Behavior of Interlocking Cross-Laminated Timber (ICLT) Shear Walls

Steven L. Sanders

A project submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

Fernando S. Fonseca, Chair
Paul W. Richards
Rick J. Balling

Department of Civil and Environmental Engineering
Brigham Young University
December 2011

Copyright © 2011 Steven L. Sanders
All Rights Reserved
ABSTRACT

Behavior of Interlocking Cross-Laminated Timber (ICLT) Shear Walls

Steven L. Sanders
Department of Civil and Environmental Engineering, BYU
Master of Science

Cross-laminated timber (CLT) walls have been utilized for a number of years in Europe. CLT panels are created by altering the grain direction of 2-7 layers of low-grade lumber, joined together using mechanical fasteners and/or adhesives. CLT has become popular because it boasts the ability for timber structures to be built taller than traditionally possible. CLT also provides an environmentally friendly building system for low-rise construction. With a move toward “green” practices, as well as the current down turn of the global economy, CLT has offered a perfect alternative to conventional building systems. A summary of traditional CLT construction is presented in this paper.

Interlocking cross-laminated timber (ICLT) is a new, innovative system similar to traditional CLT, but does not utilize fasteners or adhesives to join layers. The in-plane lateral capacity of an ICLT panel was tested using two monotonic tests. In the elastic range, the wall showed more than double the lateral strength traditional CLT tested in Europe. When compared to light wood frame construction, ICLT showed lateral strength an order of magnitude greater. These initial tests suggest that ICLT is a viable option for low-rise residential and commercial construction.

Keywords: cross-laminated timber, dovetail, joint, beetle-kill, r-value, response modification factor, standing dead, shear wall, lateral deflection
ACKNOWLEDGMENTS

