MULTI-STOREY WOOD FRAME CONSTRUCTION IN NORTH AMERICA

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ABSTRACT: Multi-storey wood frame construction is used throughout North America predominantly for multi-family residential housing. Wood is an economical choice building material compared to the higher priced steel and concrete structural components. The popularity of multi-storey wood frame condominium and rental apartment projects is spreading across America from coast to coast in major metropolitan areas to provide affordable housing to the growing population. Projects showcasing multi-story wood frame construction in North America are presented. A development of multi-storey wood frame buildings in Los Angeles, California built in 2006 is show below (photo: M. Kam-Biron).

KEYWORDS: Multi-storey, wood frame construction

1 INTRODUCTION

Multi-storey wood frame construction (Figures 1 and 2) is used for apartments/condos, motels/hotels and senior living facilities throughout the North America. These projects provide an economical solution to rising land and construction costs through reduced construction time and competitive material costs.

Wood is an economical choice compared to the higher priced steel and concrete structural components. Mixed construction with solid-sawn lumber and engineered wood products intermixed with reinforced concrete and/or steel structural assemblies provide new and exciting avenues in mixed-use projects. While multi-storey wood frame construction has predominantly been used for multi-family housing, it is also finding its way into new and innovative uses in impressive large-scale projects.

Most Americans live in the suburbs, residing in low-rise wood frame construction ranging from detached single-family houses to one- to three-story apartments and condos. Suburban growth has continued since the end of World War II, resulting in sprawl and increasing the costs for local governments in providing infrastructure and services such as streets, water, and waste management.

Figure 1: Pinnacle Pointe at Quail Ridge, Kelowna, BC, Canada, built in 2006 – a four-storey wood frame construction project atop one level of concrete parking

Today, American cities are planning for the shifting demographics and rising land costs by turning to denser

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and taller housing such as in-fill projects in the cities and suburban town centres to create affordable, healthy, sustainable communities and neighbourhoods that are transit-oriented and pedestrian-friendly (Figure 3). The easy access to public transit can reduce the need for parking spaces in these development projects.

![Figure 2: La Jolla Crossroads, La Jolla, California, built in 2007 – a five-storey wood frame construction project (plus one-story loft) atop one level of concrete parking; one building under construction (top) and completed units (bottom)](image)

The popularity of multi-storey wood frame construction for condominium and apartment projects is spreading across America. These wood frame projects are attracting developers and specifiers who are increasingly building projects certified to green building rating requirements to manage and reduce impacts to the climate and environment (Figure 4). Taller wood frame buildings are becoming a reality. In 2009, the building code in British Columbia, Canada, was revised to permit residential wood construction of six stories. Encouraged by government efforts to increase the use of wood, a number of wood frame projects are now being planned to the new maximum height. More information is available online at www.housing.gov.bc.ca/building/wood_frame/.

2 BUILDING CODES IN THE USA

U.S. building codes are flexible in giving designers a wide range of options for creating cost-effective and safe multi-storey wood frame designs. The 2006 edition of the International Building Code (IBC) is the most widely used U.S. model building code at the present time. IBC provides minimum provisions for life safety and property protection. States that do promulgate a statewide code have adopted the IBC with amendments specific to the state.

![Figure 3: Sitka Apartments, Portland, Oregon, completed in 2005 – a five-storey wood frame construction atop one level of concrete construction on ground floor. This project provides affordable apartments in a neighbourhood served by the public transit electric-operated street cars. The major focus of the building's environmental design was to reduce the use of energy and natural resources in the ongoing operation of the building.](image)
Thornton Place, Seattle, Washington, completed in 2009 – a development in a U.S. Green Building Council LEED-certified neighborhood (LEED-ND). The building is LEED Silver. The structure is five stories of wood frame construction atop two stories of concrete construction. This mixed-use project consists of condos and apartments as well as retail spaces. The developer’s goal is to transform an auto-centric shopping magnet into a vibrant, liveable, pedestrian-friendly neighborhood with entertainment, housing, public art, walking paths, and nearly three acres of green space around a new waterway. Southwest face (top) and South face (bottom) of the building.

2.1 COMBUSTIBLE AND NON-COMBUSTIBLE CONSTRUCTION

The IBC recognizes combustible construction in Building Types III, IV and V:

- Type III construction allows interior building elements to be wood but wood construction in exterior walls is limited to fire-retardant-treated wood,
- Type IV construction applies to heavy timber construction, and
- Wood framing is allowed in Type V construction.

