MULTI-LEVEL WOOD-FRAMED STRUCTURES: REQUIREMENTS FOR BUILDING BEYOND FOUR STOREYS

A SCOPING REVIEW

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INTRODUCTION

Over the past decade, several major urban centres within the western United States have loosened restrictions limiting the building of wood-frame structures to only four-storeys. The push to amend legislation to allow the building of five- or six-storey wood-frame structures reflects the desire of city planners to increase urban density and provide citizens with additional affordable housing options. As world steel costs continue to rise, developers have increasingly chosen wood over steel in the framing of multi-story buildings in jurisdictions where this type of construction is allowed. Organizations like the Canadian Wood Council, the Western Wood Products Association in the United States, and the Trees and Timber Institute of the National Research Council in Italy all advocate the increased use of wood frame for buildings of five storeys and beyond.

Legislation that limits the building of wood-frame structures to only four storeys is related to the concern that structures over four storeys represent a potential fire hazard. According to Kevin Cheung, a recognized expert in the field of multi-storey wood-frame construction, “building codes have height and area limitations on wood construction due to fire safety considerations” (Cheung, 2000, p.4). Many of the regulations that limit wood-framed structures to only four storeys have their origin in great urban fires such as the Great Fire of London in 1666 and the Boston Fire in 1872. In light of numerous fire safety innovations delivered through modern technology there is little reason to continue limiting the height of wood-framed buildings to four storeys (Smith and Frangi, 2008). In jurisdictions where legislation has been amended to allow for height increases, the assurance that fire safety would not be compromised has been central to these projects receiving city council approval.

Several jurisdictions that have amended local legislation to allow five- or six-storey wood-frame structures have stipulated that the ground floor be comprised of non-combustible material. These “four-over-one” and “five-over-one” structures are built to construction specifications that require the first floor be made of steel and/or concrete. These measures help ensure a building’s structural stability in the event of a fire as well as add a degree of fire protection for parking garages or retail space located on the first floor. In San Francisco, a common building type for these projects is four-storeys of wood-frame built over a concrete ground floor of parking and retail space (Spur, 2007, November).

Other structural considerations related to fire safety issues that have been incorporated into the design of “four-over-one” and “five-over-one” buildings include the requirement that the first wood-frame storey provide 2 hours of fire rated construction. Jurisdictions have also stipulated that buildings must contain exit enclosures that are protected by 2-hour fire resistive construction, pressurized exit enclosures and elevator shafts, fire walls, automatic fire-sprinklers, and stand-by power sources to ensure continuous operation of fire protection systems. These modifications are designed to maximize escape time in case of fire, particularly for occupants located on the top two floors.

Aside from fire safety considerations, multi-floor wood-frame construction also faces challenges related to wood shrinkage, a process in which the moisture content evaporates, which causes changes to the physical properties of the wood. According to Kevin Cheung "the cumulative effects of multi-storey shrinkage can cause large expanses of interior and exterior drywall, paneling and siding to buckle" (Cheung, 2000, p.3). Within this Review, documents listed in the "Works Cited" section provide detailed explanations on how builders can overcome wood shrinkage challenges.

Seismic considerations also pose a challenge for multi-storey wood-frame construction builders; however, experimentation within this field has proven that multi-storey wood-framed structures can withstand the most severe seismic event through specialized design and material usage.(rev 06.30.08) In 2007, the Italian SOFIE project successfully tested a seven-storey wood-framed structure on the world's largest shaking table at Japan's National Institute for Earth Science and Disaster Prevention. It must be noted, however, that this wood-framed structure used specialized wood products such as engineered laminated material and is not directly relevant to North American typical wood-frame construction. (rev 06.30.08)

In the United States at the University of Buffalo, the National Science Foundation has sponsored the multi-university NEESWood project that "seeks to take on the challenge of developing a seismic design philosophy that will provide the necessary mechanisms to safely increase the height of wood-frame structures in active seismic zones" (NEESWood, 2007). The NEESWood project will culminate in early 2009 when a six-storey wood-framed structure will be shipped to Miki City, Japan to undergo tests similar to those conducted during the SOFIE project.

CONTEXT AND SCOPE

This Scoping Review will provide analysis of the issues surrounding multi-storey wood-framed construction and an inventory of documents related to this issue. The purpose of this Scoping Review is to enlarge the readers' understanding of the regulatory solutions that have facilitated the construction of five- and six-storey wood-frame buildings. The Review will also strive to enhance the reader's knowledge of the various structural, seismic, and fire safety related challenges that are being addressed by those involved in the building of wood-framed structures over four storeys. This Review will not attempt to provide a detailed analysis of engineering technologies that support these projects, but will point to locations where information on these technologies can be located.

