Mid-rise Wood Frame Construction: Structural, Fire Safety, Environmental and Architectural Considerations

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Abstract

In the United States, low-rise wood construction is the predominant in residential construction. Mid-rise wood frame construction of 4 and more stories is increasingly popular in the last 30 years spreading across the country. Mid-rise wood frame buildings are being built atop of 1- to 2-story concrete construction to achieve even higher height. This type of construction project is common for apartments and condominiums, hotel and motels, and senior living facilities.

The International Building Code is used throughout the United States providing provisions for structural and fire safety considerations. Most recent projects of mid-rise wood frame construction are targeted to achieve levels in the Leadership in Energy & Environmental Design standards.

***Keywords*:** A. Mid-rise Wood Frame Construction, B. Structural, C. Fire Safety, D. Environmental, E. Architectural.

Introduction

In the United States, wood construction is predominant used in residential construction mostly 1 to 3 stories single family detached homes. Mid-rise wood frame construction of 4 and more stories is becoming popular in the United States and Canada. Started in the U.S. West Coast cities in the 80's, mid-rise wood frame construction has been spreading across the United States. Mid-rise wood frame buildings can be built atop of 1- to 2-story concrete construction to achieve even higher height. This type of construction is common for apartments and condominiums with amenities from affordable to luxury, hotel and motels in city centers as well as suburban areas, university student housing, and senior living facilities.

Designers have developed solutions to the design challenges. Code-compliant wood frame construction provides for good performance in safety for fire events, structural capacity during earthquakes and hurricanes, and serviceability.

In British Columbia of CANADA since 2009, the building code allows for mid-rise wood frame buildings of six stories. The Chinese code is being revised to make possible mid-rise construction of 3 stories of wood frame construction atop 4 stories of concrete construction.

United States Experience of Mid-rise Wood Frame Construction

Mid-rise wood frame buildings of 4 stories and higher in the United States can be built over 1- to 2-story concrete construction with or without 1- to 2-level underground parking. A typical development provides 40 to 250 living units and is required by building code to be of one-hour fire resistance rating. The parking garage is three-hour-rated minimum fire resistance. Figure 1 is the photos of a mid-rise wood frame building completed in 2010.

Figure 1: The MATISSE Apartment project in Portland, Oregon,United States completed in 2010 – Left: construction of 2-story underground reinforced concrete construction, Middle: 5-story wood frame over 1-story reinforced concrete with post-tension slab, Right: completed project. Photos: R&H Construction, General Contractor of the project.

Activation of the sprinklers as construction proceeds enhances fire protection during construction. The stairwells and elevator shafts require two-hour fire-resistance-rated wood frame or masonry construction. By using post-tensioning concrete slab to support the wood frame, the slab thickness is reduced to keep overall building height to the

minimum to be under the building code permitted allowable height. The typical size of apartment and condominium units is between 600 and 1,900 ft^2.

The use of 2x6 exterior wood frame wall is common to allow for the installation of thick insulation material to reduce heat loss in cold weather periods. The floor topping of lightweight concrete or gypcrete provides for enhanced sound control. Both solid-sawn lumber and/or wood I-joists are used to provide the floor framing. During construction of the wood frame, heaters and dehumidifiers may be used to reduce the moisture from the concrete and the wood framing materials.

High density housing. Many of the mid-rise wood frame construction projects are developed as high density housing achieving 100 to 140 units per acre. Figures 2, 3, 4, 5 and 6 showcase a number of high density housing projects.

Figure 2 Fashion Walk: 5 stories of wood frame over two levels of exposed concrete parking. A seven-story building utilizied a sloping site to pick up an additional story. Photos courtesy of Tim Smith, President, Togawa Smith Martin, Inc.

Figure 3 Esprit: A high density residential development of 5 stories wood frame over one level of concrete parking garage out. Photos courtesy of Tim Smith.

Figure 4 Americana: 5 story wood frame over one story retail podium of concrete construction. A typical European infill project creating high density housing with active retail base designed for 100 units per acre. Photos courtesy of Tim Smith.

Figure 5 Casa Heiwa: A 5-story wood framed building in California, built in 1995, achieved high density of 100 units per acre. Photos courtesy of Tim Smith, President, Togawa Smith Martin, Inc.

