Research & Development Summary

Value to Wood

RDS 2009-01-E

Improving the Performance of Wood I-Joists

The Canadian wood I-joist industry has enjoyed tremendous growth in recent years due to the high demand for this product in North America. This growth can partly be attributed to the investment in innovation by the industry in the last few decades. However, continued investments in research and development are required to stay ahead of competitors. As a result, the Wood Science and Technology Centre, University of New Brunswick, in conjunction with the eastern Canadian wood I-joist industry and other research partners, examined the following issues:

1. The influence of web and flange properties on structural performance of wood I-joists;
2. The availability of verified calculation procedures to predict selected structural properties of wood I-joists; and,
3. The development of a process friendly flange-web joint profile.

These issues were studied through four research projects, conducted under Natural Resources Canada's *Value to Wood* program: *Enhancing Shear and Bearing Strength of Wood I-Joists*; *Glued Engineered Products Made of Red Maple*; *Optimized design of wood I-joists; and, Influence of OSB web stock properties on performance of wood I-joists*. The research findings from these projects are discussed below,

Results of the research

Influence of Flange and Web Properties on Structural Performance of Wood I-joists

In general, the influence of flange properties (such as tensile strength and modulus of elasticity) on moment capacity and flexural rigidity of wood I-joists, is well understood. However, there are two issues that are of specific interest to the wood I-joist industry. First of all, Canadian wood I-joist manufacturers use primarily sawn lumber flanges due largely to the local availability of high quality black spruce lumber. With the increasing cost of the black spruce resource, wood I-joist manufacturers are interested in investigating the feasibility of using alternative flange materials. Secondly, the influence of web stock properties on I-joist performance is not well understood, making it difficult to specify quality control requirements for web stock.

To address the first issue, research was conducted on alternative flange stock materials. In *Optimized design of wood I-joists* (2007), the material costs of using laminated veneer lumber (LVL) and sawn lumber flange were compared. An example of this comparison is shown in *Figure 1* (the text box illustrates how to interpret the results). Based on *Figure 1*, one can conclude that unless lumber price rises to over $600/FBM, it is uneconomical to replace it with LVL as flange stock for 11-7/8" deep I-joists. Conversely,

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if LVL price rises above $18/ft3, it is not viable to use LVL in place of sawn lumber for the same depth. Note that the comparison is based on material cost only, and does not take into account production costs for the two materials (additional results are given in the final research report).

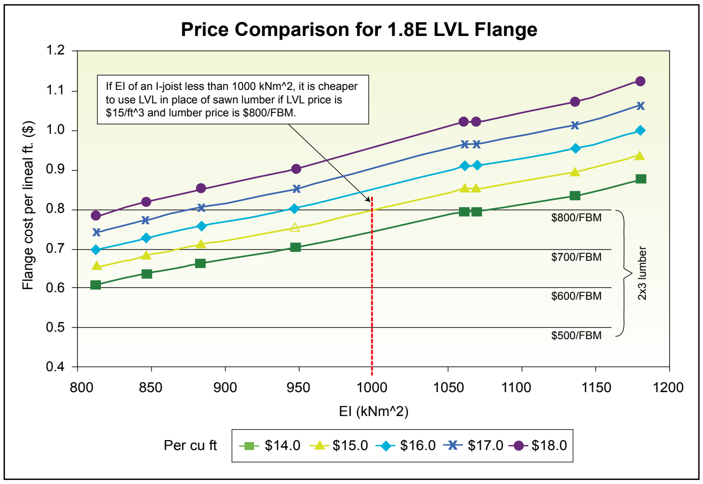

Figure 1: Cost for 1.8E LVL flange.

The feasibility of using red maple, an underutilized dense hardwood, as flange stock material was investigated in the project *Glued Engineered Products Made of Red Maple*. Red maple was selected because of its abundance in eastern Canada. *Figure 2* shows a comparison of the modulus of elasticity of black spruce and red maple 2x3 lumber from eastern Canada. This comparison clearly shows that it is feasible to produce a high performance wood I-joist using red maple. However it was also found that current structural adhesives available commercially do not appear to work well with dense hardwoods, although previous research showed that phenolic adhesives provided adequate bond strength. Therefore the key to using dense hardwood hinges on the identification of a suitable structural adhesive.