DEFINITIONS

SINGLE CONSTRUCTION

Within the context of legislation that pertains to the construction of multi-storey wood-framed buildings, the term "single construction" refers to a wood-framed building, up to a maximum of five-storeys, with Type V-1 Hour construction. Type V-1 Hour construction refers to any home built with a "Protected Wood Frame," which has no visible exposed wood, and provides 1 hour of fire resistive protection. "Single construction" is all wood-framed (Portland, Oregon. 2004).

MIXED CONSTRUCTION

Within the context of Oregon legislation that pertains to the construction of multi-storey wood-framed buildings, the term "Mixed Construction" refers to a type of wood-framed building of six-storeys, where the basement or first floor is constructed of Type I-Fire Resistive Non-Combustible materials that provide up to 3 hours of fire resistive protection in combination with the top five-storeys that meet the design specifications of TypeV-1 Hour construction. "Mixed Construction" is essentially a wood-frame built upon one storey of non-combustible material (Portland, Oregon, 2004).

DISCUSSION

1. LITERATURE REVIEW

1.1 Considerations of Multi-Storey Wood-Frame Construction

According to Kevin Cheung, an expert in the field of multi-storey wood-framed construction and an advocate for increasing this type of construction, "three- or five-storey wood-framed buildings offer economical housing through fast construction speed and low material costs" (Cheung, 2000, p.1). His essay *Multi-Story Wood-Frame Construction* (2000) discusses the structural advantages of wood-frame construction as well as wood shrinkage, fire safety, and sound transmission issues related to this area. Cheung also discusses three multi-storey wood-frame construction projects in the United States.

1.1.2 Seismic, Structural, Fire Safety and Sound Transmission Considerations

Cheung notes that wood is a timeless building material known for its structural capabilities. Wood assembly offers a high strength-to-weight ratio, resulting in a low inertia force during a **seismic event.** The large number of walls used in wood-framed construction reduces the load shared by each wall. These structural walls transfer the lateral load induced at the time of an earthquake. During recent earthquakes, damage to most wood-frame structures occurred to homes built prior to modern seismic code requirements. These buildings were inadequately braced or slid off foundations because they lacked hold-down bolts (Cheung, 2000, p.2).

Wood shrinkage must be considered for wood-frame structures over three-storeys. The use of dry lumber (below 19% moisture content) will minimize wood shrinkage problems like cracking to the finish and distress caused to plumbing systems. The effects of multi-storey shrinkage can cause interior and exterior drywall, paneling, and siding to buckle. Areas such as stairwells, shafts, and vaulted ceilings are especially vulnerable to cracking due to wood shrinkage. Cheung discusses a number of building methods that can help minimize wood shrinkage effects (Cheung, 2000, p.3). New more sophisticated engineered wood products are often used to increase performance of wood with respect to shrinkage and seismic response. The issue of shrinkage is particularly critical in coastal BC where lumber is rarely dry during the construction period and shrinkage issues are exacerbated due to the climate. This is an issue that will require expertise and knowledge on the part of the designers, contractors, trades and building officials. (rev 06.30.08)

Fire safety issues must also be addressed when increasing building height and area limitations. One-hour fire-resistive construction is usually the minimum, with higher fire endurance ratings being required for stairways and exit hallways. Fire-stopping techniques are often used to prevent flames from moving to other areas of a building. Draft-stopping is also used to prevent the movement of air, smoke, gas and flames (Cheung, 2000, p.4).

Sound transmission is an important design consideration if a structure is a multiple family residential building. Lightweight gypsum concrete and other sealers are often used to reduce sound transmission in wood-frame construction. Lightweight concrete, poured on the floor after framing has been completed, is often used to improve sound reduction (Cheung, 2000, p.4).

1.1.3 Advantages of Wood-Framed Construction

Wood-framed houses have a **low energy usage**, when compared to concrete built structures. Wood is easy to insulate to high standards, whereas concrete and steel construction must overcome challenges related to thermal bridging and moisture condensation on cold surfaces. Light metal framing reduces thermal resistance by nearly 50%, which results in increased energy use. Because wood-framed construction is easily adaptable to any energy code, wood-framed buildings help lower energy bills (CWC, 2002, p.4).

Wood-framed buildings **require less energy and emit less carbon** when compared to concrete buildings because (European Commission, 2006):

- Production of materials for wood-frame buildings uses less primary energy than for concrete-frame buildings.

- The difference in life cycle emissions between wood and concrete framed buildings ranged from 30 to 130 kg of carbon per square meter of floor area.

- From a lifecycle perspective, the net change in carbon stocks (tree biomass and wood building stocks) is insignificant when using wood-based building materials from sustainably-managed forests.