There are many people responsible for helping me to this point. Dr. Fernando S. Fonseca has been my advisor and mentor throughout this entire process. He helped provide me with this excellent research opportunity. He has stood by me and helped me perform the testing. Paul Thorley and Johnn Judd of Acute Engineering also gave me the opportunity to work on this project and allowed me to help in the analysis of projects utilizing the interlocking cross-laminated timber system. Kip Apostol of Euclid Timber Frames is the genius behind the entire project, and generously provided the test specimen. My wife, Astri, provided me with the motivation and drive to complete the project and do my best.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>LIST OF FIGURES</th>
<th>vii</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2 History of CLT and ICLT</td>
<td>3</td>
</tr>
<tr>
<td>2.1 Cross-Laminated Timber</td>
<td>3</td>
</tr>
<tr>
<td>2.2 Interlocking Cross-Laminated Timber</td>
<td>10</td>
</tr>
<tr>
<td>3 Testing Procedures</td>
<td>15</td>
</tr>
<tr>
<td>4 Results</td>
<td>23</td>
</tr>
<tr>
<td>4.1 Test Summary</td>
<td>23</td>
</tr>
<tr>
<td>4.2 Wall Response</td>
<td>24</td>
</tr>
<tr>
<td>4.3 Comparison</td>
<td>28</td>
</tr>
<tr>
<td>4.4 Failure Mode</td>
<td>29</td>
</tr>
<tr>
<td>5 Current ICLT Construction</td>
<td>33</td>
</tr>
<tr>
<td>6 Conclusions</td>
<td>37</td>
</tr>
<tr>
<td>6.1 Recommendations for Future Testing</td>
<td>37</td>
</tr>
<tr>
<td>6.2 Summary</td>
<td>38</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>39</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 2-1: CLT Panel Configuration (FPInnovations, 2011) .................................................................4
Figure 2-2: Stadthaus Apartment Building (Pryce, 2009) .................................................................5
Figure 2-3: Interior View of Stadthaus Apartment Building (Pryce, 2009) ...........................................5
Figure 2-4: Connection of CLT Panels (Pryce, 2009) ...........................................................................6
Figure 2-5: Wall to Diaphragm Connection Using Metal Brackets (Mohammed, 2011) .........................6
Figure 2-6: Wall to Diaphragm Connection Using Screws (Mohammad, 2011) .................................7
Figure 2-7: Wall to Concrete Connection Using Metal Bracket (Mohammad, 2011) ...........................7
Figure 2-8: Wall to Concrete Connection Using Wooden Profile (Mohammad, 2011) .........................8
Figure 2-9: University of Ljubljana Lateral Test Results (Dujic, 2006) ..................................................9
Figure 2-10: FPinnovations Lateral Test Results (Popovski, 2011) .......................................................9
Figure 2-11: ICLT Panel Layers (Apostol, 2011) .................................................................................11
Figure 2-12: Location of Dovetail Joints (Cramer, 2011) ....................................................................11
Figure 2-13: Cross Section of ICLT Panel (Apostol, 2011) .................................................................12
Figure 2-14: ICLT Wall to Sloped Diaphragm Connection (Acute Engineering, 2011) ....................13
Figure 2-15: ICLT Wall to Flat Diaphragm Connection (Acute Engineering, 2011) .........................13
Figure 2-16: CLT Wall to Foundation Wall Connection (Acute Engineering, 2011) .........................14
Figure 3-1: Test Assembly ..................................................................................................................15
Figure 3-2: Bottom of Wall Connection ..............................................................................................16
Figure 3-3: Wall to Steel Channel Connection ....................................................................................16
Figure 3-4: Steel Channel to Floor Connection ....................................................................................17
Figure 3-5: Channels Bearing on All-thread .........................................................................................18
Figure 3-6: Top of Wall Connection ....................................................................................................19
Figure 3-7: Steel Channel to T-beam Connection ..................................................................................20
Figure 3-8: Pinned Connection at Top of Wall .................................................................20
Figure 3-9: Actuator Connection ......................................................................................21
Figure 4-1: Results of Monotonic Lateral Testing on ICLT Panel ...................................24
Figure 4-2: Response of ICLT Panel to Lateral Load (Dujic, 2006) .................................24
Figure 4-3: ICLT Panel Deflection After Testing ............................................................25
Figure 4-4: Lateral Deflection of ICLT Panel .................................................................25
Figure 4-5: Shifting of Wall Relative to Steel Channels ..................................................26
Figure 4-6: Shifting of Horizontal Members .................................................................27
Figure 4-7: Shifting of Horizontal Members .................................................................27
Figure 4-8: Slight Crushing Perpendicular to Grain ......................................................29
Figure 4-9: Alternate View of Crushing Perpendicular to Grain ...................................30
Figure 5-1: ICLT Home in Richfield, Utah .................................................................33
Figure 5-2: Sill Plate Connection to Foundation Wall ..................................................34
Figure 5-3: ICLT Wall Connection to Sill Plate ............................................................34
Figure 5-4: Side View of ICLT Wall Connection to Sill Plate ........................................35
1 Introduction

Cross-laminated timber (CLT) is an engineered wood product developed in Europe in the 1990’s. The majority of CLT in Europe is a “solid wood” panel produced from 3-7 alternating layers of lumber, stacked and either glued or fastened orthogonally one to another. In sawmills producing light frame construction products, side boards typically go to waste. The idea was conceived to use this byproduct to create structural panels that could be used in low-rise construction. CLT has since become a successful building system in Europe, with the 9-story Stadthaus apartment building in London being perhaps the most visible project to date. In the U.S. and Canada, CLT is relatively new, with only a few CLT show-case structures. An ANSI Standard to address manufacturing, qualification, and quality assurance requirements for CLT is being developed by the APA Committee PRG-320.

Interlocking CLT (ICLT) panels are a recent innovation. Similar to CLT panels developed in Europe, ICLT panels are solid wood, fabricated from 2-7 layers of alternating direction lumber. Unlike other CLT, however, ICLT utilizes no adhesives or fasteners between layers. The panel is held together using patent-pending method of interlocking dovetailed boards. The boards and complex joinery are tooled using computer numerical control (CNC) equipment. The low-grade wood used to create the panels comes from beetle-kill trees which cover the western United States.
Because ICLT is such a brand new system, there is no concept of how such panels will perform in “real-world” applications. Traditional CLT systems have been around for many years, and various tests have been carried how to understand the capabilities of the panels. For a basic understanding of the behavior of ICLT shear walls, two sequential monotonic lateral tests were performed on a single ICLT panel. These tests allow a comparison between traditional CLT and ICLT, as well as light frame construction.

