Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

USE OF SMALL-DIAMETER ROUND TIMBER AS STRUCTURAL MEMBERS IN LIGHT FRAME CONSTRUCTION

Guofang, Wu[1,2], Enchun, Zhu[3], Haiqing, Ren[1], and Meng, Gong[2,4]

[1] Research Institute of Wood Industry, Chinese Academy of Forestry, China

[2] Wood Science and Technology Centre, University of New Brunswick, Canada

[3]School of Civil Engineering, Harbin Institute of Technology, China

[4] mgong@unb.ca

Abstract: Small-diameter round timber is a kind of by-product mainly from the thinning operation of the plantations. It is plentiful and inexpensive, and is generally destined for non-structural applications. Due to the small and varied diameter and irregularly curved axis of the timber, difficulties are confronted to process it into sawn lumber. In addition, there are also many challenges to develop efficient mechanical joints between roundwood members. Thus the small-diameter round timber is rarely used as structural members. This study was aimed to provide an innovative but simple way to use the small-diameter round timber as structural members. Three kinds of composite members were developed to be used in light frame wood construction, i.e. the built-up studs, the wood-steel joists and the wood-steel roof trusses. The shearwalls and diaphragms made of the developed composite members were also examined. To facilitate the fabrication, the configurations of these members were described in a way to provide the details. Efforts were also made to investigate the structural performances of these members, shearwalls and diaphragms via full-scale tests. It was found that the developed composite members could be used as substitutes of dimension lumber in the framework of light frame construction. The developed members could be also pre-fabricated as standard components in a mill and assembled on site. As a result, use of small-diameter round timber as structural members developed would be an efficient way to increase use of forest resource from plantation and lower the construction cost of light frame buildings.

1 INTRODUCTION

Forests, especially plantations, often contain a significant amount of juvenile trees with a small diameter. Not only do these overstocked stands increase the risk of insect, disease, fire and drought damage, but they are costly to manage (LeVan-Green and Livingston, 2011). Parts of these trees are removed to make room for the growth of others. Small-diameter round timber is the by-product from the thinning of the plantations. A large quantity of small-diameter round timber is produced every year. Small-diameter round timber is a plentiful and inexpensive natural resource. It is not suitable for direct use as structural members due to the relatively poorer mechanical properties, small size and serious natural defects. To maximize the use of the small-diameter round timber, a lot of efforts have been made. For example, Chrisp et al. (2003) applied small-diameter round timber into the structural frame of a single story residential centre. Many researchers investigated the feasibility of using the small diameter logs as structural members (Wolfe 2000, Wolfe and Moseley 2000, Wang et al. 2002, Cumbo et al. 2004, Wolfe and Murphy 2005). Fredriksson et al. (2015) utilized small diameter logs to fabricate cross laminated timber panels, in which the logs were sawn along the edge into tapered shape. However, the research and development so far cannot provide effective ways to utilize small-diameter round timber as structural members. It is generally destined for non-structural applications such as pulp for paper, board production or even fuels. A simple, economical and efficient way of using this kind of forestry by-products is needed.

Light frame construction is widely used as residential houses in North America, which mainly consists of wall, floor and roof assemblies. These components are fastened together to form a structure allowing the interior spaces to function as desired. The wall, floor and roof assemblies are manufactured by assembling dimension lumber studs, joists and trusses at a regular space into a skeleton and then applying plywood or other wood based structural panels referred to as sheathing to the skeleton to make it stable.

In this study, the conventional light frame construction was modified by utilizing small-diameter round timber to form the skeleton. A sketch of the modified structure is shown in Figure 1. Three kinds of composite members were developed, the built-up stud, the wood-steel joist and the wood-steel roof truss. Besides, the shearwalls made of the developed built-up studs and the diaphragms made of the developed wood-steel joists were also examined by replacing the framing members of conventional shearwalls and diaphragms.