Wood-framed buildings **cost less to build** than concrete and steel buildings resulting in greater urban density and, presumably, more affordable housing options. However, the use of engineered wood products, as compared to dimensional lumber, to mitigate structural, seismic and shrinkage issues will affect the overall cost of construction. A cost benefit analysis should be developed to understand the true differences in cost. (rev 06.30.08)

1.1.4 Examples of Multi-Storey Wood–Frame Buildings

- The 165,000 square–foot Copperfield Hill retirement community building in Minneapolis, Minnesota. Wood frame was chosen for this project based on cost when compared to a steel-concrete frame. The ease of wood construction **shortened construction timelines** by allowing the project to be framed in just over 5 months (Cheung, 2000, p.5).

- The Delancey Street Foundation Triangle Complex in San Francisco is also discussed. This 325,000 square foot, seven building complex has four residential buildings over one-storey of post-tensioned concrete parking and retail space. The residential structures are three-storey wood-frame over one floor built of non-combustible materials (Cheung, 2000, p.6).

- The Gatesworth building in St. Louis, Missouri is a four-storey wood-frame building with one five-storey wing. It contains 280,000 square feet of residential space plus 65,800 square feet of parking space under the building. Wood-frame was chosen for this project because of the developer's familiarity with wood frame construction. Framing was completed in only 15 months (Cheung, 2000, p.7).

- Denny Park Apartments in Seattle, Washington is a 55,000 square foot, six-storey, mixed-use building. The top five storeys of wood-framed construction contains various studio, 1 bedroom, 2 bedroom, and 3 bedroom apartments. The bottom two concrete floors contain retail space and a basement parking garage (Design Advisor Website).

Denny Park Apartments, Seattle, Washington (Design Advisor Website).

1.2. Engineering and Technological Solutions

1.2.1. "De Wiers" House – The Netherlands

"De Wiers" house, the highest multi-storey timber building in the Netherlands, is four wood-framed storeys over one floor of timber and masonry. The design and construction of "De Wiers" house has encouraged acceptance of multi-storey wood-framed building because the project addressed challenges related to floor vibrations, fire resistance, and acoustic transmission (Jorissen & Leijtin, 2008).

The structure is comprised of a five-floor 2D portal frame in four bays and is designed to allow the floors maximum flexibility. The fire resistance challenge was solved by increasing the dimension of the cross-sections. Timber floors were topped with floating concrete to increase fire resistance and limit acoustic transmission (Jorissen & Leijtin, 2008).

Huis de Wiers, Netherlands (Jorissen & Leijtin, 2008).

1.2.2. University of Canterbury – New Zealand

Presently, the University of Canterbury is developing a new system for multi-storey timber buildings to be used when building up to 10 storeys or more. Buildings designed to this system will have (Buchanan et al, 2008, May):

- Heavy timber beams, columns or walls;
- Large structural members prefabricated off-site;
- Main timber structure of glulam (glued-laminated timber) or laminated veneer lumber members;
- Post-tensioned connections for easy building and high-seismic resistance;
- Removable partitions and cladding; and
- Composite T-beam floors with concrete topping on timber joists.

The performance requirements for buildings designed to this system include (Buchanan et al, 2008, May):

- Wide open spaces, with maximum flexibility of use;
- Residential, educational or commercial use;
- Safety in fire, earthquakes or extreme weather events;
- Excellent acoustic performance;
- Excellent thermal behaviour;

- Durability for hundreds of years;
- Low levels of life-cycles energy use; and
- Low CO_2 emissions during construction, long-term use, and demolition.

1.2.3. Wood-Frame Construction Solutions – The United States

The essay *Multi-Story Wood Frame Construction in the United States* (2003) provides a technical analysis of several projects within the US that have pushed building code limits and the limits of wood as building material. The essay covers the technical aspects of multi-storey wood-framed construction and provides several examples of how builders have met the challenges associated with building beyond four-storeys. This essay provides technical information far beyond the scope of this review. A complete copy of this document is available at the web address provided below.

Web link: http://www.timberdesign.org.nz/files/Multi-Storey%20Wood%20Frame%20Construction%20in%20the%20US.pdf

1.2.4. Italian High-Tech Wood-Framed Building Passes Seismic Test

On October 23, 2007, a seven-storey wooden house passed all seismic tests after being exposed to a simulation of the earthquake that destroyed Kobe, Japan in 1995 (Carrer, 2007). It must be noted, however, that the construction methodology and materials was unique and therefore the results of this test is not directly transferable to the typical North American wood-framed building. (rev 06.30.08) The test occurred on the largest “shaking table” in the world, located in Miki, Japan, at Japan’s National Institute for Earth Science and Disaster Prevention. The SOFIE project (named after the research project "Sistema Costruttivo Fiemme") is a collaboration between the Trees and Timber Institute (IVALSA) of the National Research Council in Italy and the Autonomous Province of Torino, and was undertaken to demonstrate “the absolute reliability and safety…of wood as a construction material: a valid and cost-effective alternative to traditional building methods” (Progettosofie, 2007).