The following list summarizes the chapters contained in this project report:

1. This chapter is an introduction to CLT and ICLT, as well as the focus of this project.
2. The second chapter contains a history of traditional CLT, as well as discussion of the short history of ICLT.
3. The third chapter covers the objectives of this pilot research, and what tasks will be completed.
4. The fourth chapter contains the results of testing and a discussion of results.
5. The fifth chapter is the final chapter, and contains the conclusions of this project, such as the viability of ICLT as a building system for low-rise residential and commercial construction. Suggestions for future research are also presented in this final chapter.
2 History of CLT and ICLT

The motivation behind CLT and ICLT is to grow the market for wood construction to taller structures. Current light frame construction is limited to about 4 stories, after which light framing is no longer the economical choice. Three main disadvantages to timber construction are movement characteristics, durability, and fire (Dujic, 2008). CLT address all three of these issues. Using lower quality timber makes the system more economical, as well as being a more environmentally friendly system.

Part of the allure of using CLT construction is the option to construct very rapidly. CLT panels are pre-fabricated and delivered to the construction site. Even the openings for windows and doors are pre-cut, greatly reducing the amount of on-site work and waste. Upon delivery, the panels simply need to be put in place and installed. With ICLT, even the conduits for electrical work and plumbing can be pre-installed.

2.1 Cross-Laminated Timber

Cross-Laminated Timber systems were developed in Germany and Austria in the 1990’s. Ever since that time, CLT has been gaining popularity worldwide as a viable building system. The system began in Austria, where a cooperative research effort between industry and scholastic partners was undertaken to find a practical use for waste wood. Utilization of CLT in construction slow to commence because it was relatively unheard of, and the structural properties
had yet to be determined and accepted. As the market began demanding green building products, more and more people turned to CLT for their building needs. In Europe, light frame construction is rare, so CLT provided a market for timber construction as a “heavy” building system, similar to reinforced concrete and masonry which are heavily favored in most European countries.

CLT panels consist of orthogonally stacked layers of typically low-grade wood, glued together on the wide faces. Alternatively, the layers can be joined together using some type of mechanical fastener. Figure 2-1 shows how traditional CLT panels are constructed using individual planks.

![Figure 2-1: CLT Panel Configuration (FPInnovations, 2011)](image)

CLT has now been utilized on many large construction products, adding to the visibility and reputation. The most notable CLT building today is likely the 9-story Stadthaus apartment building in London, which can be seen in Figure 2-2, Figure 2-3, and Figure 2-4.
Figure 2-2: Stadthaus Apartment Building (Pryce, 2009)

Figure 2-3: Interior View of Stadthaus Apartment Building (Pryce, 2009)
In traditional CLT construction, metal brackets are used to connect perpendicular panels. Figure 2-4 shows this connection in the Stadthaus building. The angles are also used to transfer shear load between diaphragms and shear walls. Figure 2-5 and Figure 2-6 show the connection of a diaphragm to a wall using both metal brackets and screws. These two connection methods, or combinations of the two, are the most common used in traditional CLT construction.
The connection of CLT walls to foundation is shown below in Figure 2-7 and Figure 2-8. Both types of connection use metal brackets, one connecting the metal bracket directly to the foundation, while the other connects a wood sill plate to help connect the wall to the foundation.
None of the methods of wall to concrete connection include a typical sill plate connection, which is common in light frame construction. Both common CLT methods use metal brackets to anchor the wall to the foundation and transfer lateral loads.

