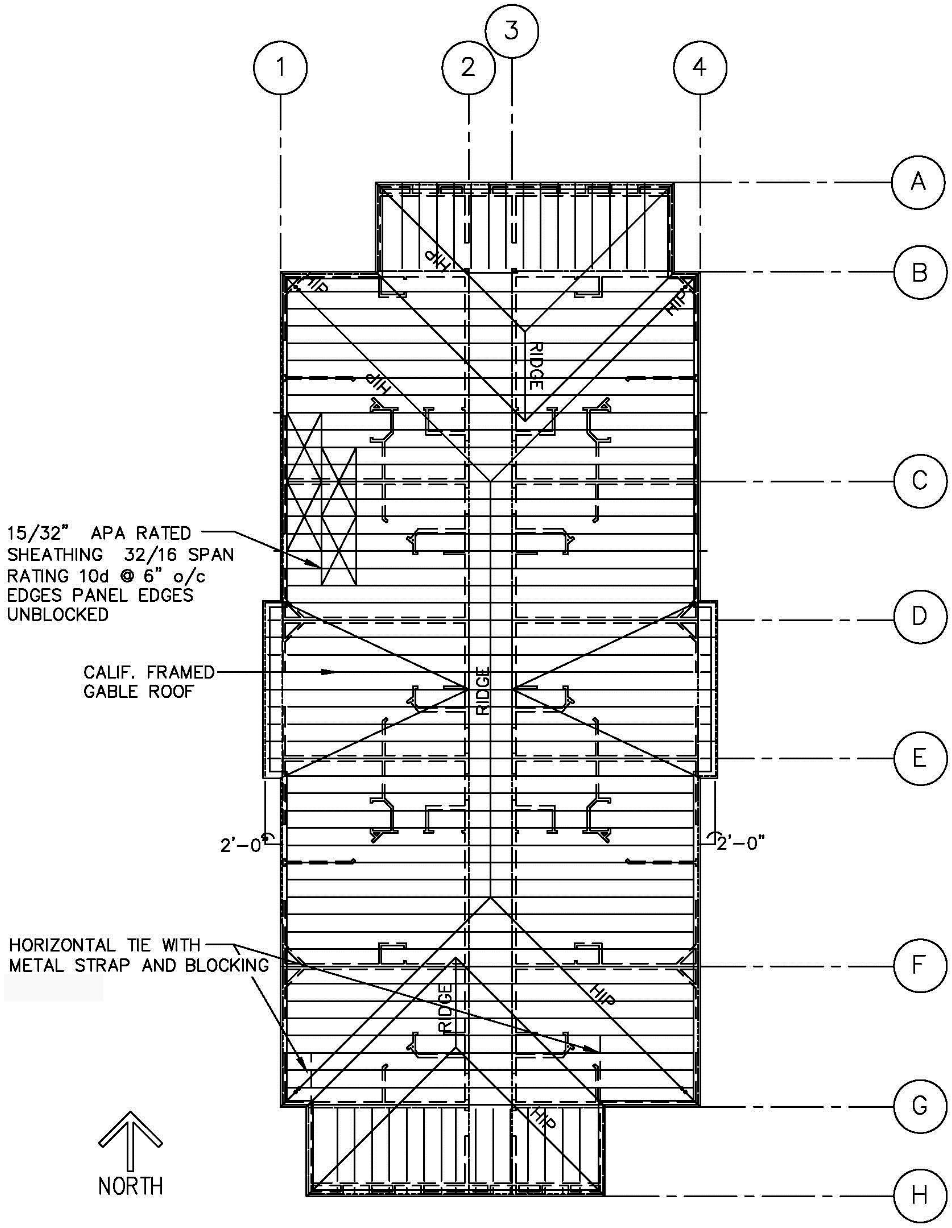

Figure 1-4. Typical roof framing plan

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).