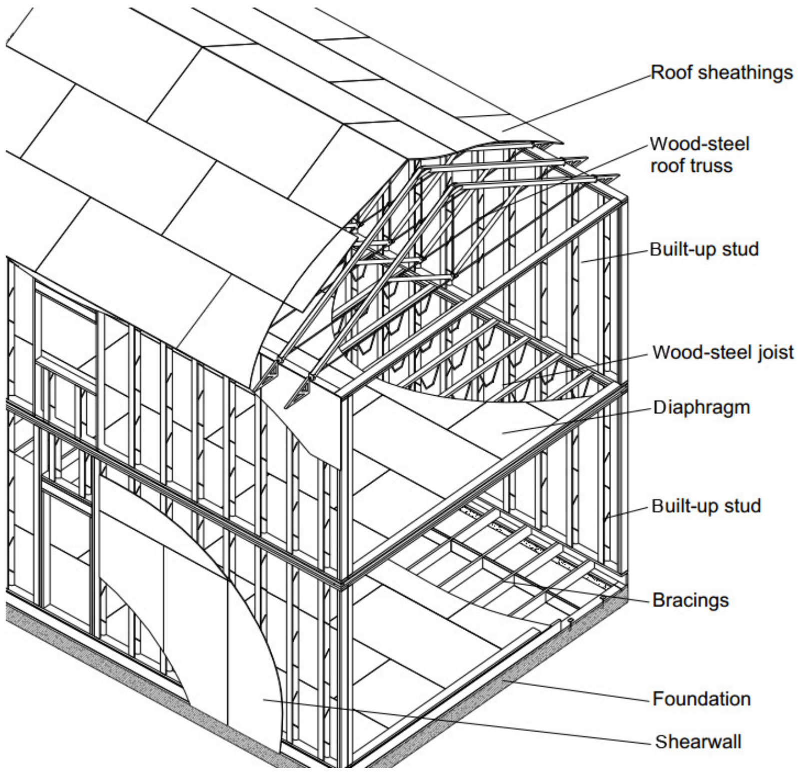

Figure 1: A sketch of the modified light frame construction

2 FORMATION OF THE DEVELOPED MEMBERS AND ASSEMBLIES

2.1 The built-up stud

As shown in Figure 2, a built-up stud is comprised of two limbs of small-diameter round timber, which are fastened using U-shaped nails. A piece of small-diameter round timber is sawn into two halves to form two semi-circular limbs, or to form one bow-shaped limb if the size is small. The larger end of one limb is placed matching the smaller end of the other limb. Arranging limbs as above reduces the property differences between studs and makes the properties more uniform along the length of the stud. The U-shaped nails are applied to both sides of the limbs. The angle between the stud and the U-shaped nails is about 45 degrees. The crown of U-shaped nail used in this study had a length of about 160mm and a diameter of 8mm, and the leg of the U-shaped nail had a length of about 35mm and a diameter of 3~4mm. The built-up stud can be assembled with a jig so that every stud comes out the same width. The stud can be manufactured in factory or on site and can be easily cut into the designed length.

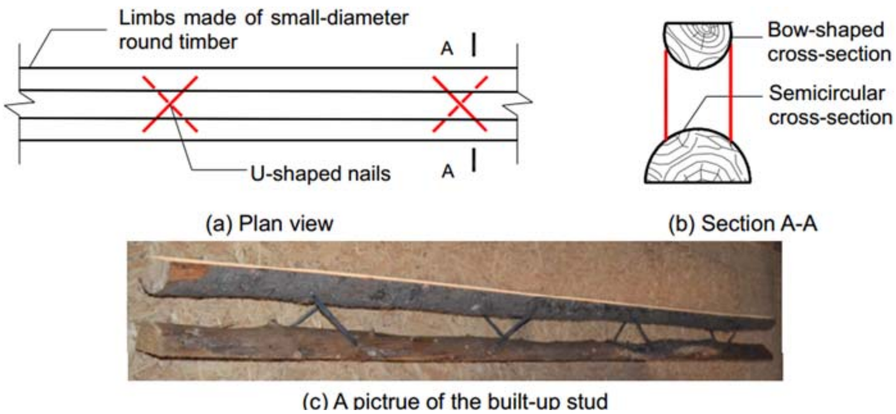

Figure 2: Formation of the built-up stud

2.2 The wood-steel joist

As shown in Figure 3, the developed wood-steel joist is a composite parallel chord truss. The top chord is made of small-diameter round timber, the bottom chord is either made of small-diameter round timber or steel rod. The web member is made of steel rod. The developed wood-steel joist is designed to have flooring material nailed or screwed to the top chord. The wood top chord is cut from small-diameter round timber that usually tapers, with a diameter of 60mm or more at the smaller end. As shown in Figure 4, the top and bottom faces of the upper chord are sawn and surfaced to accommodate the floor plates above and the web members below. After sawing, the dimension of the chord is about 45mm thick with a tapering width. The web members are actually a continuous steel rod bent into the designed zigzag shape. The bent yet continuous web member is welded to the steel lower chord, and it is connected to the upper or lower wood chord via steel plate and wood screws. The steel plate with pre-drilled holes for installing wood screws is welded to the web member at the horizontal segment. It is then fastened to the wood chord with wood screws, as shown in Figure 5. Predrilling of the wood cord is necessary to prevent splitting of wood chord. A jig may also be used to assemble the joist so that every truss comes out the same size. One advantage of the open web made of a developed joist is to enable pipes and other services to run through without drilling. Another feature is that the joist can be manufactured in factory, this can speed up installation.

