Design Example 3
Cold-formed Steel Light-frame Three-story Structure

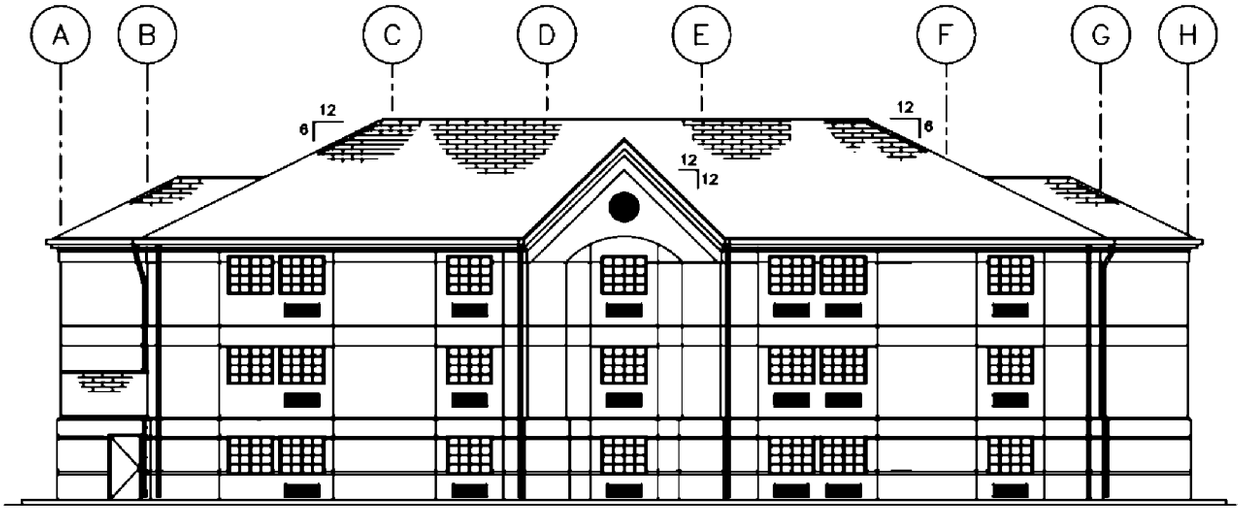

Figure 3-1. Cold-formed light-frame three-story structure elevation

Foreword

The building in this example has cold-formed light-gage steel framing, and shear walls and diaphragms that are sheathed with wood structural panels. This example presents a new approach to the seismic design of this type of building. This is because past and present design practice in seismic design of light-framed structures has almost exclusively considered flexible diaphragm assumptions when determining shear distribution to shear walls. However, since the 1988 UBC, there has been a *definition* in the code (§12.3.1.1 of ASCE/SEI 7-05) that defines diaphragm flexibility. The application of this definition often requires the use of the rigid diaphragm assumption, and calculation of shear wall rigidities for distribution to shear walls. While the latter is rigorous and complies with the letter of the code, it does not reflect present-day practice. In actual practice, for reasons of simplicity and precedence, many structural engineers routinely use the flexible diaphragm assumption.

ASCE/SEI 7-05 exempts one- and two-family residential buildings of light-frame construction from a rigid or semi-rigid structural analysis (§12.3.1.1), while the 2009 IBC exempts nearly all diaphragms of light-frame construction from a rigid or semi-rigid structural analysis (IBC §1613.6.1). This design example will follow the ASCE/SEI 7-05 requirements.

A rigid diaphragm analysis is recommended where the shear walls can be judged by observation to be flexible compared to the diaphragm, and particularly where one or more lines of either shear walls, moment frames, or cantilever columns are more flexible than the rest of the shear walls.

This design example has floor diaphragms with lightweight concrete fill over the floor sheathing (for sound insulation), making the diaphragms significantly stiffer than those determined by using the standard IBC diaphragm deflection equations.

Before beginning design, users of this manual should check with the local jurisdiction regarding the level of analysis required for cold-formed light-framed structures.

Overview

This design example illustrates the seismic design of a three-story, cold-formed (i.e., light-gage) steel structure. The structure is shown in Figures 3-2, 3-3, and 3-4. The building in this example is the same as in Design Example 2, with the exception that light-gage metal framing is used in lieu of wood. The structure has wood structural panel shear walls, and roof and floor diaphragms. The roofs have composite shingles over the wood panel sheathing that is supported by light-gage metal trusses. The floors have 1½ inches of lightweight concrete fill and are framed with metal joists.

