Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1571

SEISMIC BUILDING CODE PROVISIONS FOR MID-RISE WOOD-FRAME CONSTRUCTION IN BRITISH COLUMBIA, CANADA

S. Kuan[1], E. Karacabeyli[2], C. Ni[3]

ABSTRACT

Starting on April 6, 2009, mid-rise wood-frame residential buildings are permitted to be constructed up to six storeys in the Province of British Columbia. The previous maximum allowable height was four storeys. To make this regulatory change, however, the study of seismic performance of six-storey wood-frame construction and the development of new design practice guidelines were required. In the end, only a few amendments to the British Columbia Building Code were made to manage the risks for seismic structural safety. Specifically, two types of irregularity in a seismic force resisting system are no longer permitted, and a higher base shear is required for designs using a fundamental period not calculated by the empirical formula.

Introduction

In May 2008, the government of British Columbia announced its intention to increase the allowable maximum number of storeys for wood-frame construction from four to six storeys. The BC Building and Safety Policy Branch examined changes to existing provincial building regulations necessary for the increase. Three areas of concern related to wood construction were identified. They were fire safety, shrinkage and seismic structural safety. After consultations with many stakeholders including building officials, designers and builders, it was decided that amendments to the 2006 edition of the British Columbia Building Code (BCBC) (Ministry of Forests and Range and Minister Responsible for Housing 2006) were required in order to address these concerns. On April 6, 2009, new code provisions for design of mid-rise (five and six storey) wood-frame buildings came into effect in British Columbia. They apply only to buildings for residential use.

---

[1] Senior Seismic Engineer, Building and Safety Policy Branch, BC Ministry of Housing and Social Development, Victoria, BC V8W 9T2

[2] Manager, Building Systems Department, FPInnovations, Forintek Division, Western Region, Vancouver, BC V6T 1W5

[3] Wood Engineering Scientist, Building Systems Department, FPInnovations, Forintek Division, Western Region, Vancouver, BC V6T 1W5

This paper describes the challenges faced and actions taken by the BC Building and Safety Policy Branch in addressing the issue of structural safety of mid-rise wood-frame buildings, in particular under seismic loads. The challenges and actions were informed by concurrent activities and development in research, computer modelling, building codes and material standards. The final amendments in the British Columbia Building Code for seismic structural safety are presented at the end of the paper.

Situation and Challenges

Provincial building codes, including the British Columbia Building Code, adopt provisions from the National Building Code of Canada (NBCC). In the 2005 edition of the NBCC (National Research Council of Canada 2005), the height of wood-frame buildings is limited to four storeys. This is a general requirement for buildings of combustible construction. For wood buildings in moderate and high seismic regions, there is an additional height limit for buildings consisting of timber shear walls. This limit is 20 m. The background of the seismic force modification factors for this system is given by Mitchell (2003). Both the general and seismic height requirements were adopted by the 2006 edition of the BCBC.

The majority of low-rise residential buildings up to four storeys in North America are constructed with wood-frame construction. Builders expressed a need for application of wood building systems for mid-rise construction above four storeys. British Columbia was the only province at the time to have the intention to deviate from the four-storey national limit. Therefore, it was not possible to collaborate on the policy analysis with other provinces or territories. Although changes were proposed at the same time for the next edition of the NBCC, including changes to seismic design of wood structures, increasing the maximum number of storeys of wood buildings was not a part of the proposal. Meanwhile, the wood standard CAN/CSA-O86 (Canadian Standards Association 2005) was being revised to incorporate capacity-based design philosophy which was considered to be essential to address concerns regarding seismic performance of wood structures.

Even with the current and proposed new provisions in the building codes and the material standard, it remains that seismic design requirements for wood-frame buildings continue to be based on experiences with and analyses of buildings up to four storeys only. Although surveys show that low-rise wood-frame buildings performed well in past earthquakes from a life safety point of view (Rainer 1999), no mid-rise wood-frame buildings constructed with modern-day techniques have been subjected to an actual moderate or strong earthquake. This is, of course, based on the fact that mid-rise wood-frame structures are not permitted by building codes in almost all countries in the world including Canada, U.S.A. and Japan. A seven-storey wood building was tested on a shake table (Trees and Timber Institute IVALSA 2007), but its method of construction was different than the conventional methods used in North America.

The absence of field data was also accompanied by a lack of analytical data on mid-rise wood-frame buildings. Again, without any actual projects, the need to analyze taller wood structures had not been present. Adding to this, much research was still required to be done to arrive at representative modeling of seismic behaviour of wood seismic elements. All these factors led to a lack of understanding among engineers in seismic performance of mid-rise wood buildings and consequently a lack of confidence with designing them.