Types I and II construction are generally limited to non-combustible materials (concrete and steel) with only limited applications for wood construction. Building Types are further classified as protected “A” (fire-resistive) and unprotected “B” based on the fire resistive requirements of walls, floors and roofs – fire resistance rating requirements for building elements per IBC Table 601. This system of five Types of construction and associated allowable building heights and areas was first developed about 75 years ago by the National Board of Fire Underwriters, now called the American Insurance Association.

2.2 ALLOWABLE BUILDING HEIGHT AND FLOOR AREA

The 2006 IBC prescribes maximum allowable building height and floor area in Table 503 for different construction Types, primarily to address life safety considerations and fire-fighting strategies. Allowable building area increases may be taken for open spaces around the perimeter of a building (yards, courts, parking areas and streets) providing for fire-fighting access per IBC 506. For most occupancy groups, an increase to the allowable height (and number of stories) and floor area are permitted according to IBC Sections 504.1 and 506.3 for the use of an approved automatic fire suppression system, such as sprinklers. The American Wood Council provides a convenient online calculator for allowable building height and area at www.awc.org.

IBC 705.1 permits those portions of a building separated by one or more fire walls to be considered as separate buildings side by side. In this way, wood-frame buildings can be designed as connected buildings (Figure 5). However, the California Building Code in Section 705.1.2 does not permit fire walls to create separate buildings for the purpose of avoiding thresholds for automatic fire sprinkler system requirements unless the building is separated by a continuous four-hour fire-resistant construction without openings.

Meridian Luxury Suites, Las Vegas, Nevada, completed in 1985 – a luxury apartment hotel project that consists of five large structures. Fire walls divide each large structure into two or more buildings to meet building code’s building area requirements. Fire walls are two- to four-hour-rated fire-resistant construction.
IBC considers buildings with a floor used for human occupancy located more than 75 feet (22.9 meters) above the lowest level of fire department vehicle access as high-rise buildings. Additional code provisions apply to these buildings to accommodate different fire protection strategies for safe emergency egress and fire-fighting access. Wood frame construction is generally below this height.

2.3 PEDESTAL BUILDING DESIGN
(Podium Construction)
The IBC permits a building of non-combustible construction to serve as the pedestal (podium) for a multi-storey wood frame building separated by a three-hour fire-resistance-rated horizontal assembly. Pedestal buildings, also referred to as Podium construction, are permitted for assembly, business/office, mercantile/retail and parking garage uses below the three-hour horizontal fire separation with residential occupancy above the fire separation (Figure 6). The number of wood frame stories can be measured from the floor above the parking garage of Type I or Type IV construction one-storey above grade plane per IBC Sections 509.2 and 509.4.

2.4 FIRE-RETARDANT-TREATED WOOD
Type III Construction provided in IBC 602.3 requires that exterior walls to be of a two-hour fire resistant rating and constructed of non-combustible materials and the interior building elements are of any material the IBC permits, including untreated wood. Fire-retardant-treated (FRT) wood is permitted in Type III Construction as an alternative to non-combustible materials in exterior wall structural frame assemblies.
Type III Construction is allowed to be four stories. When protected by automatic sprinklers, in accordance with NFPA 13, five-storey buildings are allowed. Note: NFPA 13R is restricted to buildings up to four stories. IBC Special Provision Section 509.5 for Group R-2 (residential occupancy such as apartments) buildings of Type IIIA (protected) are allowed to be six stories and 75 feet (22.9 meters) in building height.

2.5 MEZZANINES
IBC Section 505 excludes mezzanines from the determination of number of stories or building area. Lofts and penthouses are generally excluded from the determination of number of stories.

2.6 USE AND OCCUPANCY
IBC Chapter 3 defines each use and occupancy classification according to the fire safety and relative hazard involved, see IBC Section 302.1. Separation requirements and/or protection for mixed use and occupancy are provided in Section 508.

3 LOCAL CITY ORDINANCE FOR FIVE-STOREY WOOD FRAME BUILDINGS
Some cities have approved local ordinances to allow five-storey Type V wood frame construction.

