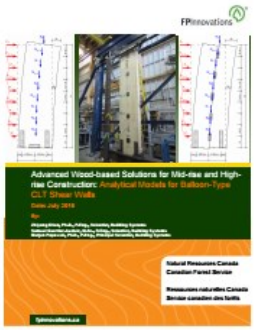


Advanced wood-based solutions for mid-rise and high-rise construction: analytical models for balloon-type CLT shear walls

https://library.fpinnovations.ca/en/permalink/fpipub52680

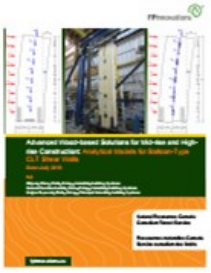
Author: Chen, Zhiyong
Cuerrier-Auclair, Samuel
Popovski, Marjan

Contributor: Natural Resources Canada. Canadian Forest Service

Date: July 2018
Material Type: Research report
Physical Description: 83 p.
Sector: Wood Products
Field: Sustainable Construction
Research Area: Building Systems
Subject: Cross Laminated Timber
Performance
Building construction
Building materials
Energy
Language: English

Abstract: Lack of research and design information for the seismic performance of balloon-type CLT shear walls prevents CLT from being used as an acceptable solution to resist seismic loads in balloon-type mass-timber buildings. To quantify the performance of balloon-type CLT structures subjected to lateral loads and create the research background for future code implementation of balloon-type CLT systems in CSA O86 and NBCC, FPInnovations initiated a project to determine the behaviour of balloon-type CLT construction. A series of tests on balloon-type CLT walls and connections used in these walls were conducted. Analytical models were developed based on engineering principles and basic mechanics to predict the deflection and resistance of the balloon-type CLT shear walls. This report covers the work related to development of the analytical models and the tests on balloon-type CLT walls that the models were verified against.

Documents



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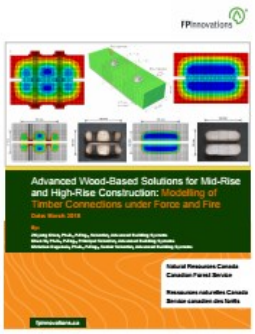


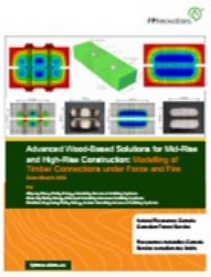
Advanced wood-based solutions for mid-rise and high-rise construction: modelling of timber connections under force and fire

https://library.fpinnovations.ca/en/permalink/fpipub49851

Author:	Chen, Zhiyong
	Ni, Chun
	Dagenais, Christian
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	March 2018
Material Type:	Research report
Physical Description:	85 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Advanced Wood Materials
Subject:	Cross Laminated Timber
	Fire
	Performance
	Timber
Language:	English

Abstract: FPInnovations carried out a survey with consultants and researchers on the use of analytical models and software packages related to the analysis and design of mass timber buildings. The responses confirmed that a lack of suitable models and related information for material properties of timber connections, in particular under combination of various types of loads and fire, was creating an impediment to the design and construction of this type of buildings. Furthermore, there is currently a lack of computer models for use in performance-based design for wood buildings, in particular, seismic and fire performance-based design.
In this study, a sophisticated constitutive model for wood-based composite material under stress and temperature was developed. This constitutive model was programmed into a user-subroutine and can be added to most general-purpose finite element software. The developed model was used to model the structural performance of a laminated veneer lumber (LVL) beam and a glulam bolted connection under force and/or fire. Compared with the test results, it shows that the developed model was capable of simulating the mechanical behaviour of LVL beam and glulam connection under load and/or fire with fairly good correlation. With this model, it will allow structural designers to obtain the load-displacement curve of timber connections under force, fire or combination of the two. With this, key design parameters such as capacity, stiffness, displacement and ductility, which are required for seismic or fire design, can be obtained.
It is recommended that further verification and calibration of the model be conducted on various types of wood products, such as CLT, glulam, SCL and NLT, and fasteners, e.g. screw and rivet. Moreover, a database of the thermal and structural properties of the wood members and fasteners that are commonly used in timber constructions need to be developed to support and facilitate the application of the model.