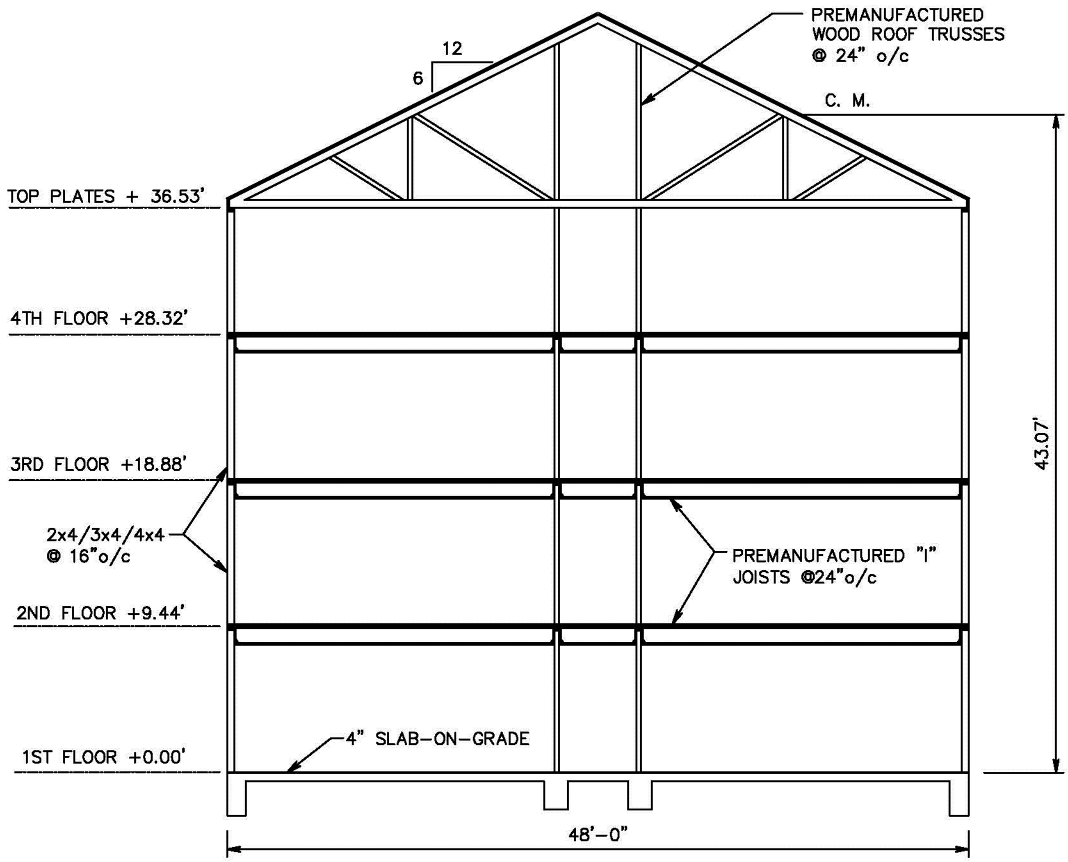

Figure 1-5. Typical building sections

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:

Commentary on Nail Lengths for Diaphragms and Shear Walls

The *2021 Special Design Provisions for Wind and Seismic* (SDPWS) lists the dimensions for the prescribed nails (e.g., 10d common, 8d common) for diaphragms and shear walls. Previous editions of SDPWS listed only the prescribed nail without the associated dimensions. The 2021 SDPWS does not have an associated "reduction factor" for nail lengths that are less than the standard dimensions of the prescribed nails (e.g., 10d common, 8d common) listed in the diaphragm and shear wall tables. This commentary will discuss the reasons for the change in SDPWS and possible problems for the structural designer as well as construction issues for new and existing construction.

To determine the minimum nail lengths required for diaphragm and shear wall sheathing attachment, building designers have been using nails of diameter associated with the prescribed nails and the "minimum fastener penetration in framing member or blocking" listed in the diaphragm and shear wall tables. This approach facilitated the use of "short" nails known by building designers and contractors to produce fewer splitting problems with the framing members. Likewise, "short" nail lengths instead of full-length nails have been listed on the structural drawings as meeting the minimum sheathing fastener requirements. Specific nail lengths were then purchased by the contractor to meet the minimum, and special inspectors would then check that these lengths were being installed in the field. Other building designers would simply specify that 8d common or 10d common nails be used without specifying nail length, in effect, leaving the decision of nail length to the contractor. Some building engineers would specify the full-length nail.

<u>Terms</u>

Common Nail Sizes: (shank diameter × nail length × head diameter)

8d common nail size: 0.131″ × 2½″ × 0.281″

10d common nail size: 0.148″ × 3″ × 0.312″

Common "Short" Nail Sizes

8d common nails and 10d common nails have the same diameter and head sizes but are available in varying lengths, ranging from 1⅞ inches to 2⅛ inches.

Power Actuated Fasteners (Nail Guns)

Framers use power tools (nail guns), either chorded or cordless, for two basic nail types: finish nails (finish nailer) and framing nails (framing nailer). The framing nailers can accommodate all nail sizes. While some engineers have a misconception that a nail gun can accommodate only "short" nail sizes, nails guns can handle all commonly used nail sizes (including 16d × 3½″ nails).

<u>Testing on Diaphragms and Shear Walls</u>

Testing on Diaphragms

APA—The Engineered Wood Association tested full-scale diaphragms with "short" common nails in their 1966 testing (Tissell, 1967) and their testing of high-load diaphragms following the 1971 San Fernando earthquake (Plywood Diaphragms: APA Report 138, 2000). In the 2000 revision of APA Report 138, it states "past APA diaphragm tests have demonstrated an adequate margin of shear strength (e.g., load factor) when nailed sheathing connections provided penetration of 11× the nail diameter." Based on the diaphragm tests, APA 138 recommends a reduction factor of 1.5/1.625 (i.e., 0.92) for 10d "short" nails with 1½-inch embedment into the main member.