

Research & Development Summary



Value
to
Wood

RDS 08-08
April 2008

Design Methods for Connections in Engineered Wood Products

Despite their excellent mechanical properties, Engineered Wood Products (EWP) like Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL) and Laminated Strand Lumber (LSL) have not been widely used in structural applications. Such products have largely been employed as substitutes for sawn lumber materials in 'small building' applications. To change this, it is essential that engineers gain knowledge of the strength and stiffness characteristics of mechanical connections, to supplement what is known about properties of EWP themselves. Connections must be designed to transfer forces between structural elements; to couple elements to create compound members; to attach claddings, floors and roofs; and to anchor superstructures to foundations. Currently, only very conservative approaches exist as the basis for deriving design properties for connections in EWP. In North America, the primary approach has been to seek equivalency between the performances of EWP connections and similar connections in sawn lumber. Although such an approach has permitted engineers to design structural systems, it tends to result in oversize connections and therefore wasted materials and lost market opportunities, especially for non-residential applications.

This project was aimed at developing generalized structural design information for mechanical connections in EWP, taking into account the physical characteristics of such products. Part of this was recognition that, because the physical compositions of most EWP are unlike those of sawn lumber, failure modes should not be presumed to mimic those in sawn lumber connections. Project activities involved gaining an understanding of the mechanical properties of EWP being joined by

connections, the behaviour of connection systems themselves, how to select suitable combinations of fasteners and EWP for particular end-use situations, and how to establish design capacities for connections. The type of EWP material investigated was Structural Composite Lumber (SCL) including LVL (2600Fb-1.9E), PSL (2900Fb-2.0E) and LSL (2250Fb-1.5E). This reflects that LVL is by far the most commonly manufactured wood composite in Canada, and PSL and LSL are those least similar to sawn lumber amongst those currently manufactured in North America. Because of the need for consistency between design of connections in EWP and sawn lumber, attention was also directed at behaviour of matched connections in sawn pine lumber (SG=0.38) and sawn spruce (SG=0.40). Results of the project provide a database of properties for types of products that were evaluated, and are being used to establish technically sound bases for engineering use of that data. The test program involved connections with single and multiple fasteners loaded statically in parallel- and perpendicular-to-grain (main axis of member) orientations. Subsidiary tests were also conducted to determine material properties of EWP and bending strength of the fasteners.



Natural Resources
Canada

Ressources naturelles
Canada

Results of the project

General outcome:

The broadest finding from this project was that for the purpose of designing structural connections, it is appropriate to think of EWP as either “splitting-prone” or “splitting-resistant” materials. Materials like LVL and PSL, as sawn lumber, have internal structural arrangements of material (e.g., veneer, strands, longitudinal cells) that create large inequalities in directionally dependent stiffness and strength properties. Thus, they have a pronounced strong axis direction of material symmetry. In LVL this direction is parallel to the average grain direction in the stacked layers of veneer from which it is made; and in PSL it is parallel to the average direction of the component veneer strands.

At mechanical connections, or at other locations where there are features that can raise stresses locally to critical levels, there is an inbuilt tendency of the material towards failure modes involving fracture in planes running parallel to the strong axis of material symmetry. Like sawn lumber, splitting-prone EWP has little inherent ability to toughen itself against propagation of such cracks once they are initiated. Strategies for making strong and stiff connections in them must match those that are traditional for connections in sawn lumber. Suitable strategies are: using slender dowel fasteners that absorb energy through their own deformation, reinforcement of members in the vicinity of connections, and use of novel connection hardware that circumvents creation of stress concentrations.

Materials like LSL have internal structural arrangements of strands that reduce the tendency towards large directional inequalities in stiffness and strength. Also very importantly from the perspective of making mechanical connections, such splitting resistant EWP contain much ability to toughen themselves against propagation of cracks. Therefore, strategies for making strong and stiff mechanical connections in them do not have to match those that are traditional for sawn lumber.

Connection in wood products like LSL will ultimately break in an apparently catastrophic manner if applied loads are increased sufficiently, as will steel components, but that does not happen until very large deformations have occurred.

Failure and deformation mechanisms:

Figure 1 shows typical failed specimens in which a sawn pine or EWP member had been loaded by four 3/8-inch (9.5 mm) bolts that bore on pre-drilled holes in the member perpendicular to the strong material axis. As can be seen, failure mechanisms were rather similar for sawn pine, LVL, and PSL specimens, with unstable propagation of cracks (horizontal as shown) parallel to the strong axis of the material. However, in the case of the LSL specimen it was the LSL member itself that failed and not the connection.