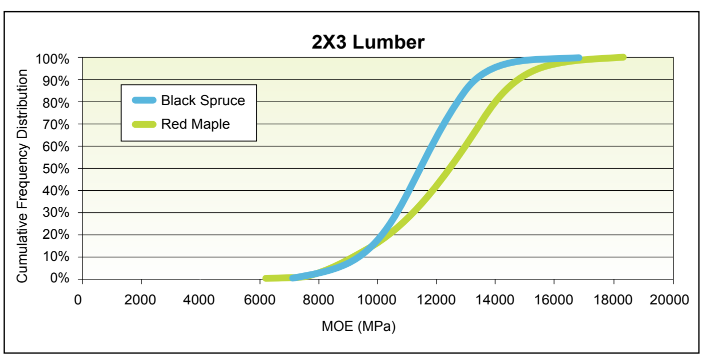

Figure 2: Cumulative frequency distribution of black spruce and red maple 2x3 lumber

Regarding the second question of interest to manufacturers, the following conclusions are drawn from the research project *Influence of OSB web stock properties on performance of wood I-joists*:

- From the perspective of structural design properties, the important web properties are edgewise MOE, through-thickness shear modulus and shear strength. The first two properties affect deflection behaviour of wood I-joists whereas the last property dictates the shear capacity of wood I-joists.
- Wood I-joist deflection behaviour is sensitive to shear modulus of web if it is less than 500 MPa, therefore shear modulus of web stock should be well above this value.
- Internal bond of OSB has no useful correlation with any of its mechanical properties that affect wood I-joist properties.

Development of a Process-friendly Flange-web Joint Profile

It was shown in the research project Enhancing Shear and Bearing Strength of Wood I-Joists that the so-called "knife–through" failure under bearing load is affected by the flange-web joint profile. This flange-web joint profile is also considered to play a critical role in holding the flange and web together during manufacturing. One of the objectives of *Optimized design of wood I-joists* was to identify a flange-web profile that optimizes bearing resistance of I-joists and process efficiency. The flange-web joint profile is defined by the groove slope, rout depth and web tip. Through a combination of experimental work and numerical modeling, the optimum flange-web joint for a 9.5 mm thick web was found to have the profile shown in *Figure 3*.

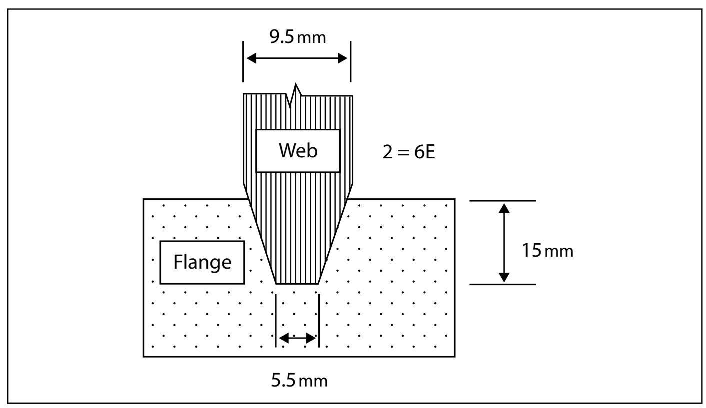

Figure 3: Optimum flange-web joint profile.

It was found that bearing strength increases with an increase in rout depth. Further research revealed that a rout depth of 9 mm can be used from a material saving standpoint while maintaining the same groove slope, but there is a 20% reduction in bearing strength. This reduced bearing strength would not have a significant impact on allowable floor spans in residential construction because this property rarely governs floor spans. Note that using a 9 mm rout depth instead of 15 mm, which is closer to the profile commonly used by wood I-joist manufacturers, leads to saving in web material and reduced wearing on cutting tools. For example, for a 241mm deep wood I-joist, the saving in web material is about 6%. The material saving is progressively lower for deeper joists.