Documents



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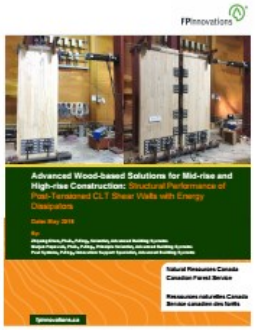
Advanced Wood-based Solutions for Mid-rise and High-rise Construction: Structural Performance of Post-Tensioned CLT Shear Walls with Energy Dissipators

https://library.fpinnovations.ca/en/permalink/fpipub49859



Author:	Chen, Zhiyong
	Popovski, Marjan
	Symons, Paul D.
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	May 2018
Material Type:	Research report
Physical Description:	117 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Advanced Wood Materials
Subject:	Cross Laminated Timber
	Performance
	Building construction
	Building materials
	Energy
Language:	English

Abstract: The latest developments in seismic design philosophy have been geared towards developing of so called "resilient" or "low damage" innovative structural systems that can reduce damage to the structure while offering the same or higher levels of safety to occupants. One such innovative structural system is the Pres-Lam system that is a wood-hybrid system that utilizes post-tensioned (PT) mass timber components in both rigid-frame and wall-based buildings along with various types of energy disspators. To help implement the Pres-Lam system in Canada and the US, information about the system performance made with North American engineered wood products is needed. That information can later be used to develop design guidelines for the designers for wider acceptance of the system by the design community. Several components influence the performance of the Pres-Lam systems: the load-deformation properties of the engineered wood products under compression, load-deformation and energy dissipation properties of the dissipators used, placement of the dissiaptors in the system, and the level of post-tensioning force. The influence of all these components on the performance of Pres-Lam wall systems under gravity and lateral loads was investigated in this research project. The research project consisted on two main parts: material tests and system tests.

In the material tests part of the program, a total of 110 compression tests were conducted to determine the load-deformation properties of four different engineered wood products (LVL, LSL, Glulam and CLT) in various directions. The LVL, LSL and Glulam specimens tested under compression parallel to grain had similar linear elastic behaviour with limited ductility. The CLT specimens tested under compression in the major-axis direction had linear elastic behaviour with moderate plasticity. Depending on the type of engineered wood product, typical failure modes included crushing, shear, wedge split and splitting. The compressive strength of the products tested ranged from 42.1 to 53.5 MPa, the global MOE (of the entire specimen under compression) varied between 6390 and 9554 MPa, the local (near the crushing surface) MOE parallel to grain was in the range of 2211 to 5090 MPa, while the local to global MOE ratio ranged from 29.2 to 58.0%, and was higher with the increase in the oven-dry density.

The specimens of the four different engineered wood products tested

under compression perpendicular to grain or in the minor-axis direction had elastic-plastic behaviour with a clearly defined plastic plateau. Crushing (densification) of the fibres perpendicular to grain was the main failure mode for all specimens, and was in some cases followed by in-plane shear failure or cracking perpendicular to grain. Compression parallel to grain in the middle layer that was followed by its delamination and buckling was a unique failure mode for CLT specimens tested under compression in the minor strength direction. The compressive strength of the engineered wood products tested were in the range of 4.8 to 27.8 MPa, while the global and local MOE perpendicular to grain were in the range of 244 to 2555 MPa, and 320 to 1726 MPa, respectively. The compressive strength and global MOE perpendicular to grain increased with an increase in the oven-dry density. The results show no well-defined trend for the local MOE perpendicular to grain. The specimens loaded in the centre perpendicular to grain had higher strength, global and local MOE than those loaded at the end.

A convenient and timesaving design for the axial energy dissipators (fuses) was developed by replacing the epoxy in the original design with two half-tubes. Compared to the original design of fuses with epoxy, the new design with two half-tubes had similar necking failure mode and a longer failure displacment, thus providing user-friendly fuses that performed similar or even better than the original design.