The anticipated changes to the 2010 version of NBCC and the 2009 version of CAN/CSA-O86 standard, which contain a new design philosophy, although welcomed by the engineering community, would complicate cross referencing and application of design requirements in an amendment to 2006 BCBC.

Actions

To address the issue of seismic design of mid-rise wood-frame buildings, a proactive approach was taken by initiating or supporting work to generate information to fill in some of the gaps in the knowledge. The approach involved three different activities.

Analytical Study

The BC Building and Safety Policy Branch contracted with Forintek Division of FPInnovations to carry out an analytical study to find out differences, if any, in seismic response of 4- and 6-storey wood-frame buildings designed in accordance with the BC Building Code.

A residential building from an actual project in Vancouver, B.C. was used as the base model. A 4-storey version and a 6-storey version of this building with the same floor plans and layout of walls were studied. Both versions were designed in accordance with the 2006 edition of the BC Building Code which was the code in effect at the time. The 4-storey and 6-storey buildings were also designed in accordance with the next editions of the National Building Code of Canada and the wood standard CAN/CSA O86, assuming that the proposed changes were accepted. All buildings were examined with a three-dimensional, time-history analysis using a suite of ground motions expected for the city of Vancouver, B.C.

Hold-downs with shrinkage compensator were required for all the shear walls. In the model, spring elements were used to model the uplift actions and shear deformations. The computer model has been validated with shake table tests of CUREE 2-storey wood-frame buildings and has also been used in the prediction of the NEESWood shake-table tests of a 6-storey wood-frame building.

As part of the work, a separate analysis was also conducted by Colorado State University, who used their own and new computer modelling program, to act as a check of the results.

Results of the study showed no adverse deviation in the general seismic behaviour when the number of storeys was increased from four to six.

Support for NEESWood Capstone Tests

The government of British Columbia provided funding to the NEESWood capstone tests.

NEESWood is a major research project in the Network for Earthquake Engineering Simulation program to develop performance-based seismic design philosophy for mid-rise wood-frame construction. Led by Colorado State University, this multi-year program has three key phases of work involving experimental and analytical studies. In particular, the third and last phase of the project --- the NEESWood capstone tests --- involves testing of a full-scale 6-storey wood building on the largest shake table in the world at E-Defense in Japan (van de Lindt et al. 2006).

The test building consisted of LVL floor joists and walls made up of dimensional-lumber studs and plates and oriented-strand-board sheathing. On all floors of the wood-frame building except the top one, regular shearwalls and Midply walls, which were placed in locations of expected high seismic loads, were used to resist the lateral loads from the earthquake. Steel rods with shrinkage-compensating devices were installed at each end of shear walls and Midply walls. Midply wall system is a high-capacity wall that was developed by FPInnovations and the University of British Columbia (Varoglu 2007). FPInnovations' scientists participated in the blind prediction of the test and integration of Midply wall system in the test building.

The project was about to enter this final phase when British Columbia started its initiative. With the large size of the specimen and the use of platform-frame construction that is typical in North America, the NEESWood capstone tests presented an opportunity to reveal for the first time actual responses of a mid-rise wood-frame building in an earthquake. Although it was understood that the NEESWood capstone tests would not be conducted in time for decisions on changes to regulations, the funding was made to help ensure that the tests would proceed as planned so valuable and representative information would be obtained, especially for verification of the results of analytical studies.

The final NEESWood Capstone shake table test was conducted in Japan in July 2009. The building was subjected to 180% (2% in 50 year) of the original ground motion recorded at Canoga Park during the Northridge Earthquake in California in 1994. The scaled earthquake record represents the Maximum Credible Earthquake given in the building code for design in California. The building performed very well during the shaking. It survived this major earthquake without any significant structural damage. Damage was observed in the gypsum sheathing only, particularly at corners of doors and windows. The Midply wall system also performed very well.

The results demonstrated that a six-storey building with a platform frame construction can resist a very rare earthquake that can happen in regions of moderate to high seismicity such as the west coast of North America. The tests results were timely in assisting to assure designers, building officials, and regulators in the Province of British Columbia that a six-storey, wood-frame building can be built to withstand the intensity of a powerful, very rare earthquake event.

Technical Bulletin for Engineers

The BC Building and Safety Policy Branch contributed funding to the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to develop guidance for structural engineers on the design of mid-rise wood-frame buildings.