The seismic test in Miki was the final component of the SOFIE project, which examined the performance and capabilities of the X-Lam (Cross-Laminated Timber) construction system. The X-Lam technique originated approximately ten years ago in Germany but has been recently perfected in Italy. The X-Lam system is comprised of massive cross-laminated wooden panels that range from 5 to 30 centimetres in thickness. Panels, door openings, windows, and staircases are cut to size then fastened with steel angles, ringed shank nails, and self-drilling screws (Progettosofie, 2007).

X-Lam (Cross-Laminated Timber) Construction System (Holz Build)

The specifications of the seven-storey house tested in Miki were 15m by 7.7m floor plan area and 24m total height with one pitched roof. The building walls were constructed of X-Lam panels with a thickness of 142mm at the first two floors, 125m on the third and fourth floor and 85 mm at the last three floors. Several inner walls, with a same thickness as the outer walls, served as load carrying walls. The walls were connected with self-drilling screws. The floors were made of X-Lam panels with a thickness of 142mm that were connected to the walls by screws and steel brackets. The total volume of wood for the panels was around 250m³ (Progettosofie, 2007).

Seven-Storey, X-Lam System Seismic Test (Progettosofie, 2007)

1.3 Scientific Literature – Multi-Storey Wood-Frame Construction

Web link:
http://www.ingentaconnect.com/content/iabse/sei/2008/00000018/00000002;jsessionid=7usee34nfu8k7.alice

This section of the Review provides a list of abstracts that have been excerpted verbatim from their original source and can be located at the web link address listed above. The May 2008 edition of *Structural Engineering International* provides several other articles pertaining to multi-storey wood-frame construction; however, those listed below examine the issues most prevalent to this Review.

1.3.1 Urban Timber Houses in Vienna

Author: Martin Teibinger
Cost: $25US

Project "Mühlweg" of more than 250 flats in Vienna with four-and five-storey timber houses is described in this paper. In 2001, the building code of Vienna was modified to make way for the establishment of multi-storey timber houses with up to five storeys, provided that the supporting elements for the ground floor are made of mineral materials. In regard to multi-storey apartment building in Vienna these building methods were innovative. The city of Vienna has initiated a new focal point in public housing by promoting timber construction through advertising a competition amongst property developers. These timber constructions constitute something of an innovation in the area of multi-storey housing in Vienna. The advantages of timber buildings clarify why timber construction will play a major role in the future: High-grade prefabrication along with shorter construction periods, minor construction material moisture and ecological aspects (Structural Engineering International, 2008 May).

1.3.2 Case Studies of Multi-Storey Wood-Frame Construction in USA

Author: Cheung, Kevin C.K.

Shortage of affordable housing is a problem shared by many major cities in the USA. Three- to five-storey wood-frame buildings offer economical housing through low construction cost and high speed of construction.
In the designing of multi-storey wood-frame buildings, fire-safety and structural considerations are required by building codes. In addition, shrinkage and sound transmission do require special attention.
Most Americans live in the suburbs in low-rise wood-frame constructions, including single-family detached houses and one- to three-storey apartments and condos. This has resulted in what is known as suburban sprawl—widely spread

population, increasing the cost to the local government in providing streets, water, and sewer services. Planning for the shifting demographics and rising land cost, US cities are turning to densifying housing development of in-fill projects in the city and new development projects in suburban town centres.

1.3.3 Building Tall with Timber: A Paean to Wood Construction

Author: Randolph Langenbach
Cost: $25US

It may seem strange at first to propose that timber be used for the structural system of mid-rise buildings. Steel and concrete have held that position so long that the question of wood as an alternative for large-scale multi-storey construction would strike many people as archaic and impractical, but until the modern age, this was the case. The following essay highlights some interesting examples in history, concluding with the 17 blimp hangers constructed in the USA during World War II when steel was in short supply. Each of these structures was a third of a kilometre in length and equivalent in height to a 17 storey building, containing a single, column-free room (Structural Engineering International, 2008 May).

1.3.4 Overview of Design Issues for Tall Timber Buildings

Authors: Ian Smith and Andrea Frangi
Cost: $25US

Timber buildings, like any others, exhibit exemplary performance when materials are used appropriately, when structural forms and construction details address overload and serviceability requirements, and when geometry and interior layouts address fire safety. Many building codes restrict timber buildings to four and six storeys, reflecting societal consciousness of effects of conflagrations like the Great Fire of London in 1666. However, the regulatory landscape is changing to recognize contemporary capabilities to detect, suppress and contain fires within buildings. This is freeing architects and engineers to fully exploit structural capabilities of timber as a construction material. On the basis of the notion that tall modern timber buildings means those of approximately 10 storeys to a maximum of about 20 storeys, this paper is a commentary on the main structural engineering issues and how to address them systemically (Structural Engineering International, 2008 May).