3.1 PORTLAND, OREGON
The City of Portland has had a city ordinance Chapter 24.95 Special Design Standards for Apartment Buildings since 1995. With the additional requirements of firefighting access and a maximum building height of 65 feet (19.8 meters), this local ordinance permits for (1) single construction of five-storey Type V (wood frame) one-hour-rated fire-resistive construction and (2) mixed construction of six-storey buildings with basement/first-floor of Type I non-combustible construction and the top five stories of Type V one-hour-rated fire-resistive construction (Figure 7).

3.2 SEATTLE AND TOCOMA, WASHINGTON
Seattle, Washington, implemented a city ordinance in 1985 allowing for five-storey wood frame construction. Additional cities in the State of Washington, including Tacoma (Figure 8), Bellevue, Renton (Figure 9) and Spokane have followed Seattle with similar city
ordinances. The 2006 Seattle Building Code (amended 2008) Section 509.2 allows for up to two stories of a pedestal building of Type IA non-combustible protected construction above grade plane adding to a five-storey wood frame above for buildings totalling up to seven stories of occupied areas. The maximum building height is 75 feet (22.9 meters) above the lowest level of fire department vehicle access.

4 DESIGN CONSIDERATIONS

When designing multi-story wood frame buildings, key factors are fire safety, structural performance (strength and serviceability/deflection checks), shrinkage and sound transmission.

4.1 STRUCTURAL

Wood strength is highest in the direction of the grain and lowest across the grain. Designed and constructed properly, wood has very few structural limitations. In multi-storey wood frame projects, it is common to use solid-sawn lumber for studs, joists, rafters and beams/headers; other wood products are used such as wood I-joists for joists; LVL and glulam for beams; and metal-plate connected wood trusses for floor and/or roof framing.

In wood frame construction projects, walls are used as shearwalls and floor/ceiling assemblies are used as diaphragms to transfer lateral forces from winds and earthquakes to the foundation. Constructed as repetitive wood framing members sheathed with plywood or OSB wood structural panels, these assemblies maintain high stiffness and strength in the design range and, if pushed to their ultimate capacity, tend to yield gradually while continuing to carry high loads and absorb a great deal of energy before failure.

Recent advances have been made in the performance of tall multi-story wood frame buildings to resist large earthquakes. In July 2009, the NEESWOOD project tested a seven-storey building (Figure 10, a six-story wood-frame structure built atop one-storey steel-frame system) to simulated earthquakes. The structure performed well under conditions approximated the 1994 Northridge quake in California, as well as stronger quakes. More information is available online at www.nsf.gov/news/newsmedia/neeswood/.

4.2 FIRE SAFETY

For fire protection in multi-family residential structures, the building code uses the concept of compartmentation to contain a fire by requiring the use of fire-resistive assemblies for corridor fire separations and for separations between units. In addition, fire stops and draft stops are required to prevent movement of flame and hot gases (including smoke) to other areas of the building.

One-hour fire-resistive construction is usually the minimum required fire-resistance rating for vertical and
horizontal fire separations between each dwelling unit. Higher fire-resistance ratings are required for stairway enclosures and exit passageways to protect the egress for occupants. ASTM E119 fire tests have been conducted on many wood frame wall and floor/ceiling assemblies sheathed with fire-rated (Type X) gypsum wallboard to demonstrate their fire-resistance performance for establishment of fire-resistance ratings.

4.3 SHRINKAGE
IBC 2304.3.3 requires consideration of wood shrinkage for wood frame buildings of more than three stories. Using dry lumber will minimize shrinkage issues such as cracking of finish and distress in plumbing systems. Longitudinal shrinkage (parallel to grain) is small and a majority of the shrinkage occurs in the tangential and radial directions of the wood annual ring. In lower wood frame buildings, the total shrinkage in a wood frame building can be calculated by summing the shrinkage of the horizontal wood members in the walls and floors, such as wall plates and floor joists in platform construction. In taller wood frame buildings, the longitudinal shrinkage of the studs may also need to be considered. The overall shrinkage in multi-storey wood frame construction can be further reduced by placing floor joists in metal joist hangers off the wall top plates instead of bearing on top of the walls.

General contractors of multi-storey wood frame projects are now often use hot air blower to speed up the drying of wood framing before finishing/enclosing the building. Particular attention needs to be given in wood frame construction mixed with concrete and steel elements where differential shrinkage/swelling may occur, such as wood-frame structures combined with a brick veneer, a steel-frame atrium space, or a concrete block elevator shaft. Using materials that have different shrinkage/swelling (contraction/expansion) properties in the same assembly – such as a joist floor – may result in some unevenness of the finished surface.