Consulting structural engineers in B.C., who are experienced in the design of wood buildings, expressed strongly a need for design guidelines if the maximum height of wood structures was to be increased. This was mainly to develop a consistent design methodology for 5- and 6-storey wood-frame buildings. APEGBC worked with the Structural Engineers Association of British Columbia (SEABC) to organize a task force of local expert practitioners to develop a technical and practice bulletin to provide guidance to structural engineers on how to design 5- and 6-storey wood buildings (Association of Professional Engineers and Geoscientists of BC 2009). This bulletin discusses practice issues, provides guidance on design and detailing of shear walls, diaphragms and fire separation walls and on design for deformations such as shrinkage. It includes a design example for a six-storey building that was developed by a local design consultant under the direction of FPInnovations Forintek and peer reviewed by the Wood Frame Committee of the SEABC. The APEGBC bulletin was released the same time as the code amendments came into effect.

Amendments to the British Columbia Building Code

Following a public review of proposed changes, comments from engineers, building officials and other code users were reviewed and several code provisions were amended to regulate the design and construction of mid-rise, wood-frame buildings (Minister of Housing and Social Development, 2009a; Minister of Housing and Social Development, 2009b). The ones for seismic structural safety are shown below with only minor editing or removal of cross code referencing to make reading easier. Readers are asked to refer to the BC Building Code or the National Building Code of Canada for definitions of abbreviations and code clause numbering.

The main revision --- the change in the maximum number of storeys --- is given in the section on building size and construction relative to occupancy for building fire safety as follows:

> 3.2.2.45. Group C, up to 6 Storeys, Sprinklered
> 1) A building classified as Group C is permitted … [to be of combustible construction] … provided
> a) … the building is sprinklered throughout,
> b) it is not more than 6 storeys in building height, and
> c) has a maximum height of less than 18 m measured between grade and the uppermost floor level of the top storey, and
> d) it has a building area not more than:
>   i) 7 200 m^2 if 1 storey in building height,
>   ii) 3 600 m^2 if 2 storeys in building height,
>   iii) 2 400 m^2 if 3 storeys in building height,
>   iv) 1 800 m^2 if 4 storeys in building height,
>   v) 1 440 m^2 if 5 storeys in building height, or
>   vi) 1 200 m^2 if 6 storeys in building height.

Group C is the major occupancy classification group for residential occupancies. It should be noted that the total building area is the same for the different numbers of storey. The important point of note in this requirement is that the 18-m height limit is measured to the uppermost floor level and not to the roof. This limit is very close to the 20-m height limit for timber shear walls, which is measured to the top of the walls.

Four provisions were amended specifically for seismic structural safety. Collectively, they are intended to reduce the seismic risk and to allow structural engineers to be confident with their designs because of the lack of information to date on seismic performance and analysis of taller wood structures.

Firstly, irregularities in vertical seismic force-resisting elements are prohibited, as specified by the following provision:

> 4.1.8.10.(4)
> In cases where $I_E F_a S_a(0.2)$ is equal to or greater than 0.35, for buildings constructed with 5 or 6 storeys of continuous combustible construction as permitted by Article 3.2.2.45 and having any fundamental lateral period, T_a, walls forming part of the SFRS within the continuous combustible construction shall not have irregularities of Type 4 or 5 ...

A Type 4 irregularity is an in-plane discontinuity in the vertical seismic force-resisting elements, while a Type 5 irregularity is an out-of-plane offset. This new provision was added to ensure that expected responses are maintained at reasonable levels by having a well-defined or straightforward seismic force resisting system (SFRS) without transfer of excessive forces through the diaphragms or large concentrated loads in the shear walls. A simpler SFRS would also facilitate design and detailing of shear walls. However, it is important to point out that layout of walls from an architectural point of view could be impacted. This restriction applies over the entire height of a mid-rise, shear-wall structure. For a building consisting of a mid-rise timber structure on top of above-grade reinforced concrete construction, the requirement applies to the timber structure portion of the building. It is understood that this approach is conservative, and so it will be reviewed as more research data become available. This restriction is not required for buildings in low seismic regions.

Secondly, if the fundamental period is calculated using established methods of mechanics other than the empirical formula given in the code, a higher design base shear is to be used or maintained. This applies to both the base shear calculated by the equivalent static force procedure and the base shear determined by a dynamic analysis procedure. For the base shear calculated by the equivalent static force procedure, it is increased by 20% as specified in the following provision:

> 4.1.8.11.(11)
> Where the fundamental lateral period, T_a, is determined by 4.1.8.11.3.(d) for buildings constructed with 5 or 6 storeys of continuous combustible construction as permitted by Article 3.2.2.45. and having an SFRS of nailed shear walls with wood-based panels, the lateral earthquake force, V, as determined in Sentence (2) shall be multiplied by 1.2.