In the system tests part of the program, a total of 17 different PT and Pres-Lam CLT walls with six different configurations were tested under monotonic and reversed cyclic loading. The studied parameters included the level of PT force, the position of the fuses, and the number of UFPs. CLT shear walls subjected only to post-tensioning, had non-linear elastic behaviour. The behaviour of the PT walls with and without energy dissipators was relatively similar under monotonic and cyclic loading. The strength degradation observed during the cyclic tests was low in all wall configurations suggesting that very little damage was inflicted upon the structure during the first cycles at any deformation level. Four major failure modes, including yielding and buckling of fuse, crushing and splitting of wood at the end of wall, and buckling of lumber in the exterior-layer of CLT wall, were observed in the tests. The yielding in fuses occurred at the early stage of loading as designed and the other failure modes happened when the lateral drift reached or beyond 2.5%.

The initial stiffness of the single-panel PT CLT walls tested ranged from 1.80 to 2.31 kN/mm, the load at the decompression point and 2.5% drift were in the range of 4.2 to 14.9 kN and 32.7 to 45.9 kN, respectively. The initial stiffness of the single-panel Pres-Lam CLT walls tested ranged from 1.69 to 2.44 kN/mm, the load at the decompression point and 2.5% drift were in the range of 21.0 to 30.2 kN and 59.6 to 69.8 kN, respectively. All the mechanical properties increased with an increase in the PT force. The average initial stiffness and the load at 2.5% drift of the coupled-panel Pres-Lam CLT walls tested were 4.59 kN/mm and 151.3 kN, respectively, while the load at the decompression point increased from 58.4 to 69.7 kN by increasing the number of UFP. The test results show that the behaviour of the Pre-Lam CLT shear walls can be de-coupled and a “superposition rule” can be applied to obtain the stiffness and resistance of such system.

The test results gave a valuable insight into the structural behaviour of the PT and Pres-Lam CLT shear wall under in-plane lateral loads. The data from the testing will be used in the future for development of numerical computer models. They will also be used for development of design guidelines for this system. All tests conducted in this study and the analyses in the future modelling research will form the basis for

developing future design guidelines for PT and Pres-Lam mass timber systems.

Documents

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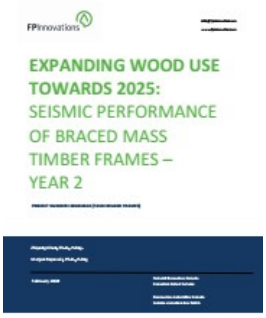


Expanding wood use towards 2025: seismic performance of braced mass timber frames, year 2

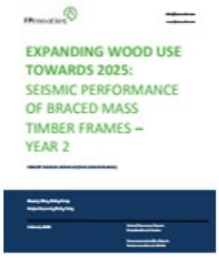
https://library.fpinnovations.ca/en/permalink/fpipub52921

Author:	Chen, Zhiyong
	Popovski, Marjan
Date:	February 2020
Material Type:	Research report
Physical Description:	40 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Building Systems
Subject:	Cross Laminated Timber (CLT)
	Performance
	Building construction
	Building materials
	Seismic
Series Number:	Expanding wood use towards 2025
Language:	English

Abstract: Braced timber frames (BTFs) are one of the most efficient structural systems to resist lateral loads induced by earthquakes or high winds. Although BTFs are implemented as a system in the National Building Code of Canada (NBCC), no design guidelines currently exist in CSA O86. That not only leaves these efficient systems out of reach of designers, but also puts them in danger of being eliminated from NBCC. The main objective of this project is to generate the technical information needed for development of design guidelines for BTFs as a lateral load resisting system in CSA O86. The seismic performance of 30 BTFs with riveted connections was studied last year by conducting nonlinear dynamic analysis; and also 15 glulam brace specimens using bolted connections were tested under cyclic loading.

In the second year of the project, a relationship between the connection and system ductility of BTFs was derived based on engineering principles. The proposed relationship was verified against the nonlinear pushover analysis results of single- and multi-storey BTFs with various building heights. The influence of the connection ductility, the stiffness ratio, and the number of tiers and storeys on the system ductility of BTFs was investigated using the verified relationship. The minimum connection ductility for different categories (moderately ductile and limited ductility) of BTFs was estimated.