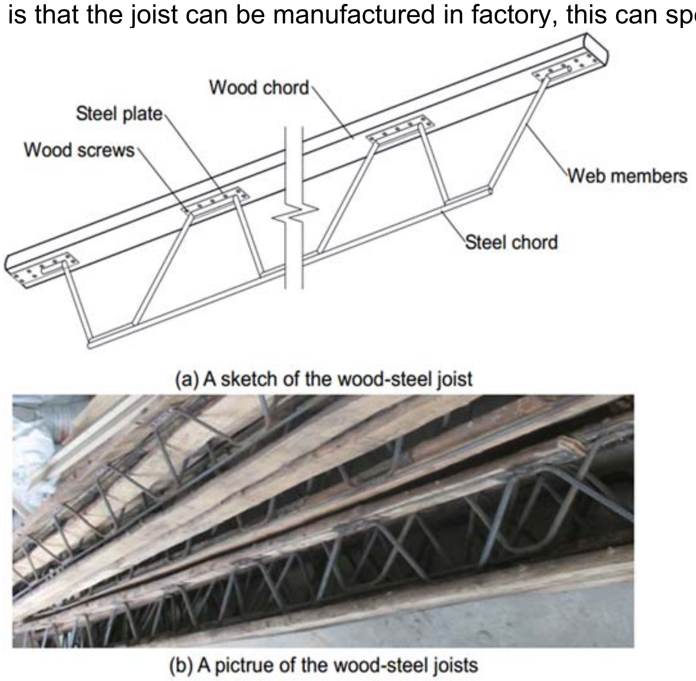

Figure 3: Formation of the wood-steel joist

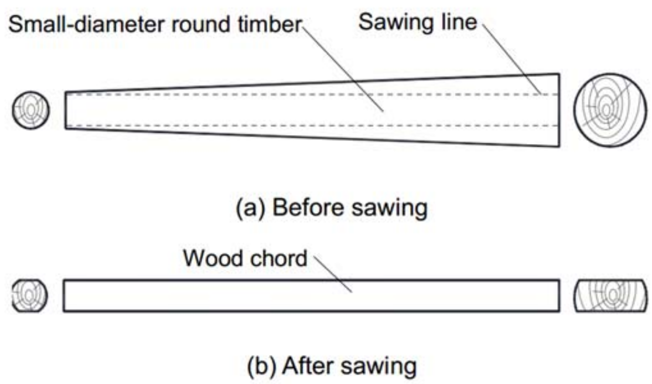

Figure 4: Processing the round timber into a wood chord

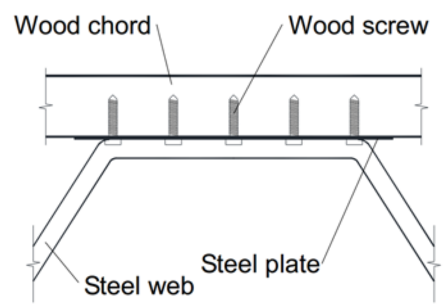

Figure 5: Joint between wood chord and web members

2.3 The wood-steel roof truss

As shown in Figure 6, the developed wood-steel roof truss consists of two top chord members made of the small-diameter round timber, a bottom chord made of steel tension rod, a vertical tension web member made of steel, and two diagonal web members made of the small diameter round timber.

