High Rise Wood Frame Construction

Cornerstone Condominiums

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Case Study

The Cornerstone Condominium Building is a six-story mixed-use structure located in downtown Portland, Oregon, USA. The building consists of a five-story wood framed structure above a one-story concrete structure. When designing four to five story, or "high rise", wood frame buildings, there are some unique structural aspects that should be considered during the design process.

Project Description

The Cornerstone Condominium Building is located at the corners of 12th Street and Jefferson Avenue in downtown Portland. (*Figure 1*) The occupancy consists of retail spaces at the ground story with 46 residential units in the upper five stories. The building is rectangular in plan with dimension of 50- by 100-feet and a total area of 32,500 square feet. The total building height is 65 feet, with a typical residential story height of 10 feet and ground-level story height of 15 feet. The project was completed in August, 2000, with a total construction cost of $3.4 million (U.S.).

Currently, to the best of the author's knowledge, the only two municipalities in the United States that allow five-story wood frame buildings are Seattle, Washington and Portland, Oregon. Over the past 10 years there have been several high rise wood frame buildings constructed in the City of Portland, of which Cornerstone Condominiums is one.

Figure 1: Cornerstone Condominiums

Building Code Review

The *1997 Uniform Building Code* (UBC) allows up to 4 stories of Type V-1 Hour construction, provided fire protection systems are installed. However, the City of Portland Title 24.85 statutes allow an additional story for Type V-1 Hour provided the following requirements are satisfied:

- Type V-1 Hour (up to 5 stories) over Type I Construction with 3-Hour Separation (i.e. concrete slab),
- Top four stories must be R-1 Occupancy,
- Fire Protection System throughout entire structure,
- Maximum total building height of 65 feet, and
- Fire Fighting Access requirements.

In addition, supplemental special inspections are required for the wood framed portion of the structure, primarily of the lateral force resisting elements. The additional required inspections include nailing of floor and roof diaphragms and shear walls, installation of metal strapping, holdowns, collectors, and stud wall sill and top plate connections.

Structural Systems

Gravity Load Resisting System

The typical wood frame floor consisted of ¾-inch plywood supported by pre-engineered I-joists and Parallel Strand Lumber (PSL) beams and headers. Interior and exterior wood stud bearing walls support the floor framing. The roof framing consisted of pre-manufactured, "gang-nailed" metal plate connected wood trusses.

The second floor consisted of a 13-inch, one-way cast in place concrete slab supported by 16- by 26-inch beams spaced at 17 feet on center. During design, additional attention was given to the concrete slab since it supported the five-story wood frame structure constructed above. The second floor was supported by a combination of concrete columns and concrete masonry unit bearing walls. The need for open storefront on the 12th Street and Jefferson Avenue sides of the building resulted in concrete piers and spandrel beams. The foundation consisted of conventional concrete spread footings placed on native soil or compacted fill.

Lateral Load Resisting System

The five-story wood building relied on a combination of interior and exterior plywood shear walls for lateral force resistance. The ground story concrete structure utilized a combination of concrete masonry unit shear walls and concrete pier & spandrel frames.

Based on the large difference in lateral stiffness between the "flexible" wood frame building and the "rigid" ground-story concrete structure, a two stage static lateral analysis was used in accordance with the 1997 UBC. Using the two stage analysis, the wood and concrete portions are each analyzed as separate buildings for the prescribed UBC lateral forces. However, as part of the concrete building analysis, in addition to its own earthquake lateral force demands, the earthquake base shear of the wood building is also applied to the concrete building.

Structural Design Elements

Wood Stud Framing

The wood stud bearing walls at the lower stories are required to carry significant vertical loads. Based on these high vertical load demands, the wood stud material grade varied over the height of the building. At the 2nd and 3rd stories (1st and 2nd wood stories), Select Structural grade lumber was used, while Douglas Fir #1 grade lumber was used in the 4th through 6th stories. The change in material grade was used to provide uniformity of the stud wall construction over the height of the building.