Sentence 4.1.8.11.3.(d) referred to in this provision allows the use of established methods of mechanics to determine the fundamental period but also limits the value to two times that from the empirical formula. For the base shear determined by a dynamic analysis procedure, the 20% reduction is not permitted as specified in the following companion provisions. Sentence 4.1.8.12.(5) referred to in the provisions defines the base shear as that obtained from a linear dynamic analysis adjusted by the importance factor and the product of the force modification factors R_dR_o.

> 4.1.8.12.(6)
> Except as required by Sentence … (10), if the base shear, V_d, obtained in Sentence (5) is less than 80% of the lateral earthquake design force, V, of Article 4.1.8.11., V_d shall be taken as 0.8V.
>
> 4.1.8.12.(10)
> The base shear V_d shall be taken as 100% of the lateral earthquake design force, V, as determined by Article 4.1.8.11. for buildings
>
> a) constructed with 5 or 6 storeys of continuous combustible construction as permitted by Article 3.2.2.45.,
> b) having an SFRS of nailed shear walls with wood-based panels, and
> c) having a fundamental lateral period, T_a, as determined by 4.1.8.11.(3).(d).

During the development of the technical bulletin, the fragility of 6-storey shear walls with varying strengths based on different values for the force modification factor was examined. Based on a two-dimensional dynamic analysis of single, 6-storey shear walls, it was found that soft-storey failure could occur in walls designed with lower base shears (communications with SEABC Wood Frame Committee 2009). Relatively low base shears could result from the use of established methods of mechanics to calculate the fundamental periods because periods calculated by established methods of mechanics are typically higher than periods calculated by the empirical formula and so in most cases would be in the descending part of the design response spectrum. Therefore, to reduce the risk of shear-type soft storeys occurring, the design base shear is raised for structures characterized by higher fundamental periods.

Conclusion

Developing design code provisions becomes challenging when the availability of supporting technical data is limited. A tight timeframe and anticipated changes to the national model code and the referenced 1material standard make the work even more challenging. In the case of regulatory changes for mid-rise wood-frame construction in B.C., concurrent research activities and the availability of local expertise helped to inform the policy analysis. However in the end, a conservative and cautious approach for seismic design requirements was deemed necessary to ensure low seismic risks for taller wood buildings. Feeling comfortable and confident with their designs is also important to structural engineers when accepting a code change.

References

Association of Professional Engineers and Geoscientists of BC, 2009. Structural, Fire Protection and Building Envelope Professional Engineering Services for 5 and 6 Storey Wood Frame Residential Building Projects (Mid-Rise Buildings), *APEGBC Technical and Practice Bulletin*, Burnaby, British Columbia.

Canadian Standards Association, 2005. Engineering Design in Wood. CAN/CSA-O86-01. Mississauga, Ontario.

Minister of Housing and Social Development, 2009a. Ministerial Order No. M008. Regulation of the Minister of Housing and Social Development. Province of British Columbia. January 8, 2009.

Minister of Housing and Social Development, 2009b. Ministerial Order No. M121. Regulation of the Minister of Housing and Social Development. Province of British Columbia. April 3, 2009.

Ministry of Forests and Range and Minister Responsible for Housing, 2006. *British Columbia Building Code 2006*, Queen's Printer, Victoria, British Columbia.

Mitchell, D., R. Tremblay, E. Karacabeyli, P. Paultre, M. Saatcioglu and D.L. Anderson, 2003. Seismic force modification factors for the proposed 2005 edition of the National Building Code of Canada. *Can. J. Civ. Eng.* 30 (2), 308-327.

National Research Council of Canada, 2005. *National Building Code of Canada 2005*, National Research Council of Canada, Ottawa, Ontario.

Rainer, J.H., E. Karacabeyli, 1999. Performance of wood-frame building construction in earthquakes. *FPInnovations Forintek Special Publication No. SP-40*. FPInnovations, Vancouver, British Columbia.

Trees and Timber Institute IVALSA, 2007. Italian High-Tech Building in Japan to Pass the Last Test. Press Release. Progettosofie.

van de Lindt, J., D.V. Rosowsky, A. Filiatrault, M.D. Symans and R.A. Davidson, 2006. Development of a Performance-Based Seismic Design Philosophy for Mid-Rise Woodframe Construction: Progress on the NEESWood Project. *Proceedings of World Conference on Timber Engineering*, Portland, OR.

Varoglu, E., E. Karacabeyli, S. Stiemer, C. Ni, M. Buitelaar and D. Lungu, 2007. The Midply wood shear wall system: performance in dynamic testing. *American Society of Civil Engineers Journal of Structural Engineering* 133 (7).