Extensive lateral testing has been performed on CLT wall panels in Europe. Such testing is just now beginning in North America in order to include the CLT system in building codes. Beitrag Dujic, from the University of Ljubljana, is among the many researchers involved in such testing. The three-ply panels tested were 8’ long by 8’ tall by 3.7” thick (2.44 m x 2.44 m x 9.4 cm) (Dujic, 2006). Figure 2-9 shows the results of one such test.
Marjan Popovski and Erol Karacabeyli at FPinnovations’ Wood Products Laboratory in Vancouver, Canada performed similar lateral tests on CLT panels. They determined that the strength of the wall was significantly higher than the strength of the connections. More often than not, the end of testing came when a connection would fail. The three-ply panels tested were 7.55’ long by 7.55’ tall by 3.7” thick (2.3 m x 2.3 m x 9.4 cm) (Popovski, 2011). Figure 2-10 shows the results of one of the tests conducted at FPinnovations Laboratory.
The results of the tests performed in Ljubljana show a maximum load of 9.89 kips (44 kN) at a displacement of 1.06 inches (27 mm) (Dujic, 2006), while the FPinnovations’ test show a maximum load of approximately 23.6 kips (105 kN) at a displacement of 1.85 inches (47 mm) (Popovski, 2011).

2.2 Interlocking Cross-Laminated Timber

Interlocking Cross-Laminated Timber (ICLT) construction was conceived by Kip Apostol of Euclid Timber Frames. The main motivation behind ICLT was to get all the benefits of CLT construction, but without the adhesives or mechanical fasteners. Removing such methods of construction makes ICLT walls recyclable and/or reusable once the structure is beyond its service life. Deconstruction of the panels is relatively simple, and allows individual members to be used elsewhere.

ICLT utilizes standing-dead beetle-kill timber in the construction of the panels. The trees that produce this timber have been killed by pine beetles, and remain standing and dead for years where they will eventually decay. These trees have often decayed before harvesting, leaving them unsuitable as higher grade timber traditionally used in stick frame construction. This wood is either left to decay, or is harvested and used as a fuel source (USDA, 2006). Euclid Timber Frames has pioneered the use of this timber in ICLT panels.

Rather than use mechanical fasteners or adhesives to join plies, an innovative and complex system of dovetail joints is used. These dovetails are milled into the individual members, and then the wall is assembled like a puzzle. Figure 2-11 and Figure 2-12 show how ICLT panels are constructed, and where the dovetail joints are typically located.
Figure 2-11: ICLT Panel Layers (Apostol, 2011)

Figure 2-12: Location of Dovetail Joints (Cramer, 2011)
The above figures show how only a few dovetails are needed to connect the members and plies together. These dovetails provide all the connection needed to develop the structural qualities of ICLT. Figure 2-12 shows that dovetails can be positioned in different locations in the wall depending on the location of window or door openings. Figure 2-13 below is an cross-sectional view of an actual ICLT wall panel, showing the dovetail joints between plies.

Figure 2-13: Cross Section of ICLT Panel (Apostol, 2011)

Figure 2-14 and Figure 2-15 show the connection of ICLT walls to diaphragms.
In Figure 2-14 and Figure 2-15, it can be seen that the wall to diaphragm connection is very simple, using lag screws as often as needed to transfer the lateral loads. This connection can be done very quickly on the job site.
In Figure 2-16, it can be seen that the connection of the wall to the foundation wall is patterned after traditional light frame construction. The ICLT wall is secured to a sill plate using lag screws, again as often as needed for lateral load transfer. The sill plate is then connected to the foundation wall using anchor bolts.

Figure 2-16: CLT Wall to Foundation Wall Connection (Acute Engineering, 2011)
3 Testing Procedures

One of the main reasons for performing lateral capacity tests on the ICLT wall panel is to determine the seismic response modification factor (R-value). This factor is an attempt to determine the response of various building systems in seismic events. When a building undergoes a nonlinear ductile response, more energy is dissipated in the deformation of the material than had the material remained elastic. Through testing and observation of past seismic performance, R-values are assigned to different building materials. The R-value is used when calculating the seismic force to apply to a structure during design.

A series of two consecutive monotonic lateral loads were performed on an ICLT panel at Brigham Young University. Figure 3-1 is a picture of how the test was assembled.
The wall to diaphragm and wall to foundation connections, depending on how the connection is performed, are likely weaker than the wall itself. For this reason, the top and bottom connections were not performed as shown in the details above, but were made stronger, allowing the lateral strength of the wall to be tested. Figure 3-2 and Figure 3-3 below show the connection of the bottom of the wall to steel channels.