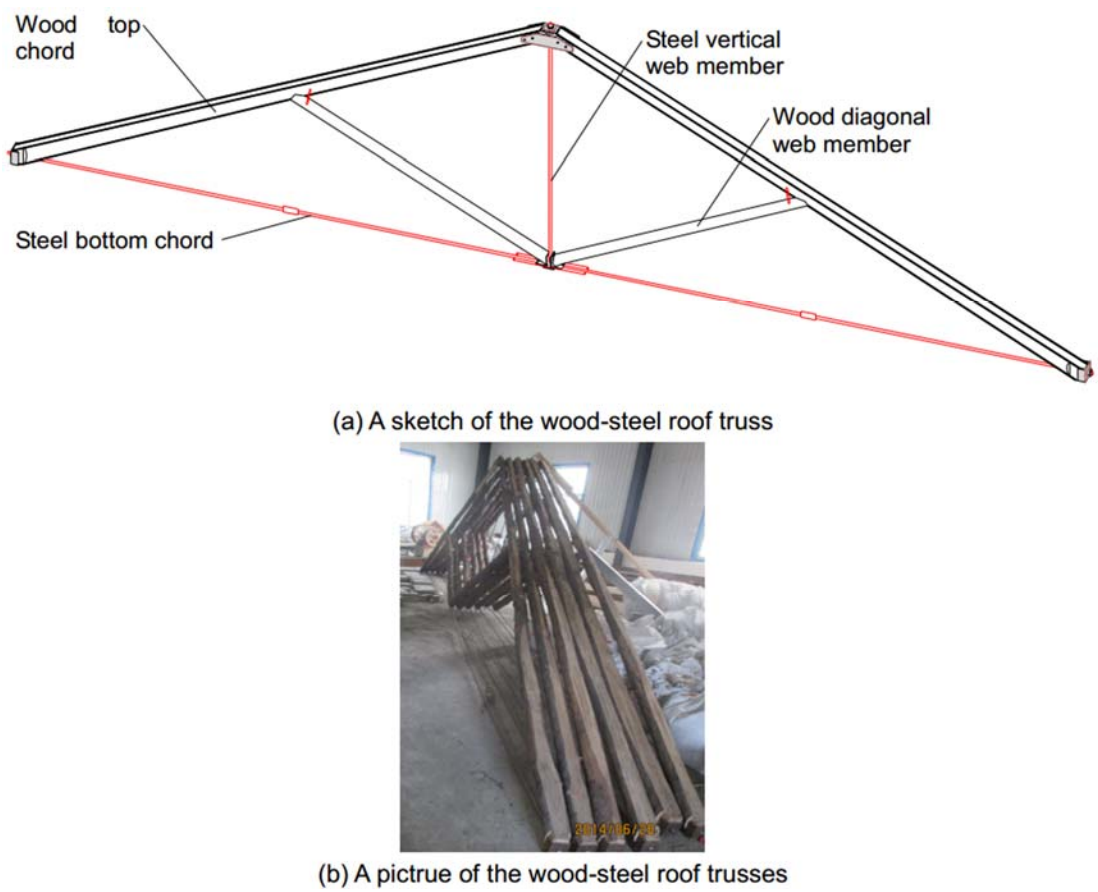

Figure 6: Formation of the wood-steel roof truss

Figure 7 shows that the top chord is manufactured by sawing a small-diameter round timber into a bow-shaped cross-section. The flat top face of the chord provides a plane to connect with the roof decking or purlin. The smaller end of the timber is placed towards the ridge. The diagonal web member is manufactured with the timber by cutting it into appropriate length without dealing with the surface. To make sure that every truss comes out the same shape, full-sized setting out is required.

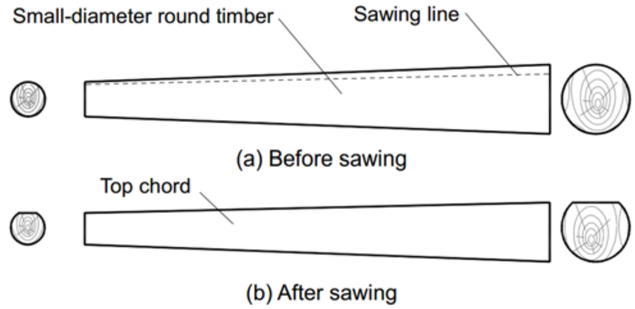

Figure 7: Processing round timber into a top chord of truss

The details of all joints of a truss are shown in Figure 8. The details of the end joint are shown in Figure 8a. It shows that the end of the round timber is cut into a flat bottom face, which is used to connect with the top plates of the supporting wall. Two vertical flat faces are made to fit the end into a section of steel channel. A hole is drilled through the end of the round timber and the steel channel. The steel bottom chord with a threaded end goes through the hole and is fixed with double nuts. The channel spreads the compressive stresses from the steel chord, which assists to prevent the timber from splitting.

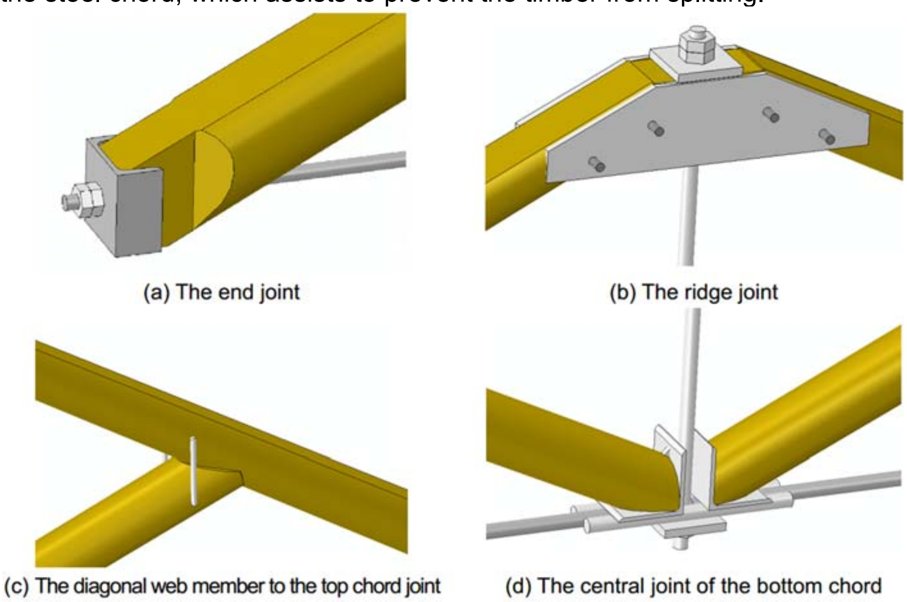

Figure 8: Details of the joints in the wood-steel roof truss

The details of the ridge joint are shown in Figure 8b. The joint is a kind of steel plate-clamped connection tightened with bolts. The end of each timber chord is cut to form a vertical plane, and then they are butted at the plane. A steel side plate is applied to each side of the joint and is tightened with four bolts. A vertical hole is drilled through the butted plane between the two timber chord members for the vertical steel web member to pass through. The end of the steel web is threaded for it to be fixed with double nuts. A thick enough steel pad is required to spread the compressive stresses.