Figure 6 Union Square & Elan: 7 levels residential building - one level of concrete and 6 levels of wood framing. Density of 130-140 units per acre. Photos courtesy of Tim Smith, President, Togawa Smith Martin, Inc.

Environmental Benefits

Mid-rise wood frame projects are often targeted for certification to the Leadership in Energy & Environmental Design (LEED) standard. The use of wood in construction is environmentally friendly as carbon is stored in the wood used. The manufacturing of wood products produces greenhouse gas emissions significantly less than that from other building materials.

A carbon calculator from WoodWorks is available at www.woodworks.org for estimation of stored carbon dioxide equivalent in wood products used in construction projects.

Rick Bergman of the U.S. Forest Products Laboratory studied carbon impact factors for a range of wood products and its alternatives. With the use of life cycle assessment, he quantified the net CO_2 balance as total carbon footprint, see Table 1. He concluded that all wood products have a negative carbon dioxide balance from cradle-to-gate.

Product	Unit	Category	A	B	C	D	Alternative	E
Hardwood Lumber	One board foot	NE/NC	0.89	0.59	1.84	2.63	PVC	**-4.16**
	One board foot	SE	1.08	0.79	1.77	2.64	PVC	**-4.12**
Softwood Lumber	One 2x4 'stud'	NE/NC	1.85	1.23	6.63	6.97	Steel stud	**-13.0**
	One 2x4 'stud'	SE	3.90	3.32	8.42	7.01	Steel stud	**-14.9**
Wood Flooring	1 square foot	Solid wood	1.06	0.69	2.12	-0.13	Linoleum	**-1.61**
	1 square foot	Engineered	0.98	0.52	1.10	-0.22	Linoleum	**-0.42**
Doors	One door	Solid wood	46.5	29.4	100	228	Steel door	**-311**
Decking	One deck board	Treated pine	5.18	1.70	16.1	11.9	WPC	**-24.5**
Siding	100 square feet	WRC	37.7	5.96	77.7	20.4	Vinyl	**-66.3**
Poles	One 45' pole	Treated wood	454	431	1160	1380	Concrete	**-2520**
OSB	One 4'x 8' sheet	SE	19.0	10.7	34.7	-	n/a	**-26.3**
Plywood	One 4'x 8' sheet	PNW	5.72	4.13	25.5	-	n/a	**-23.9**
	One 4'x 8' sheet	SE	10.1	6.48	30.9	-	n/a	**-27.3**

Table 1 Carbon Impacts of Wood Products

The wood product carbon impact equation A-B-C-D = E

in which

A is Manufacturing Carbon
B is Bio-fuel
C is Carbon Storage
D is Substitution
E is Total Carbon Footprint or Carbon Credit

These data in Table 1 are compiled from life cycle assessment (LCA) of the various products. All "carbon" values are kilograms of CO_2. To convert from CO_2 to elemental carbon, multiply by 0.27. For comparison, a car produces 8.8 kg of CO_2 when it burns one gallon of gasoline.

U.S. Building Code

The International Building Code (IBC) is a model code used throughout the United States. Each local government adopts IBC with amendments to address local preferences and conditions. IBC provides provisions for safety considerations in design and construction of building structures including the allowable building height, number of stories and floor area for wood frame construction. These allowable can be increased when additional measures to provide for fire protection are used such as sprinkler system for fire suppression.

Designers has successfully addressed the design challenges from the increasing height of wood framed buildings that includes wood shrinkage, lateral shear force resistance, overturning moment resistance (including compression perpendicular to the grain on wood members and hold-down anchor design) and fire regulations (risk of fuel load and egress of occupants) that are requirements of IBC.

The IBC allows the ground floor, when non-combustible construction is used such as reinforced concrete, to be treated as a separate building when considering the limitation of number of stories. This is called podium construction as shown in Figure 7.

Figure 7: Podium Construction in San Francisco, California in 2010

Some local building regulations allow wood frame construction for up to five stories over a podium construction. The podium structure is limited to one story in Portland, Oregon, and to 2 stories in Seattle, Washington as shown in Figure 8.