4.4 SOUND TRANSMISSION
Sound transmission is an important design consideration for multi-storey wood frame construction that may control material and construction choices. Lightweight gypsum concrete floor toppings, sound-absorbing wall boards, acoustic mats, and acoustic sealants filling the gaps between wall and floor elements are often used to achieve satisfactory sound transmission control. Assemblies with sound transmission class (STC) rating of 45 to 55 are commonly cited for providing good sound barriers. For improved sound reduction, lightweight concrete toppings are often used on floors – usually 1.5 inches (38 mm) thick standard lightweight concrete of 60 lbs/ft³ (970 kg/m³) to 90 lbs/ft³ (1450 kg/m³), or 3/4 inch (19 mm) thick gypcrete of 100 lbs/ft³ (1610 kg/m³) to 130 lbs/ft³ (2090 kg/m³).

5 MIXED CONSTRUCTION
Reinforced concrete and steel assemblies can be mixed with wood-frame construction to provide added fire protection and lateral force resistance for earthquake and wind. Reinforced concrete or steel construction is often used to build stairwells and elevator shafts in wood-frame buildings. Steel frame is used to resist lateral forces when large openings are desired and shearwalls are not suitable, commonly found in hotel lobbies in high-seismic zones. The type of steel frames used are concentrically braced frame or Chevron-braced frame (inverted V bracing), and K-Frame, where the bracing intersects the column (similar to a K). There are also projects where solid-sawn lumber joist floor systems are used in the steel-frame construction (Figure 11).

Using wood-framed assemblies with steel and concrete can offer many advantages to designers and developers. Material costs for wood stud walls, floor joists, ceiling rafters and roof trusses are typically lower than steel and concrete. Wood provides a more accommodating surface for fastening interior wall panels, flooring and roof sheathing. Openings for electrical and plumbing can be made more easily in wood. Special attention is required if fireproofing is needed for the steel frame in the wood frame system.

Fastening wood members to steel members and concrete is often a design challenge. Wood blocking serving as nailing is often connected with bolts or welded studs/pins to the steel beams to make a standard wood-to-wood connection possible (Figures 12 and 13). The attachment of wood stud wall sill plates to a concrete slab is accomplished using Vs-in. (12.5-mm) diameter steel anchor bolts cast in the slab. The attachment can also be accomplished by the use of expansion/wedge anchors, epoxy bolts, and powder-actuated fasteners installed into the concrete slabs.

5.1 MIXED USE CONSTRUCTION
Applying the various building code provisions reviewed above, multistory wood-frame mixed with steel/concrete construction can provide for mixed uses and occupancies (Figure 14).

5.2 WARP CONSTRUCTION
In recent years, wrap construction (Figure 15) has gained popularity as a new design of building configuration. Wrap construction is generally designed and built with wood frame apartment buildings wrapping around a reinforced concrete parking structure on three or four sides. Apartment tenants can park their cars on the same floor level of their own apartment units adding convenience. The wood frame apartment buildings are built at the same time as the concrete parking structure to shorten project construction time.

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Figure 11: (From top) Mixed construction – steel frame in wood-framed wall, steel frame in wood-frame construction to create wide open space free of wood frame load bearing walls, wood joist floor/ceiling system used in steel-frame construction, and metal-plate-connected wood roof trusses used in a steel-frame construction.

Figure 12: A floor detail at stair corridor – wood blocking bolted to the steel beam is used as a nailer for fastening standard metal joist hangers (courtesy of Architect Office of Galpin Ciaccio Klick).

Figure 13: A wood-to-steel connection conceals the steel beam. Wood floor trusses hang from the double top chord. The connection of wood floor trusses to steel beam was made by bolting a continuous wood plate to the top of the steel beam.
Figure 14: Pine Court, Long Beach, California, built in 1992—a building complex comprised of two-level underground parking, two-storey steel-frame lower floors used for retail and theatre, and four- and five-storey Type III wood frame construction of residential apartments on top.

Figure 15: GRIGIO Apartments, Phoenix, Arizona—a wrap construction apartment project under construction (top) and completed in 2007 (bottom) showing the wood frame building wrapped completely around the concrete parking building.