Technical ABSTRACT

Multistory Wood-Frame Construction

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

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

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 local government costs to provide infrastructure and services such as streets, water, and waste management.

Today, American cities are planning for the shifting demographics and rising land costs by turning to denser and taller housing solutions such as in-fill projects in the cities and town centers in the suburbs. The focus is to create affordable, healthy, sustainable communities and neighborhoods 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.

The popularity of multistory 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

Figure 1: La Jolla Crossroads, La Jolla, California, built in 2007 – a five-story wood-frame construction project (plus one-story loft) atop one level of concrete parking; one building under construction (left) and completed units (right)

Figure 2: Pinnacle Pointe at Quail Ridge, Kelowna, BC, Canada, built in 2006 – a four-story wood frame construction project atop one level of concrete parking

Figure 3: Sitka Apartments, Portland, Oregon, completed in 2005 – a five-story wood-frame construction atop one level of concrete construction on ground floor. This project provides affordable apartments in a neighborhood served by the public transit electric-operated street cars.
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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 provincial 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/.

Building Codes in the U.S.

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

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. 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 are provided in IBC Table 601. This system of five Types of construction and associated allowable building heights and areas was first developed approximately 75 years ago by the National Board of Fire Underwriters, now called the American Insurance Association.

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 considers buildings with a floor used for human occupancy located more than 75 feet (23 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.

IBC 705.1 permits those portions of a building separated by one or more fire walls to be considered as separate, side-by-side buildings. In this way, wood-frame buildings can be designed as connected buildings (Figure 5). However, Section 705.1.2 of the California Building Code 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-resistive construction without openings.

**Fire-Retardant-Treated Wood**

Type III Construction provided in IBC 602.3 requires that exterior walls provide a two-hour fire resistance rating and be constructed of non-combustible materials and the interior building elements are permitted to be 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 assemblies.

Type III Construction is allowed to be four stories. When protected by automatic sprinklers, in accordance with NFPA 13, five-story 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.

**Mezzanines**

IBC Section 505 excludes mezzanines from the determination of number of stories or building area. Lofts and pent-houses are generally excluded from the determination of number of stories.

**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.

**Pedestal Building Design (Podium Construction)**

The IBC permits a building of non-combustible construction to serve as the pedestal (podium) for a multistory wood-frame building where the concrete pedestal and wood framing are separated by a three-hour fire-resistance-rated horizontal assembly. Pedestal construction is permitted for assembly, business/office, mercantile/retail and parking garage uses below the three-hour horizontal
fire separation and residential occupancy above the fire separation (Figure 6). The number of wood-frame stories can be measured from the floor above the one-story-above-grade parking garage of Type I or Type IV construction per IBC Sections 509.2 and 509.4.

**Local City Ordinance for Five-Story Wood-Frame Buildings**

Some cities have approved local ordinances to allow five-story Type V wood-frame construction.

**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 fire-fighting access and a maximum building height of 65 feet (19.8 meters), this local ordinance permits for; (1) single construction of five-story Type V (wood-frame) one-hour-rated fire-resistive construction and (2) mixed construction of six-story 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).

**Seattle and Tacoma, Washington**

Seattle, Washington, implemented a city ordinance in 1985 allowing for five-story 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. In the 2006 Seattle Building Code (amended 2008) Section 509.2 allows for up to two stories of pedal building of Type IA non-combustible protected construction above grade plane plus a five-story wood frame above for buildings totalling up to seven stories of occupied floors. The maximum building height is limited to 75 feet above the lowest level of fire department vehicle access.

**Design Considerations**

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

**Fire Safety**

For fire protection in multiple-unit 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).
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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.

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 multistory 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 are used for beams; and metal-plate connected wood trusses are used 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 multistory wood-frame buildings to resist large earthquakes. In July 2009, the NEESWOOD project tested a seven-story building (Figure 10), a six-story wood-frame structure built atop one-story steel-frame system) to simulated earthquakes. The structure performed well under conditions approximating the 1994 Northridge quake in California, as well as stronger quakes. More information is available online at www.nsf.gov/news/newsmedia/neeswood/.

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 multistory 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.

Particular attention needs to be given in wood-frame construction mixed with concrete and steel elements where differential shrinkage may occur, such as...
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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 unless considered in design.

Sound Transmission

Sound transmission is an important design consideration for multistory wood-frame construction that may control material and construction choices. Lightweight gypsum-concrete floor toppings, sound-absorbing wall boards, acoustic mats, and acoustic sealers 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 ½-in. (38mm) thick standard lightweight concrete of 60lbs/ft³ (970kg/m³) to 90lbs/ft³ (1450kg/m³), or ¾-in. (19mm) thick gypcrete of 100lbs/ft³ (1610kg/m³) to 130lbs/ft³ (2090kg/m³).

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. This is common practice in buildings with large areas such as 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 with 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...
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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 nailers is often connected with bolts or welded studs/pins to the steel beams to make a standard wood-to-wood connection possible. The attachment of wood stud wall sill plates to a concrete slab is accomplished using ½-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.

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 12).

Wrap Construction
In recent years, wrap construction (Figure 13) 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 12: Pine Court, Long Beach, California, built in 1992 – a building complex comprised of two-level underground parking, two-story steel-frame lower floors used for retail and theatre, and four- and five-story Type III wood-frame construction of residential apartments on top.

Figure 13: GRIGIO Apartments, Phoenix, Arizona – a wrap construction apartment project under construction (left) and completed in 2007 (right) showing the wood-frame building wrapped completely around the concrete parking building.