Calculation Procedures to Predict Selected Structural Properties of Wood I-joists

Qualification requirements generally stipulate that structural properties, with the exception of flexural properties, of wood I-joists be determined by testing. Through *Enhancing Shear and Bearing Strength of Wood I-Joists and Influence of OSB web stock properties on performance of wood I-joists*, two mechanics-based models have been developed or verified. These models can be used to minimize the amount of qualification test work, adopted as design tools or used in product design. These models are summarized below.

Shear Strength of Wood I-joists

Shear strength (V) of wood I-joists, without a web hole, can be estimated from the shear strength of the web using *Equation 1* (Ozelton and Baird, 1976). Shear strength was determined using ASTM D2719 (ASTM 2004) two-rail shear arrangement. This equation has been validated with test data from tests performed on 241 mm and 406 mm deep wood I-joists.

$$V = \frac{v\,t(EI_X)}{EQ_X}$$

Equation 1: Where v = web shear strength; t = web thickness; EIx = sum of product of modulus of elasticity and second moment of area about centroidal axis for flange and web; EQx = sum of product of modulus of elasticity and first moment of area abut the centroidal axis for flange and web (see the Influence of OSB web stock properties on performance of wood I-joists project report for calculation of EIx and EQx).

Strength of Wood I-joist With a Square Web Hole

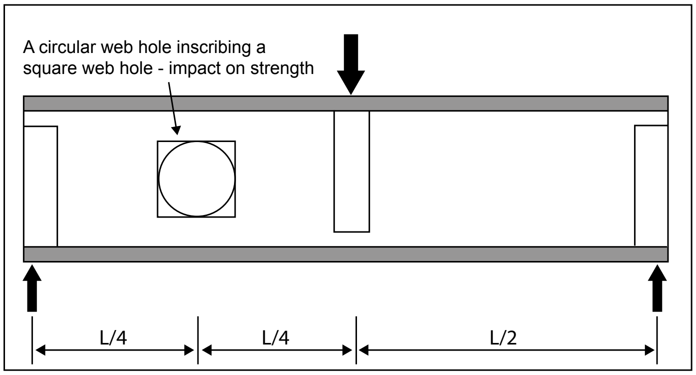

Figure 4: Wood I-joist web hole shear test arrangement.

The load, P, causing failure of a wood I-joist with a square web hole when tested in a typical qualification test arrangement (*Figure 3*), can be calculated using *Equation 2*.

$$P = \sqrt{\frac{S_1^{\,2} S_{12}^{\,2}}{S_{12}^{\,2}\,\sigma_{crit}^{\,2} + S_1^{\,2}\,\tau_{crit}^{\,2}}}$$

Equation 2: Where S_1 = flatwise bending strength of web; S_{12} = shear strength of web; σ_{crit} = shear stress at the critical corner of the web hole caused by applied load; τ_{crit} = shear stress at the critical corner of the web hole caused by applied load (see the project report for *Enhancing Shear and Bearing Strength of Wood I-Joists* for the calculation of σ_{crit} and τ_{crit})

For a wood I-joist with a circular web hole, it was found that its strength is similar to the same I-joist with a square web hole to which the circular web hole can inscribe as illustrated in *Figure 4*. Therefore *Equation 2* can be used to predict the strength of a wood I-joist with a circular web hole. It should be noted that, although Equation 2 is presented in a format for predicting the strength of a wood I-joist tested under the specific arrangement shown in *Figure 4*, with some modifications it can be used to predict the strength of a wood I-joist with a square or circular web hole under other loading arrangements, such as a uniformly distributed load.

References

ASTM. 2004. Standard test methods for structural panels in shear through-the-thickness. Designation D2719. American Society for Testing and Materials, West Conshohocken, PA.

Ozelton, E. C. and Baird, J. A. 1976. Timber designers' manual. Granada Publishing Ltd, London, UK.

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