1.3.5 Fire Design Concepts for Tall Timber Buildings

Authors: Andrea Frangi; Mario Fontana and Markus Knobloch
Cost: $25US

Based on the current knowledge in the area of fire design of timber structures this paper presents a generic fire safety concept for tall timber buildings. The first part of the paper gives an overview of fire action and fire safety concepts and presents the main differences between medium-rise and tall buildings with regard to fire safety. The analysis enables the formulation of a generic fire safety concept for tall timber buildings. In the second part of the paper some experimental results on the fire performance of timber structures under natural fire conditions relevant for tall timber buildings are presented (Structural Engineering International, 2008 May).

1.3.6 New Technologies for Construction of Medium-Rise Buildings in Seismic Regions: The XLAM Case

Author: Ceccotti, Ario
Cost: $25US

This paper reports on the outcomes of an experimental test performed on a full-scale building constructed using innovative technology. The experimental results are compared with the outcomes of a numerical analysis with the aim to derive the behaviour factor q used in a simplified elastic design of the building under seismic actions (Structural Engineering International, 2008 May).

1.3.7 Multi-Storey Pre-stressed Timber Buildings in New Zealand

Authors: Andy Buchanan; Bruce Deam; Massimo Fragiacomo; Stefano Pampanin and Alessandro Palermo
Cost: $25US

This paper describes recent research and development of a new system for multi-storey prestressed timber buildings in New Zealand. The new system gives opportunities for much greater use of timber and engineered wood products in large buildings, using innovative technologies for creating high-quality buildings with large open spaces, excellent living and working environments, and resistance to hazards such as earthquakes, fires and extreme weather events (Structural Engineering International, 2008 May).

1.3.8 Performance-Based Seismic Design of Six-Storey Wood-frame Structures

Authors: Weichiang Pang and David Rosowsky
Cost: $25US

This paper presents a performance-based seismic design of a six-storey light-frame wood building using a new direct displacement design (DDD) procedure specifically developed for mid-rise wood buildings. The proposed displacement-based design procedure uses normalized modal analysis and equivalent linearization techniques, along with segmented shearwall concepts, and allows engineers to select shearwalls from a database of backbone curves. The multi-storey direct displacement-based procedure is a promising design tool for performance-based seismic design of mid-rise wood buildings because it allows consideration of multiple performance objectives and does not require nonlinear time-history analysis of the complete structure. The proposed procedure further does not require the engineer to provide an estimate of equivalent damping. The proposed procedure is illustrated on a six-storey building and is validated using nonlinear time-history analysis results (Structural Engineering International, 2008 May).

1.3.9 Performance and Drift Levels of Tall Timber Frame Buildings under Seismic and Wind Loads

Authors: Andreas Heiduschke; Bo Kasal and Peer Haller
Cost: $25US

This paper discusses the potential for use of multi-storey timber frames when subjected to earthquake and wind loadings. With the advent of new technologies and materials, such as laminating and composite-fibre reinforcement, the performance of tall spatial timber frames can be significantly enhanced. Two issues are of concern when designing tall timber frames: flexibility that translates into relatively large drifts and non-linearity that represents uncertainty in estimating fundamental periods. This article focuses on the potentials and limitations in designing tall timber frames from serviceability and safety points of view.

As part of the permit application, design considerations include, but are not limited, to the splitting of wood members from shear wall nailing; differential shrinkage of wood, steel and concrete members; differential shrinkage of load bearing walls with and without wood panels; axial and flexural capacity of lower floor studs; and compression of lower floor wood plates (Structural Engineering International, 2008 May).

2. AMENDING BUILDING AND FIRE CODES

This section of the review will summarize the city council proceedings of three jurisdictions where construction of wood-frame buildings beyond four-storeys has received approval. Each jurisdiction has placed similar stipulations on increasing building height; however, there are certain differences within each jurisdiction.

Restrictions on building height and occupancy type in multi-storey wood-frame structures are based on issues of fire safety. Issues such as escape time and the ability of fire fighters to access the building in the event of a fire are central to these concerns. These jurisdictions had the opportunity of crafting requirements that are in tune with the building inspection practices and fire fighting capabilities of their particular communities. (rev 06.30.08)

Due to similarities found in many documents pertaining to this issue, only three summaries have been included in this Scoping Review. The three examples provided were chosen because each originated from within a different US State; the first from Washington, the second from Idaho, and the third from Oregon. Additional web links to documents from other jurisdictions, where wood-frame construction has moved beyond four-storeys, are provided after the three examples.