The diagonal web member to the top chord joint is a kind of framed joint. As shown in Figure 8c, the top chord is notched with a flat face perpendicular to the web member, the web member contacts with the chord tightly. The joint is tightened with a staple at each side of the truss.

The central joint connects the vertical web, bottom tension chord and two diagonal webs together as shown in Figure 8d. The two segments of the bottom chord meet in the middle and are spliced with two additional short steel bars welded along the side of the bottom chord. A gap is left between the two segments of the chord in a size just for the vertical web to go through. A piece of steel angle is placed to each side of the vertical web and is welded on top of the steel chord. This is to accommodate the diagonal web. The vertical web with a threaded end is anchored with double nuts below the chord. A thick steel pad between the nut and the bottom chord is also needed. A stiffening rib is welded in the middle of the angle and is inserted into a groove cut in the diagonal web. It thus also prevents the diagonal web from sliding off the angle.

2.4 The shearwall made of the built-up stud

As shown in Figure 9, the shearwall consists of the bottom and top plates, studs and sheathing panels. Dimension lumber is adopted as the top and bottom plates for easier connection with the foundation or diaphragm than the irregular small-diameter round timber. Built-up studs are used as a substitute of the conventional dimension lumber studs. For the convenience of connection, dimension lumber studs may still be used as the end studs of shearwall. The built-up studs are connected to the top and bottom plates with nails. Toenailing is not recommended due to the small size of a single limb of the built-up stud. The sheathing-to-frame nail connections are the same as in a conventional shearwall, in which nails are usually used for wood based structural panels and screws are usually used for gypsum panels. Blockings are not used, because the configuration of a built-up stud makes it difficult to install the blockings within the frame of the shearwall.

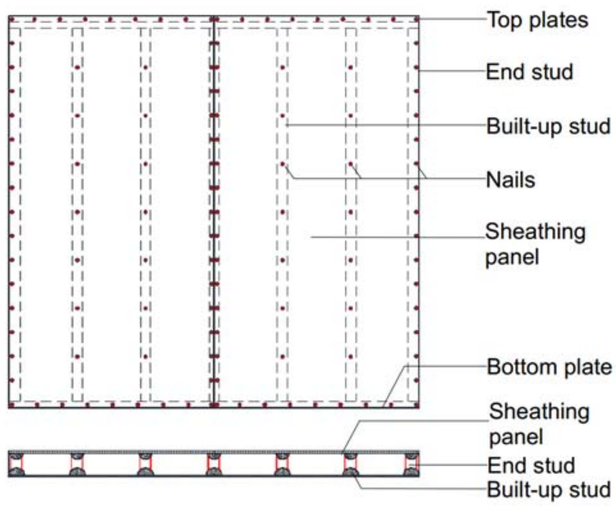

Figure 9: Formation of the shearwall

2.5 The diaphragm with the developed wood-steel joist

As shown in Figure 10, the diaphragm consists of repetitive wood-steel joists at a prescribed space. Wood-based structural panels are attached to the top of the joists as the floor plates. The panels run in the direction perpendicular to the joists, the edges of which are placed on the developed wood-steel joists or on the rim or header joists around the perimeter of the diaphragm. Each panel shall be continuous over more than one span. Finish materials such as gypsum boards are applied to the bottom of the diaphragm where they serve as the ceiling for a room below. Bracings are installed perpendicular to the joists within the framework. They are used to enhance the integrity and stiffness of the diaphragm and to reduce the deflection and vibrations via load sharing. Bracings are fixed to the bottom of the top chord of joist with nails. To increase the stiffness of the diaphragm, steel strips can be applied along the adjacent edges of the wood-based structural panels via screws or staples, as also introduced in an APA report (APA, 1997).