Alternatively, the Douglas Fir #1 grade could have been used throughout the height of the building, but a reduction in the center to center spacing of the wood stud framing would have been required. Based on experience, we have found that when designing wood frame construction, using the fewest number of pieces and keeping the framing system consistent typically provides the highest level of construction quality.

Figure 2: Perforated Shear Wall Elevation

Wood Shrinkage

One of the most significant performance issues associated with a high rise wood frame building is wood shrinkage. Typically, on the west coast, wood is installed in the "green" condition, with a moisture content ranging from 19% to 23%. After installation, the wood will dry as it achieves equilibrium with the surrounding atmosphere. During the drying process, the wood will shrink, with the majority of the shrinkage occurring across the grain of the wood.

If solid sawn, green lumber is used for both the stud wall plates and the floor joist, the vertical movement due to shrinkage could be conservatively estimated at ½- to ¾-inch per floor level. When added up over the height of a five-story building, the vertical movement due to shrinkage can be significant. If not properly addressed, the vertical movement may result in damage to interior finishes, exterior cladding and water proofing assemblies.

To minimize the effects of wood shrinkage, engineered wood products, such as I-joists and PSL beams, were used for construction of the typical floor framing. Based on the manufacturing process and the types of materials used, engineered wood products are produced with a low moisture content, resulting in minimal member shrinkage.

For this project, the use of solid sawn wood members was limited to the interior and exterior stud walls. Since shrinkage of wood parallel to grain is very small, green lumber was used for all vertical wood stud and post framing. However, to minimize shrinkage, kiln-dried lumber (moisture content < 15%) was used for all stud wall sill and top plate members.

Regardless of the wood framing material used, a five-story wood frame building will shrink. One strategy to minimize the impact of shrinkage on the building finishes is to delay the start of interior finish installation as long as practical to allow most of the wood shrinkage to be realized. For this building, the project specifications required the measured in-place moisture content of the wood framing to be less than 12% prior to installation of gypsum wallboard sheathing. The contractor achieved the moisture content threshold by drying the wood framing with portable heaters throughout the building during construction.

Perforated Wood Shear Walls

Prior to the adoption of the 1997 UBC, only solid wood structural panel wall segments were allowed for use as shear wall elements. However, the 1997 UBC provisions allow for use of perforated wood shear walls as long as openings are reinforced to resist the expected force demands around the openings. Based on the limited number of interior wood shear walls, several perforated exterior wall segments were designed as wood shear walls. Metal straps nailed to the exterior sheathing were used to reinforce the openings contained within the shear wall segment. (*Figure 2*) This project was one of the first five-story wood frame buildings in the City of Portland to incorporate extensive use of reinforced, perforated wood shear walls.

Anchor Bolts and Embedded Plates

The attachment of wood shear walls to the concrete slab is typically accomplished either by drilling in mechanical or adhesive anchors after the slab is cast and cured or by casting anchor bolts directly into the slab. The use of cast in place anchor bolts is problematic when a precise location of the bolt is required. Misplaced anchor bolts can result in reduced shear wall capacity due to the bolts being too close to the edge of the wood sill plate. Alternatively, if anchor bolts are drilled into the slab, it should be anticipated that a portion of the reinforcing steel will be damaged by drilling. As a result, additional reinforcing is typically added to the top of the concrete slab to compensate.

However, for this project, there were several locations where the plywood shear walls aligned directly above the second floor concrete beams. The use of drilled in anchors may have resulted in damage to the top layer of longitudinal beam reinforcing. The design solution included the use of steel plates cast into the top of the second floor slab at locations of concrete beam and plywood shear walls. (*Figure 3*) The steel plates allowed the wood shear wall sill bolts to be field welded in place at the proper location and spacing without damage to the concrete beam reinforcing. In addition, this connection provided flexibility to the contractor since precise location of cast in place anchors was not required.