The key risks addressed by the following communities were as follows

- Fire safety risks were addressed by:
    - sprinkler systems, monitored fire protection system, emergency power, pressurized stairwells; and
    - maximum allowable building height.
- Shrinkage and compression risks were addressed by:
    - structural observation.
- Noise transmission and seismic risks were not addressed beyond the current code requirements.

2.1 Bellevue, Washington-City Council Meeting

Building Code Amendment Proceeding Supporting the Allowance of Five-Storey Framed Buildings

The following section of this Review has been included for the purpose of informing the reader how a discussion surrounding the amendment of the building code to allow five-storey wood-framed structures has proceeded in the past.

Bellevue Building Official Division Director Gregg Schrader has stated that previous limits placed on wood-framed construction in Bellevue likely had to do with theoretical limits of wood-framed design at the time the code first addressed the issue. Mr. Schrader has also stated he would be pleased to answer any further questions related to this subject. He can be reached by phone at 425-452-6451, or via e-mail at gschrader@bellevuewa.gov (Schrader, 2008).

On July 16, 2001, Bellevue, Washington City Council met to discuss amending the Building Code to allow five-storey wood framed buildings, with additional fire and life safety features incorporated into their construction. The Planning and Community Development Director stated that this initiative evolved from the City of Bellevue's objectives of:

1) Encouraging the availability of more, and particularly affordable, housing,
2) Maintaining the ability to compete with cities in the area that now allow five-storey wood framed construction, and
3) Maintaining and enhancing fire and life safety requirements for wood framed structures.

Bellevue's building codes are based on those adopted by the International Conference of Building Officials, the National Fire Protection Association, and the Washington State Building Council. At the time of this discussion, the 1997 Uniform Building Code specified the following for residential multifamily buildings constructed in Bellevue:

- Type V, 1-Hour Construction;
- Maximum area of 42,000 square feet;
- Maximum of four storeys; and
- Maximum buildings height of 50 feet.

The Planning and Community Development Director noted that a fifth storey was currently allowed if the first storey of the building was constructed of non-combustible materials and if the building had a sprinkler system and fire-resistant components. He also noted that the Construction Code Advisory Committee recommended allowing an increase to five storeys, a 15-foot increase in building height, and a 25 percent increase in floor area for wood framed structures. Building size can be increased by providing firewalls between portions of the building meeting the maximum square footage. The Construction Code Advisory Committee recommended the following requirements for five-storey wood-framed buildings:

- National Fire Protection Association 13 sprinkler system (highest level protection sprinkler system) with quick response sprinkler heads.

- Pressurized stair enclosures and elevator shafts.

- Emergency power on site to ensure continuous operation of fire protection systems.

- Monitored automatic fire protection system.

- Structural observation to address shrinkage and compression issues associated with wood construction.

The Planning and Community Development Director stated that the communities of Burien, Everett, Federal Way, Portland, Seattle and Tacoma have all adopted provisions allowing five-storey wood-framed buildings and that Bellingham, Shoreline, and King County were all considering similar proposals. He also noted that the Construction Code Advisory Committee believed allowing five-storey wood-framed buildings offered a cost-effective alternative for Bellevue builders but recommended that five-storey wood-frame structures be limited to housing and office uses. The Planning and Community Development Director also noted that the proposed Building Code amendment would allow non-combustible fire construction, such as concrete for the first floor, topped by five storeys of wood framed construction (City of Bellevue, 2001 July).

The Washington State Fire Marshall noted that the Fire Department had reviewed and was supportive of the proposed Building Code amendment. The Fire Marshall also noted that jurisdictions that had adopted five-storey wood framed construction had not experienced any negative, unanticipated impacts. The Planning and Community Development Director stated that the additional height of 15 feet was consistent with the allowable building height of 65 feet for the next level of construction (City of Bellevue, 2001 July).

City Councillors also noted that the additional building height would provide greater flexibility for architectural design features and provide more housing opportunities, particularly in the downtown area. Also, that fire safety issues had been thoroughly discussed and evaluated by the Construction Code Advisory Committee and the Fire Department. The Planning and Community Development Director also confirmed that wood framed buildings were more affordable than concrete and steel structures (City of Bellevue, 2001 July).

The Planning and Community Development Director concluded by stating that he was confident that the proposed amendment would provide a level of protection equivalent to that proposed by four-storey wood framed structures and larger concrete and steel structures. Proceedings closed with the Bellevue Mayor noting Council's support for the proposal and asking staff to prepare an ordinance for Council's consideration (City of Bellevue, 2001 July).