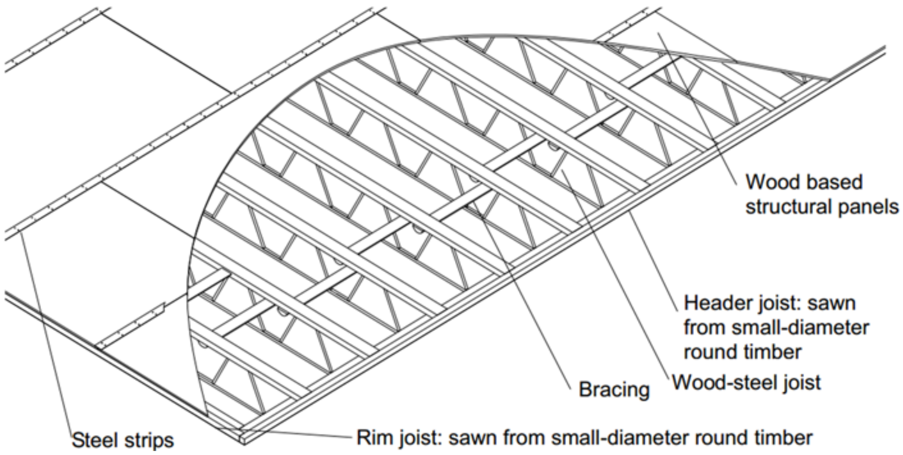

Figure 10: Formation of the diaphragm

3 TEST OF THE STRUCTURAL PERFORMANCE OF THE DEVELOPED MEMBERS

To investigate the structural performance of the developed members, full-size specimens of the built-up studs, wood-steel joists, wood-steel roof trusses, shearwalls and diaphragms were manufactured with small-diameter round timber of larch trees growing in the northeast China, steel rods and connectors. The average diameter of the smaller end of the timber used in the test was 75.8 mm, with a coefficient of variation in the diameter of about 0.20. The average moisture content of the timber during test was 12%.

12 specimens of the built-up stud were manufactured, as shown in Figure 11. Each wall-type specimen consisted of three built-up studs, which were partly sheathed with some OSB panels. 6 of these specimens were tested under axial compression and the other 6 were tested under eccentric compression. The load-bearing capacity was obtained and the failure modes observed. Under compression, the specimens of the built-up studs buckled out of plane. The buckling load of the stud developed under the axial load was nearly 91% that a 2x4 SPF stud with the same length and boundary conditions (Wu et al. 2014). This indicates that the built-up stud can be used as a substitute for dimension lumber stud.

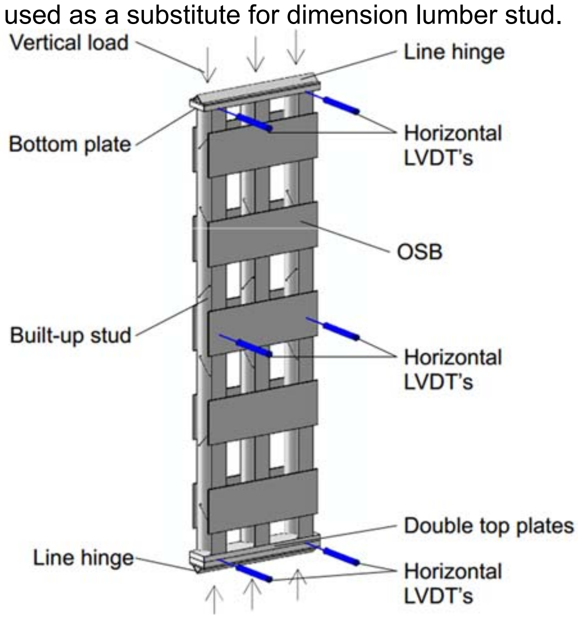

Figure 11: Test arrangement of the built-up stud

To investigate the structural performance, 18 wood-steel joists were manufactured. The joists all had a span of 4.8m, among which 6 were 400mm in height with steel bottom chord, 6 were 300mm in height also with steel bottom chord, and the other 6 were 340mm in height but with wood bottom chord made of the small-diameter round timber. As shown in Figure 12, a specimen for testing was fabricated by linking two joists together with intermittent OSB strips. They were tested under multiple-point loading. The failure mode was either that the compression web members buckled or that the joint between the tension web members and the wood chord at either end of truss fractured under the applied load. It was found that the bearing load of each test specimen was higher than 7.6kN when the deflection at mid span reached 1/360 of the span (Wu 2015), suggesting the joist developed had sufficient strength and stiffness for the intended use.