Documents



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Expanding wood use towards 2025: seismic performance of midply shear walls

https://library.fpinnovations.ca/en/permalink/fpipub7699

Author: Chen, Zhiyong
Ni, Chun
Karacabeyli, Erol
Yeh, Borjen
Line, Philip

Contributor: Engineered Wood Assocation (APA)
American Wood Council (AWC)

Date:	March 2020
Edition:	52949
Material Type:	Research report
Physical Description:	47 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Advanced Wood Materials
Subject:	Cross Laminated Timber (CLT) Performance Building construction Building materials Seismic Shear walls Standards
Series Number:	Expanding wood use towards 2025
Language:	English

Abstract: Midply shear wall (hereafter Midply), which was originally developed by researchers at Forintek Canada Corp. (predecessor of FPInnovations) and the University of British Columbia, is a high-capacity shear wall system that is suitable for high wind and seismic loadings. Its superior seismic performance was demonstrated in a full-scale earthquake simulation test of a 6-storey wood-frame building in Japan. In collaboration with APA–The Engineered Wood Association and the American Wood Council (AWC), a new framing arrangement was designed in this study to increase the vertical load resistance of Midply and make it easier to accommodate electrical and plumbing services. In this study, a total of 14 Midply specimens in six wall configurations with different sheathing thicknesses and nail spacing were tested under reversed cyclic loading. Test results showed that Midply has approximately twice the lateral load capacity of a comparable standard shear wall. The drift capacity and energy dissipation capability are also greater than comparable standard shear walls. For Midply to use the same seismic force modification factors as standard shear walls, seismic equivalency to standard shear walls in accordance with ASTM D7989 was also conducted. Although Midply has superior lateral load and drift capacities, it does not seem to be as ductile as the standard shear walls at the same over-strength level. Additional testing and dynamic analysis are recommended to address this issue.

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Performance-based approach to support tall and large wood buildings: fire and seismic performance

https://library.fpinnovations.ca/en/permalink/fpipub49569

Author:	Dagenais, Christian
	Chen, Zhiyong
	Popovski, Marjan
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	October 2017
Material Type:	Research report
Physical Description:	48 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Building Systems
Subject:	Cross Laminated Timber
	Fire
	Performance
	Adhesives
Language:	English
Abstract:	The objective of the current project is to develop a performance-based design process for wood-based design systems that would meet the objectives and functional statements set forth in the National Building Code of Canada. More specifically, this report discusses the fire and seismic performance of buildings, as identified as a priority in a previous FPInnovations report.

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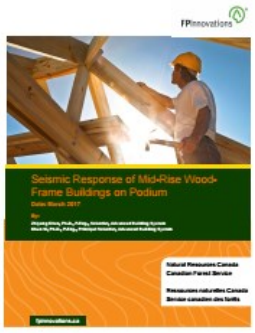

Seismic response of mid-rise wood-frame buildings on podium

https://library.fpinnovations.ca/en/permalink/fpipub49447

Author:	Chen, Zhiyong
	Ni, Chun
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	March 2017
Material Type:	Research report
Physical Description:	37 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Advanced Wood Materials
Subject:	Building construction
	Seismic
	Structural design
	Walls
Language:	English

Abstract: An analytical study to examine the seismic performance of wood-frame podium buildings up to 8 storeys is presented in this report. Simple archetype podium buildings of 5 to 8 storeys in total height were designed in accordance with the two-step analysis procedure given in 2015 NBCC or ASCE 7-10. Nonlinear time-history dynamic analyses were conducted using earthquake ground motions selected and scaled based on the guidelines proposed by Tremblay et al. to match the reference design spectra in NBCC. Using the performance-based seismic design criteria established in the NEESWood project, it was found that:

Podium buildings with a building period ratio of 1.1 (ASCE 7-10) did not meet the performance criteria, thus the period ratio requirement of 1.1 was not appropriate.