2.2 Boise City, Idaho

Ordinance Adding a New Chapter to Regulate Construction of Mixed-Use, High Density Housing-August 2004

Web link: http://www.cityofboise.org/city_clerk/081704/Council/o-43-04.pdf

In August 2004, Boise City, Idaho approved the addition of a new chapter to the Boise City Code to regulate the construction of mixed-use, high density housing located within the Boise City Fire Department's Response Zone. This ordinance allows a builder to use wood to make buildings larger and taller than the code previously allowed. The ordinance was added because:

- Moderately priced housing was lacking and needed in the City's downtown core.
- Other communities have solved the above problem by adopting an ordinance that allows for less expensive building materials (wood) to be utilized.
- The ordinance added a number of life safety provisions beyond what the previous code required, so that less expensive materials (wood) may be utilized.
- The ordinance decreases car usage, as housing will be closer to work and shopping opportunities.
- The ordinance increases the viability of the City's downtown core as increased housing will support more downtown business.
- The ordinance increases building alternatives available to developers.

For single construction, the ordinance allows a five-storey wood frame building over a basement parking garage with a maximum height of five storeys that does not exceed 65 feet in overall height. For mixed construction, the ordinance allows a structure to be divided into an upper and lower building with a maximum height of 95 feet. The lower building may contain a basement and up to three storeys above grade being constructed of non-combustible material (steel and concrete) with the upper building height of a maximum of five storeys constructed of combustible wood frame construction. The upper and lower buildings are to be separated by a horizontal, three-hour fire-rated, floor/ceiling assembly. Floors constructed of combustible wood frame material are reserved for residential occupancy. The highest occupied level cannot exceed 75 feet above the lowest fire apparatus access road (Boise City, August 2004).

This ordinance does not allow the square footage increase usually allowed with the installation of a fire sprinkler system but does allow for an increase of 25% over the area listed under the previous code. Travel distances to exits in the combustible wood frame portion of the building must be reduced by 40% of what the previous code allowed. Exterior walls must be constructed to be a minimum 1-hour fire resistive and are required to have an exterior finished with non-combustible material. The ordinance increases the frequency of fire alarm maintenance and sprinkler inspections from once a year to quarterly, and requires special inspection to address critical design considerations related to wood shrinkage (Boise City, August 2004).

2.3 Portland, Oregon

City of Portland-Chapter 24.95 Special Design Standards for Five Storey Apartment Buildings

Web link:
http://www.portlandonline.com/Auditor/index.cfm?cce_28675_print=1&c=28675

The provisions of Chapter 24.95 allow for the construction of a five-storey, wood-frame apartment building. Single construction buildings complying with this chapter may be a maximum of five-storeys of combustible wood material. The occupancy of the top four floors is limited to apartments while occupancy of the bottom floor and/or basement is limited to offices; dining and drinking establishments; day care facilities; retail stores, and parking spaces/garages. *Six-storey* buildings complying with this chapter may be constructed if the first storey is constructed of non-combustible material and separated from five storeys of combustible material by a three hour occupancy separation (City of Portland, 2007 August).

All portions of the building are to be protected by an automatic sprinkler system which does not substitute for one-hour fire resistive construction and cannot be used as justification to increase the overall building area. The maximum height of any building cannot exceed 65 feet, measured from the lowest level of fire department vehicle access to the highest point of the building, excluding any mechanical, elevator or stairway penthouses. Access for fire fighting, rescue, and related purposes state fire department vehicle must be provided an access road and that at least 50% of all apartments with windows must be reachable by a ladder truck. At least two stairways must provide access to the roof (City of Portland, 2007 August).

2.4 King County, Washington

Five-Storey Wood-Frame Construction: Model Ordinance.
Web link: http://www.metrokc.gov/ddes/gmpc/housing/5strywd.doc

2.5 City of SeaTac, Washington.

Ordinance No. 04-1029: An Ordinance amending Section 13.110.020 of the SeaTac Municipal Code to allow five-storey, wood-framed buildings.
Web link: http://www.ci.seatac.wa.us/mcode/ordinances/04-1029.pdf

2.6 Des Moines, Washington.

Chapter 14.12 Five-Storey Wood-Frame Buildings.
Web link:
http://www.codepublishing.com/wa/desmoines/html/dmoins14/dmoins1412.html

2.7 Federal Way, Washington

Article IV. Five-Storey Wood-Frame Buildings.
Web link: http://www.mrsc.org/mc/fedway/fedwy05.html

3. ISSUES AND CONCERNS

3.1 Pre-Completion Fire Prevention

There is not much information related to the area of pre-completion fire prevention. However, this topic may be of concern as efforts to push wood-frame construction over four-storeys moves forward. Although there is no evidence to confirm that multi-storey wood-frame structures are necessarily more at risk during construction than after completion it must be noted that there may be a phase of construction when the building is more vulnerable than at other times. One example of a pre-completion wood-frame fire occurred at the Kearney Plaza Apartment Complex in Portland, Oregon in August 1999.