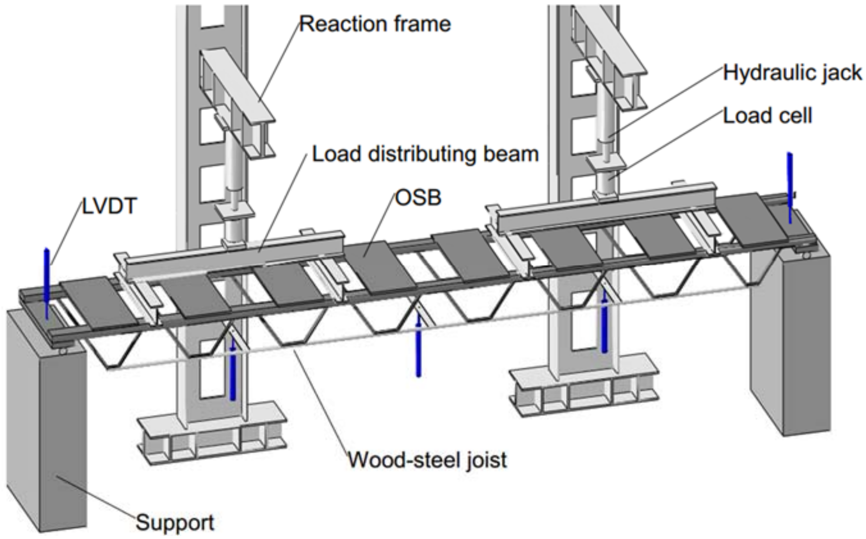

Figure 12: Test arrangement of the wood-steel joist

To investigate the structural performance, 6 wood-steel trusses with a span of 9m and a height of 2.25m were manufactured with small-diameter round timber and 14mm-diameter steel rod for the bottom chord and the vertical web member. Similar to the test of the wood-steel joists, a specimen for testing is formed by linking two roof trusses with OSB strips, as shown in Figure 13. The specimens were loaded at the ridge joint and the diagonal web member to the top chord joint until failure. It was observed that the small-diameter round timber between the ridge joint and the diagonal web member to the top chord joint buckled under the applied load. It was found that the developed trusses had an average bearing capacity equivalent to 3.35kN/m and the vertical displacement was considerably small. Thus the strength and stiffness sufficient to support the anticipated load with a maximum truss spacing of 610mm.

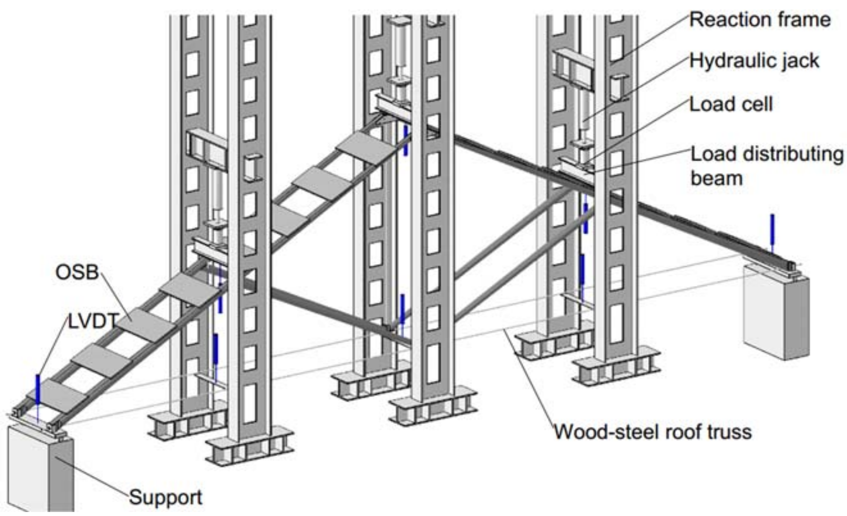

Figure 13: Test arrangement of the wood-steel roof truss

To investigate the structural behaviour of the shearwalls, a total of 15 full-size 2.44m×2.44mm shearwalls with different stud spacing, end studs and sheathing panels were manufactured and tested under cyclic lateral load, as shown in Figure 14. It was observed that the failure modes of the shearwalls with small-diameter round timber studs were similar to that of the conventional shearwalls, i.e. failure of the nail connections along the perimeter of the panels, without failure of the framing members being observed. The lateral resistance, stiffness and displacement capacity were evaluated and the results of this study showed that the developed shearwalls performed quite well under cyclic lateral load. For example, as for the shearwalls sheathed with OSB panels on one side only, the shear strength was 9.2kN/m, which was about 3% higher than that of the conventional ones of the same OSB sheathings on one side (Wu et al. 2014). This suggests that the shearwall developed had sufficient lateral resistance for use in light frame construction.

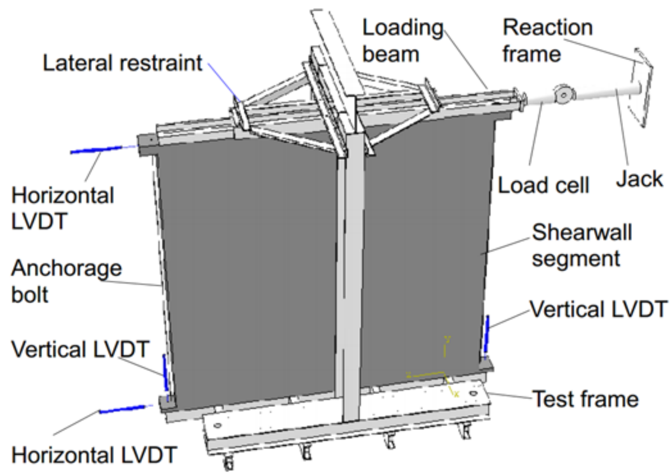

Figure 14: Test arrangement of the shearwall

The horizontal diaphragm plays a key role in the transmission of the lateral load to the vertical shearwalls. To investigate the effect of using the developed wood-steel joists in the framing on the structural performance of the diaphragm, 3 full size 4.88m×3.66m diaphragms were manufactured and tested, as shown in Figure 15. It should be noted that only the top chord of the wood-steel joist instead of the whole joist was adopted as the framing members of the diaphragm in the test specimen. This was because the steel web contributes little to the in-plane stiffness of the diaphragm. The stiffness of the diaphragm was obtained under non-destructive in-plane third point loading.