The following steps illustrate a detailed analysis of some of the important seismic requirements of the ASCE/SEI 7-05. As stated in the introduction of the manual, this example is not a complete building design. Many aspects have not been included, and only selected steps of the seismic design have been illustrated. As is common for Type V construction (see ASCE/SEI 7-05, Chapter 6), a complete wind design is also necessary, but is not given here.

Although code requirements recognize only two diaphragm categories, flexible and rigid, the diaphragms in this example are judged to be semi-rigid because the diaphragms do deflect. The code also requires only one type of analysis, flexible or rigid. The analysis in this design example will use the *envelope* method. The envelope method considers the worst loading condition from both flexible and rigid diaphragm analyses to determine the design load on each shear-resisting element. It should be noted that the envelope method is not a code requirement, but is deemed appropriate for this design example, because neither flexible nor rigid diaphragm analysis may accurately model the structure.

This Design Example illustrates wood structural panel shear walls over light-gage metal studs. This serves as a direct comparison to Design Example 2. Other types of bracing are available (e.g., steel sheets and flat strap).

Outline

This example will illustrate the following parts of the design process

1. **Design base shear and vertical distribution of seismic forces**
2. **Rigidities of shear walls**
3. **Distribution of lateral forces to the shear walls**
4. **Reliability/redundancy factor ρ**
5. **Tiedown forces for shear wall on line C**

6. **Allowable shear and nominal strength of No. 10 screws**

7. **Diaphragm deflections to determine if diaphragm is flexible or rigid**

8. **Tiedown connection at third floor for wall on line C**

9. **Tiedown connection at second floor for shear wall on line C**

10. **Boundary studs for first floor shear wall on line C**

11. **Shear transfer at second floor on line C**

12. **Shear transfer at foundation for walls on line C**

13. **Shear transfer at roof at line C**

Given Information

Roof weights (slope 6:12):		**Floor weights:**	
Roofing	3.5 psf	Flooring	1.0 psf
½-inch sheathing	1.5	Lt. wt. concrete	14.0
Trusses	3.5	⅝-inch sheathing	1.8
Insulation	1.5	Floor framing	5.0
Miscellaneous	0.7	Miscellaneous	0.4
Gyp ceiling	2.8	Gyp ceiling	2.8
DL (along slope)	13.5 psf		25.0 psf

DL (horiz. proj.) = 13.5 (13.41/12) = 15.1 psf

Stair landings do not have lightweight concrete fill

Area of floor plan is 5288 sq ft

Weights of respective diaphragm levels, including tributary exterior and interior walls

W_{roof} = 134,250 lb

$W_{3rd\ floor}$ = 228,750 lb

$W_{2nd\ floor}$ = 228,750 lb

W = 591,750 lb

The same roof, floor, and wall weights used in Design Example 2 are used in this example to better illustrate a side-by-side comparison of cold-formed light-gage steel construction with the more traditional wood frame construction used in Design Example 2. This side-by-side comparison gives the engineer a better "feel" for the similarities and differences between

structures with wood studs and structures with cold-formed metal studs. It should be noted that roof, floor, and wall weights for light-gage steel-framed structures are typically lighter than similar structures having wood framing. Because light-gage steel-framed structures are lighter, a more accurate estimate of building weight for this structure would be about 560 kips instead of the 591.75 kips used in this example. Consequently, wall shears and overturning forces would be reduced accordingly.

Weights of diaphragms are typically determined by taking one-half the height of walls at the third floor to the roof and full height of walls for the third- and second-floor diaphragms.

Wall framing is ASTM A653, grade 33, 4-inch by 18-gage metal studs at 16 inches on center (o/c). These have a 1⅝-inch flange with a ⅜-inch return lip (see Figure 3-14). Stud tracks are to have a minimum flange width of 1¼ inches. The ratio of tensile strength to yield point is at least 1.08. Studs are painted with primer. ASTM A653 steel is one of three ASTM steel specifications used in light-frame steel construction. The others are A792 and A875. The differences between the specifications are primarily the coatings that are galvanized, 55 percent aluminum-zinc (A792), and zinc-5 percent aluminum (A875), respectively. The recommended minimum coating classifications are G60, AZ50, and GF60, respectively. It should be noted that the studs do not require painting with primer.

It should also be noted that changing stud sizes or thicknesses of studs at various story heights is common (as in wood construction). The thickness of studs and tracks should be identified by visible means such as coloring or metal stamping of gages/sizes on studs and tracks.

DOC PS-1 or PS-2-rated wood structural panels with a trademark of an approved testing and grading agency (APA or TECO performance) for shear walls will be 15/32-inch-thick Structural-I, 32/16 span rating, 5-ply with Exposure I glue is specified.