Wood Wall Sill Plate/Bolt Connection

The *1997 UBC/1991 NDS* requires that all sill plate bolt holes be no more than 1/16-inch larger than the bolt diameter. Typically wood stud walls are built laying down on a horizontal surface and then tilted up into place. This requires precise alignment between the layout of

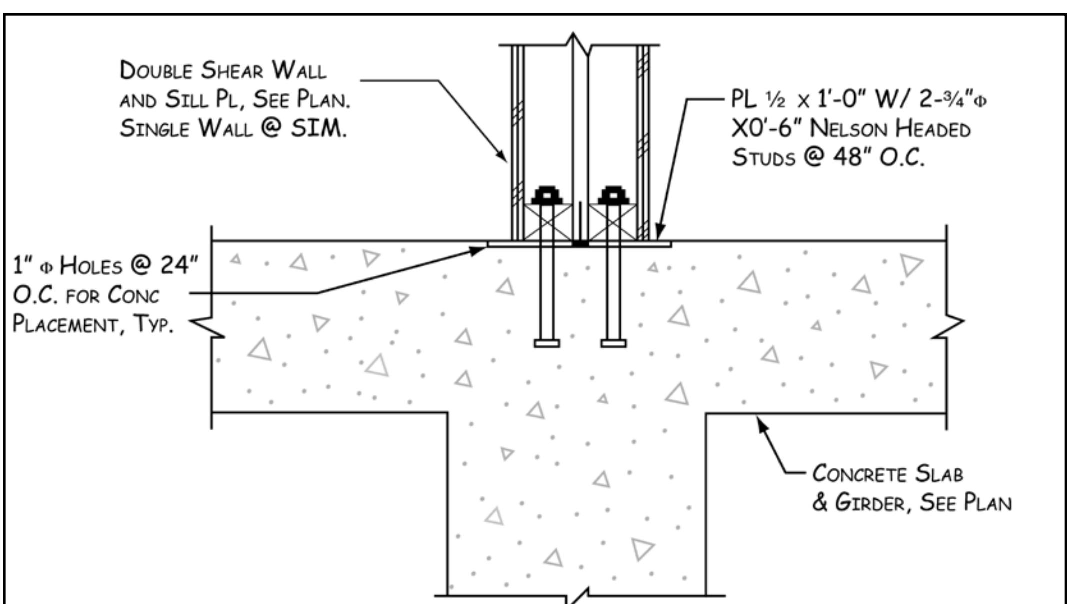

Figure 3: Steel Anchor Plate

Figure 4: Wall Sill Plate to Steel Anchor Plate Connection

the sill plate bolt holes and the anchor bolts. Based on the contractor's experience on previous projects, a request was made to use oversized bolt holes in the wood sill plate for ease of wall placement. The request for using an oversized hole was approved, but the contractor was directed to sleeve the inside of the oversized hole with a piece of metal electrical tubing. Then the annular space between the bolt and the tubing sleeve was filled with expansive cement grout. (*Figures 4* and *5*) This assembly provided a snug connection between the bolt and the sill plate.

Conclusion

The Cornerstone Condominium Building consists of five-stories of wood framed structure above a one-story concrete structure. The structural design and performance of high rise wood frame buildings require attention to issues that are usually not of great concern for the typical wood frame building less than four stories. Unique solutions are required to address issues such as the high vertical load demands on the wood stud framing, the transfer of shear wall loads and wood shrinkage.▪

Figure 5: Wall Sill Plate to Steel Anchor Plate Connection

At the time of design and construction of the Cornerstone Condominium Building the applicable building code in the State of Oregon was the *1997 UBC*. To the author's best knowledge, the 1997 UBC provisions identified in this paper can also be found in the *2003 International Building Code*, which is currently the primary applicable building code for a majority of the U.S.

Brian Knight, S.E., currently works for Axis Design Group in Portland, Oregon. This project was completed while Mr. Knight was employed at Degenkolb Engineers in Portland, Oregon.