A stiffness ratio of not less than 10 times (ASCE 7-10) was more appropriate as a requirement of using two-step analysis procedure for wood-frame podium buildings up to 8 storeys, compared to that of not less than 3 times (NBCC Commentary). With a higher stiffness ratio, the seismic response of the upper wood-frame structure of podium building was closer to that of the pure wood-frame structure.
The results of this study will be used to guide the assessment of the feasibility of constructing wood-frame podium buildings of 8 storeys in height and the development of design guidelines. This would also guide the longer-term goal of proposing changes to the building codes.

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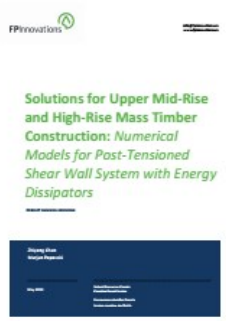

Solutions for upper mid-rise and high-rise mass timber construction: numerical models for post-tensioned shear wall system with energy dissipators

https://library.fpinnovations.ca/en/permalink/fpipub52872

Author:	Chen, Zhiyong
	Popovski, Marjan
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	May 2019
Material Type:	Research report
Physical Description:	43 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Building Systems
Subject:	Cross Laminated Timber
	Performance
	Building construction
	Building materials
	Loads
Language:	English
Abstract:	The latest developments in seismic design philosophy in modern urban centers have moved towards the development of new types of so called “resilient” or “low damage” structural systems. Such systems reduce the damage to the structure during an earthquake while offering the same or higher levels of safety to occupants. One such structural system in mass timber construction is the “Pres-Lam” system developed by Structural Timber Innovation Company (STIC) and Prestressed Timber Limited (PTL), both from New Zealand. FPInnovations has acquired the Intellectual Property rights for the Pres-Lam system for use in Canada and the United States.

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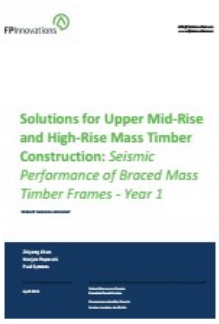

Solutions for uppper mid-rise and high-rise mass timber construction: seismic performance of braced mass timber frames, year 1

https://library.fpinnovations.ca/en/permalink/fpipub52818

Author:	Chen, Zhiyong
	Popovski, Marjan
	Symons, Paul D.
Contributor:	Natural Resources Canada. Canadian Forest Service
Date:	April 2019
Material Type:	Research report
Physical Description:	44 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Building Systems
Subject:	Cross Laminated Timber (CLT)
	Performance
	Building construction
	Building materials
	Seismic
Language:	English
Abstract:	Braced mass timber (MT) frames are one of the most efficient structural systems to resist lateral loads induced by earthquakes or high winds. Although braced frames are presented as a system in the National Building Code of Canada (NBCC), no design guidelines currently exist in CSA O86. That not only leaves these efficient systems out of reach of designers, but also puts them in danger of being eliminated from NBCC. The main objective of this project was to develop the technical information needed for development of design guidelines for braced MT frames as a lateral load resisting system in CSA O86. In the first year of the project, the seismic performance of thirty (30) braced MT frames with riveted connections with various numbers of storeys, storey heights, and bay aspect ratios were studied by conducting non-linear pushover and dynamic time-history analyses. Also, fifteen (15) glulam brace specimens using bolted connections with different slenderness ratios were tested under monotonic and cyclic loading. Results from this multi-year project will form the basis for developing comprehensive design guidelines for braced frames in CSA O86.

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WoodST: an advanced modelling tool for fire safety analysis of timber structures

https://library.fpinnovations.ca/en/permalink/fpipub7943

Author:	Chen, Zhiyong Dagenais, Christian Ni, Chun
Date:	January 2021
Material Type:	Research report
Physical Description:	5 p.
Sector:	Wood Products
Field:	Sustainable Construction
Research Area:	Advanced Wood Materials
Subject:	Fire Models Performance Timber
Language:	English
Abstract:	WoodST is capable of calculating heat transfer, charring rate, load-displacement curve as well as the time and mode of failure of timber structures exposed to fire, thus providing a cost-competitive solution for the fire safety analysis of timber structures. This InfoNote briefly introduces the development and verification of WoodST. Two applications of WoodST are also demonstrated.

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