Framing screws are No. 8 by 1-inch wafer head self-drilling with a minimum head diameter of 0.285 inch, as required by AISI-Lateral.

The roof is 15/32-inch-thick DOC PS-1 or PS-2-rated sheathing, 32/16 span rating with Exposure I glue.

The floor is 19/32-inch-thick DOC PS-1 or PS-2-rated Sturd-I-Floor 24-inch o/c rating (or APA-rated sheathing, 48/24 span rating) with Exposure I glue.

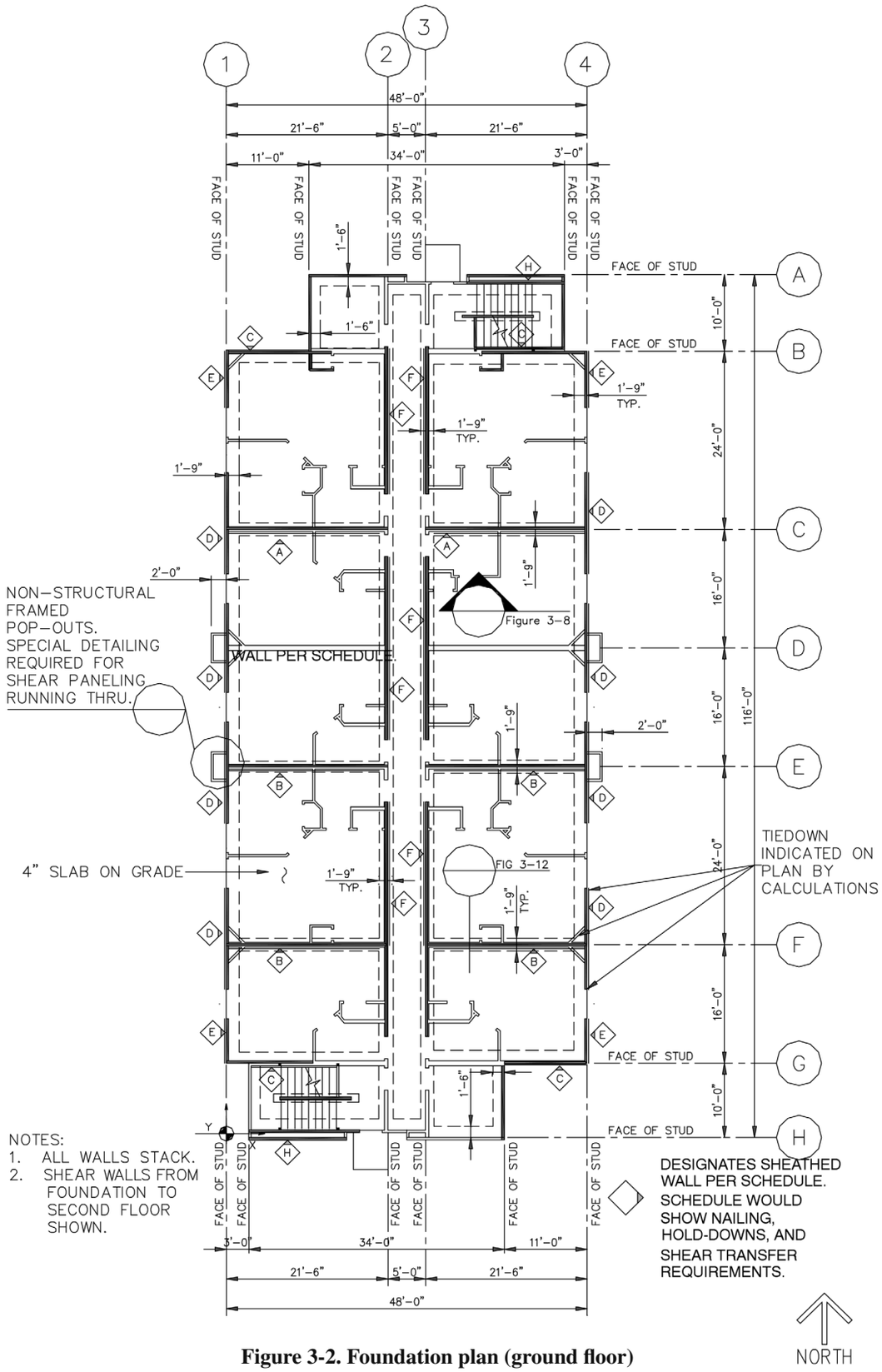

Figure 3-2. Foundation plan (ground floor)