Similarity in failure mechanisms does not always mean similarity in the stiffness and strength of similar fasteners making connections in various wood products. The temptation to try and generalize about the relative magnitudes of stiffness and strength capacities of connections in various EWP should be avoided. However, it was generally the case that LSL connections were always relatively strong and stiff, and sawn pine connections were always relatively weak.

The correct interpretation of the results is that, estimation of the design properties of EWP connections should always be based on collection of reliable test data that is specific to a particular type of wood product. Also, methods for interpreting test data need to be consistent and “standardized”. To this end, the project team created draft standard practices for evaluation of EWP connections and presented them to the Canadian Standards Association’s Technical Committee O86 – Engineering Design in Wood (CSA Technical Committee), and the International Standards Organization’s Technical Committee 165 – Timber Structures. Those proposals are currently under active development in those committees. Also, the suggested procedures can be followed by third party product assessment organizations like the National Research Council’s Canadian Construction Materials Centre (CCMC) that carries out third-party evaluations of proprietary products.

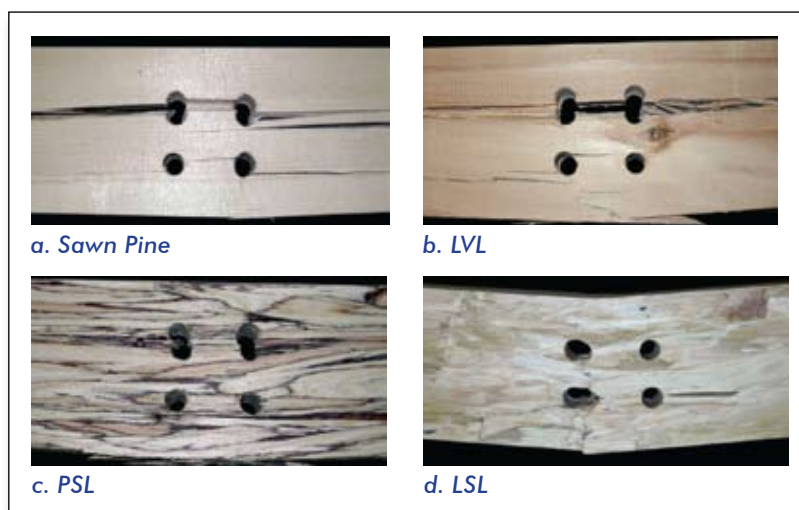


Figure 1: Failed bolted connections.

Adequacy of current standard test protocols:

This project investigated the suitability of current written standards that recommend methods for testing EWP connections. Most attention was given to the ASTM D5652-95 “Standard test methods for bolted connections in wood and wood-based products”. This is because responses of bolted connections are very sensitive to differences between wood products, and because that standard is commonly used by North American industry as the basis for evaluating EWP connections.

A key result was that using the so-called ‘three-point bending’ test setup from ASTM D5652 for determining strength of a connection with the load applied perpendicular to the strong axis of the material, it is possible to obtain completely erroneous failure mechanisms in connections. The extent to which observations are erroneous depends on the type of wood member used. This can lead to great inconsistencies in product assessments, and often to undervaluation of achievable strengths with EWP. Therefore an alternative test specimen needed to be designed.

The project team has proposed that a new statically determinate propped cantilever specimen be used, that more consistently achieves failures in connections, and is more reflective of critical in-service situations.

Novel small tube fasteners for EWP:

When traditional solid dowel-type fasteners like nails and bolts are used, stiffness and capacity of connections made in splitting-prone EWP (or sawn lumber) can be quite low, compared to capacities of the members being joined. Therefore, the project team investigated the potential of small diameter steel tube fasteners inserted in tight fitting pre-drilled holes as a novel connection method for EWP.

Tube fasteners create a softer and more intimate contact with members, than that which occurs with solid fasteners, and this reduces proneness to splitting failures (*Figure 2*). Also the tube fasteners, if slender, are better able to create favourable plastic hinge conditions in fasteners at overload. Combining tube fasteners with steel splice plates slotted into the ends of wood members (*Figure 3*) was found to be a particularly efficient means of making EWP connections. That resulted in

high initial stiffness, high strength, and high ductility at overload. With the correct choices of fastener dimensions and steel type, such connections can result in bearing failures that realize 100% of the peak capacity per fastener in all fasteners. This is an extremely important advantage, because with bolts and some other types of solid fasteners the attainable capacity per fastener can be severely discounted in multiple-fastener connections because the fasteners themselves cause stress concentrations that propagate splits. The research showed that use of steel tube fasteners with outside diameters up to ¼-inch (6.4 mm) is most efficient. Benefits from using hollow fasteners accrue to a lesser extent with larger fasteners.