The five-storey wood-framed Kearney Plaza quickly burnt to the ground. This occurred in part because fire safety features such as fire sprinklers had yet to be installed as only the skeletal frame of the building had reached completion. The cause of the fire was unknown; however, arson was suggested as a possible cause. To prevent this happening in the future the Portland Fire Bureau's Joint Code Committee considered applying new rules to the building of five-storey wood-framed structures, including (City Mulls, 1999 October 15):

- Posting an on-site security guard during hours when construction is not in progress;
- Requiring construction companies to assign staffers or hire subcontractors as construction fire-prevention oversight specialists;
- Activating sprinklers sooner in the construction progress;
- Requiring builders to install shear walls or other stabilizing systems to help ensure that critical structure components do not tip or fall into adjacent buildings;
- Requiring builders to temporarily compartmentalize buildings into smaller pieces during construction to reduce open, fire-prone spaces;
- Requiring builders to meet weekly with fire-bureau officials to ensure the builders are following preventive rules.

SUMMARY

The effort to amend legislation to allow the building of wood-framed structures over four-storeys is multi-jurisdictional. Over the past decade, several municipalities throughout the Pacific Northwest have rewritten building and fire codes to permit the building of five- and six-storey multi-use structures. Common among these jurisdictions has been the desire to increase urban density while providing citizens with additional affordable housing options. The assurance from engineers, fire marshals, and seismic experts that the safeness of wood-framed structures would not be jeopardized by allowing an increase in height restrictions has been central to any effort to amend previous legislation. It should be noted, however, that these examples are not directly transferable to a province-wide initiative. In particular, the cities did not further analysis of seismic risk for 6 storey wood-frame buildings as compared to 4 storey wood-frame buildings. The cities also had the advantage of input regarding building inspection practices and fire fighting capabilities of their communities. (rev 06.30.08)

Structural experimentation within the field of wood-framed building has bolstered efforts to increase the building height beyond four storeys. Projects undertaken in several countries throughout the world, including the United States, Italy, and New Zealand, is beginning to influence the engineering community (rev 06.30.08) that multi-storey wood-framed structures can withstand the force of an extreme seismic event. Engineers have also tackled several structural challenges related to wood frame construction including sound transmission, wood shrinkage, and fire safety issues. It must also be noted that in an era where environmental issues remain at the forefront, wood-framed structures exceed the sustainable capabilities of both concrete and steel framed buildings. Also, wood frame construction projects are built faster and are more cost effective than comparable steel- or concrete-framed buildings.

Beyond the issue of increased height are issues of whether to allow increased floor area and if there is an increased need for third party review of design and building inspections during construction. There will also likely be a need for increased education for the developers, contractors and the trades to support the successful construction of these multi-storey wood-framed buildings.

Based on the environmental benefits, recent technological improvements, and mounting evidence that concludes wood-framed structures over four storeys are both safe and reliable, the effort to amend legislation to allow builders to increase wood-framed buildings beyond four storeys should only continue to gain momentum.

Codes and standards are beginning to respond to the challenge. However, in order to avoid unintended tragedies such as loss of life due to fire or collapse during a seismic event or premature building envelope failure, it is important to ensure that codes are developed in a thorough and evidence-based manner with appropriate opportunities for public consultation. Pilot testing, for instance, of new code provisions is a tried and true approach to increasing the probability of success in the final regulatory requirements. (rev 06.30.08)

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APPENDIX A – SEARCH TERMS AND DATABASES

The Following Search Terms Were Used:

Building Code Amendments
Building Code Height Limit
B.C. Fire Code
Canadian Wood Council
Combustible Construction
Combustible Wood Construction
Fire Code Regulations
Fire Code Amendments
Five Over One
Five Over One Construction
Five-Story Wood-Frame
Five-Story Wood-Frame Construction
Five-Story Wood-Frame Fire
Height Limits
Kearney Plaza Apartment Fire
King County Building Officials
Mid-Rise Wood-Frame Construction
Portland Five-Story Wood-Frame
San Diego Five-Story Wood-Frame Construction
Seismic Multi-Story Wood-Frame
Six-Story Wood-Frame
Structural Engineering International
Tall Timber Buildings
Uniform Building Code
Uniform Building Code Amendments
Washington Association of Building Officials
Washington State Building Code

The Following Engines Were Used:

EbscoHost
Google
IngentaConnect