4 CONCLUSIONS

This study examined the feasibility of utilizing the small-diameter round logs as structural members for the light frame construction. Three kinds of structural composite members were developed, say built-up stud, wood-steel joist and wood-steel roof truss. In addition, the shearwalls with the built-up studs and the diaphragms with the wood-steel joists were also studied by replacing the conventional framing members with the studs and joists developed. All the members developed in this study were simple in configuration and could be easily manufactured. It was found that the developed composite members could be used as substitutes of dimension lumber in the framework of light frame construction. The members developed could be also pre-fabricated as standard components in a mill and assembled on site. As a result, use of small-diameter round logs as structural members could be an efficient way to increasing use of forest resource from plantation and lowering construction cost of light frame buildings.

It should be noted that the finite element analysis on the behaviour of such an innovative light frame construction system has been done and will be reported elsewhere.

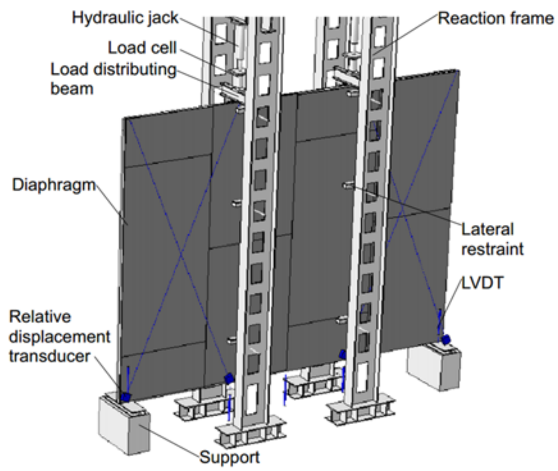

Figure 15: Test arrangement of the diaphragm

Acknowledgements

The authors gratefully acknowledge the financial support from 'The Twelfth Five-Year-Plan' in National Science and Technology for the Rural Development in China (Project Designation: 2011BAJ08B02-05) and the New Brunswick Innovation Foundation under its New Brunswick Research Innovation Chair Program.

References

American Plywood Association. 1997. Stapled Sheet Metal Blocking for APA Panel Diaphragms. Technical Note of American Plywood Association (N370C).

Chrisp T.M., Cairns J. and Gulland C. 2003. The Development of Roundwood Timber Pole Structures for Use on Rural Community Technology Projects. *Construction and Building Materials*, **17**(4): 269-279.

Cumbo D.W., Smith R.L. and Cwiii B. 2004. Value Analysis of Lumber Produced from Small-diameter Timber. *Forest Products Journal*, **54** (10): 29-34.

Fredriksson M., Bomark P., Broman O. and Gronlund A. 2015. Using Small Siameter Logs for Cross-Laminated Timber Production. *Bioresources*, **10** (1): 1477-1486.

LeVan-Green S.L. and Livingston J. 2011. Exploring the Uses for Small-diameter Trees. *Forest Products Journal*, **51**(9): 10-21.

Wang X., Ross R.J., Mattson J.A., Erickson J.R., Forsman J.W., Geske E.A. and Wehr M.A. 2002. Nondestructive Evaluation Techniques for Assessing Modulus of Elasticity and Stiffness of Small-Diameter Logs. *Forest Products Journal*, **52** (2): 79-85.

Wolfe R. 2000. Research Challenges for Structural Use of Small-diameter Round Timbers. *Forest Products Journal*, **50**(2): 21-29.

Wolfe R. and Moseley C. 2000. Small-diameter Log Evaluation for Value-added Structural Applications. *Forest Products Journal*, **50**(10): 48-58.

Wolfe R. and Murphy J. 2005. Strength of Small-Diameter Round and Tapered Bending Members. *Forest Products Journal*, **55** (3): 50-55.

Wu G. 2015. Light Wood Frame Construction Utilizing Small-Diameter Round Timber and Investigation of The Structural Behaviour. *Harbin Institute of Technology*, Harbin, China.

Wu G., Zhu E., Zhou H. and Pan J. 2014. Load-carrying Capacity of a Built-up Stud Fabricated with Small-diameter Round Timber. *World Conference on Timber Engineering*, Quebec, Canada, August 10-14.

Wu G., Zhu E., Zhou H. and Pan J. 2015. Testing and Modelling of Shearwalls Studded with Small-diameter Round Timber under Cyclic Lateral Load. *Construction and Building Materials*, **77**(2015): 288-296.