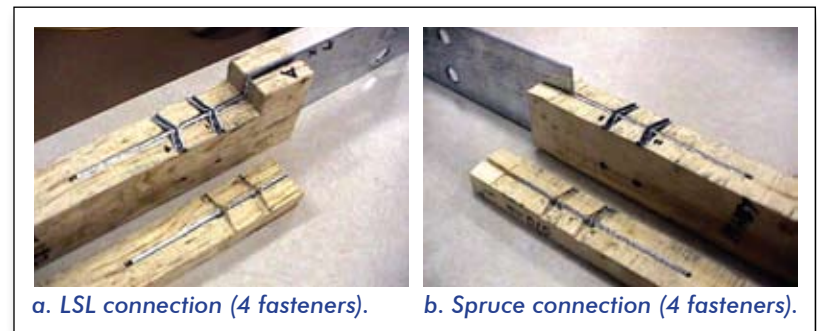


Figure 2: Typical steel tube connections after failure.

Updating the Canadian timber design code:

The project team undertook an analysis of current and proposed design provisions for connections in wood based on the Canadian Standard Association’s CAN/CSA-O86-01 ‘Engineering Design in Wood’. It was found that both existing and proposed provisions are poorly suited to design of EWP connections because the special nature of those materials is not recognized.

For example, in bolted connections in LSL, it may not be necessary to reduce the capacity per bolt if there are a number of laterally loaded bolts arranged in columns and rows, despite that being required by current provisions. With some EWP connections it is possible to create simple connections with very few fasteners that are stronger than EWP members that they connect together. This can include capability to transfer moment from members to other parts of structural systems.

Implications are radical, as this totally alters the basic precepts of decades of timber engineering design practices that are based on assuming structures always behave like those made from sawn lumber. Revamping design codes in Canada and elsewhere to reflect this is an enormous task, but the project team has begun the process in conjunction with colleagues in Canada and abroad. This includes refocusing attention from design of individual components to the design of structural systems. In Canada the process is occurring via activities of the CSA O86 Technical Committee, and elsewhere via the International Council for Building Research Studies and Documentation’s Working Commission W18 - Timber Structures.



Potential benefits at the business level

The major benefit to the wood industry is provision of an essential foundation of understanding to further develop design specifications that will allow engineers to design buildings containing EWP. That creates pull through demand for products like LVL that is being manufactured on an increasingly massive scale in Canada. This project has created an independent data base on certain EWP products that is a reference source for both the manufacturing industry and product users.

Less directly, sales of EWP could be increased by creation of know-how for the manufacture of a novel connection that utilizes small steel tube fasteners. This makes larger spans possible, and thereby penetration of new, mainly non-residential, market niches. Potential benefits to users of wood products and the general public are the provision of a technically sound basis for safe and economic design of connections in structural systems employing EWP materials. Creation of a new mechanical connection method provides business opportunities for manufacturers of proprietary products and systems. UNB is seeking avenues for further exploitation.

Acknowledgement

The University of New Brunswick acknowledges the financial support of this project by Natural Resources Canada. Thanks are due to the project champion Kenneth Koo of Jager Building Systems and industry liaisons Eric Jones of the Canadian Wood Council and Darian Wentland of Jager Building Systems. The project team also thanks Jager Building Systems and Trus Joist (USA) for in-kind contributions of test materials.

For further information contact:

Professor Dr. Ian Smith
University of New Brunswick
Tel: 506-453-4944 Fax: 506-453-3538
Email: ismith@unb.ca

Ce Sommaire de recherche et développement est également disponible en français.

Value to Wood Research Program Partners



**Value
to
Wood**

As part of the *Value to Wood* program, funded by Natural Resources Canada, Forintek's Industry Advisors are providing technical services to value-added wood product manufacturers in all regions of Canada. Find out about upcoming workshops or seminars in your area by visiting us at www.valuetowood.ca or make a request for information on any technical issue related to wood product manufacturing via valuetowood.ca (Help Desk).

To obtain the full report, contact:

Library
FPInnovations – Forintek Division
Western Region
publications.forintek@fpinnovations.ca
Tel: (604) 224-3221
Fax: (604) 222-5690

Marielle Martel
FPInnovations – Forintek Division
Eastern Region
publications.forintek@fpinnovations.ca
Tel: (418) 659-2647
Fax: (418) 659-2922