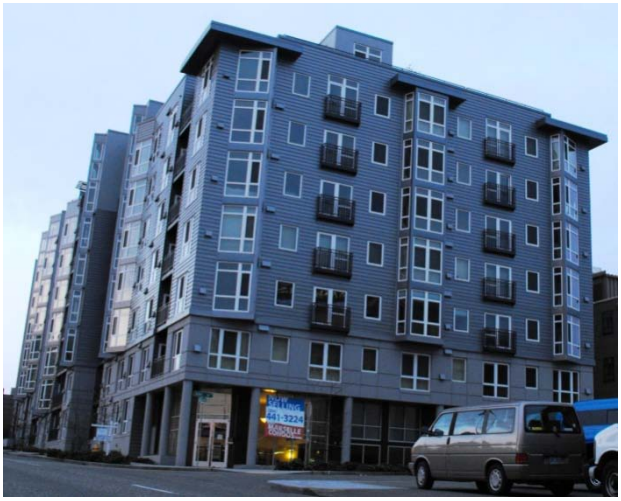

Figure 8: Marselle Condos in Seattle, Washington – a 160,000 square feet condo project of IBC Type III construction has five floors of wood construction over a two-story concrete podium construction.

Chinese Codes and Standards

Wood frame construction was introduced into China in the early 1990s. To provide design professionals, builders, and architects with guidelines on design and construction of wood frame construction, the Chinese code development body, in cooperation with industry associations from the U.S., Canada, and Europe, adopted the North American wood frame construction in 2003 in to the China Timber Structure Design Code GB50005. A three-story wood frame building in Shanghai is shown in Figure 9.

Figure 9: Three-story wood frame building in Shanghai, CHINA completed in 2004

Following the release of GB50005, the Chinese wood industry developed product standards in response to the need for conformity assessment and development of the wood frame construction market. These standards provide performance criteria for the use of engineered wood products in structural applications as alternatives to the solid sawn lumber products.

China timber structure design code (GB50005-2003). The most recent revision of the standard was completed in 2003. One major revision was the inclusion of design requirements on wood frame construction. Both prescriptive design method, which is primarily used in the design of floor and wall system, and engineered design method are provided in this version. Besides, design strength of shearwall and diaphragm are also included. Despite the fact that use of wood frame construction is limited in buildings up to three stories, the release of GB50005 paved the road for use of hybrid wood frame construction over three stories of concrete construction in the future. The committee of China Timber Structure Design Code is currently in the process of revising China Timber Structure Design Code (GB50005-2003) in the hope that more information about the use of engineered wood products and connection design will be included in the future.

Technical Specification for Wood Frame Construction (J11461-2009). Following the release of the China Timber Structure Design Code (GB50005-2003) in 2003, Shanghai local government developed this technical specification in 2009 in an effort to expand application of wood frame construction (WFC) method from three story WFC buildings to four story (one story concrete/masonry/steel buildings topped with three story WFC buildings) and five story (four story concrete/masonry/steel buildings topped with one story WFC buildings) hybrid construction buildings. Given the fact that design requirements on seismic resistance and durability issues covered in GB50005-2003 are not sufficient enough for designers to adequately perform their design services in some cases, this technical specification provides users with two separate chapters specifically dealing with these issues.

Chinese Building Fire Code (GB50016). Chinese Building Fire Code is a nationally enforced mandatory code, providing designers with design requirements on all the issues associated with fire safety design. In the most recently revised version, wood frame hybrid construction is allowed to be built up to seven stories (four story concrete/masonry/steel sub-structure + three story wood frame construction) as long as at least two hour fire resistance is provided between the substructure built with non-combustible material and superstructure constructed with wood frame construction. At the moment, this revised version is pending the official approval from Chinese government agencies. It is believed that the release of this standard will be helpful to significantly expand use of wood frame construction in multi-story residential as well as commercial buildings.

Technical Specification for Light-gauge Metal Plate Connected Wood Trusses. The design requirements on wood trusses provided in GB50005-2003 is insufficient and generic, which is hard to be used by designers when they run into projects associated with use of wood trusses. As such, the GB50005 committee, in cooperation with Canadawood, Europeanwood, MiTek and several other major truss manufacturers in China, developed the standard in 2010 in the hope to provide designers with viable method in design of wood trusses. The standard was developed based upon ANSI/TPI 1 – National Design Standard for Metal Plate Connected Wood Truss Construction and TPIC- Truss Design Procedures and Specifications for Light Metal Plate Connected Wood Trusses.