**Figure 3-2: Bottom of Wall Connection**

**Figure 3-3: Wall to Steel Channel Connection**
The bottom of the wall was connected to two steel channels, one on each side, using one inch diameter threaded rods. The threaded rods go through both steel channels and the wall, and are secured on each side with nuts. Eight total threaded rods were used to connect the wall to the steel channels, each threaded rod having a capacity of approximately 5700 lbs (AFPA, 2005). Upon installation, the bottom of the steel channels were flush with the bottom of the wall.

The steel channels were then anchored to the concrete floor using post tensioned all-threads, as shown below in Figure 3-4.

Figure 3-4: Steel Channel to Floor Connection
Post-tensioning was done to ensure minimal lateral and vertical movement at the bottom of the wall. Lateral deflection of the top of the wall is one of the desired end results. Knowing the story drift is important in determining the magnitude of lateral load the wall can resist in service. As a redundancy to reduce lateral movement at the bottom of the wall, the steel channels butted up against a third all-thread. This all-thread also ran through the floor, similar to the post-tensioned rods. This arrangement, which can be seen in Figure 3-5 allows the bottom of the wall to bear laterally on the concrete floor.

![Figure 3-5: Channels Bearing on All-thread](image)

The top of the wall was connected to the actuator as shown below in Figure 3-6.
At the top of the wall, steel plates were welded to the flanges of a steel channel, as shown above in Figure 3-6. The top of the wall was shaved to accommodate the steel channel, which was snug fit on top of the wall. Holes were drilled through the steel plates as well as the wall, and one inch diameter threaded rods were placed through the holes. The threaded rods were secured using nuts. Again, each threaded rod has a capacity of approximately 5700 lbs (AFPA, 2005).

A steel t-beam was bolted to the top of the steel channel, as shown below in Figure 3-7.
The t-beam was then slid between two HSS steel shapes and pinned in the center, as shown below in Figure 3-8.

The pinned connection at the top of the wall was important, as it allowed the wall to rack in the test apparatus. Had the t-beam been continuously attached, or had the actuator pushed on
the top of the wall itself, outside forces would have been generated within the wall, making the test results more difficult to decipher.

The actuator was then connected between the HSS shapes and a rigid “end-plate,” strong enough to direct all load into the wall. This connection is shown below in Figure 3-9.

![Figure 3-9: Actuator Connection](image)

String pots were added on the three corners away from the actuator in order to measure lateral deflection of the wall. The string pots at the bottom of the wall helped determine if the bottom of the wall was sliding, regardless of the redundant connection. This lateral deflection could then be subtracted from the deflection of the top of the wall to get a true deflection for the wall.
4 Results

4.1 Test Summary

Euclid Timber Frames provided one 8’ x 8’ x 13.75” (2.44m x 2.44 m x 34 cm) five-ply ICLT panel for testing, each ply being 2.75” (7 cm). Initially, a single monotonic test was to be performed using an actuator with a load capacity of 22 kips (97.9 kN), and a lateral deflection of 20 inches (508 mm). This load capacity was higher than the maximum load sustained by a traditional CLT panel. At the end of 20 minutes, because of the hydraulic system providing power to the actuator, the test ended at a maximum load of 20430 pounds (90.92 kN) and had displaced 3.86 in (97.94 mm). The load was removed from the wall, and the lateral deflection of the top of the wall returned to within 0.45 inches (11.4 mm) of the initial position. Because an ultimate load was not achieved with this first actuator, it was decided that a second test would be performed.

The actuator was replaced with one having a total capacity of 100 kips (444.8 kN), and a maximum displacement of 6 inches (152.4 mm). This second test lasted about 30 minutes, with the actuator and wall traveling a total distance of 5.97 inches (151.6 mm). The reason this test stopped was because the actuator had reached its maximum displacement. The load at the end of this test was 38295 pounds (170.4 kN). Figure 4-1 shows the results of the two monotonic lateral tests performed on the ICLT panel.
4.2 Wall Response

Both rocking response and shear response were observed upon application of a lateral load at the top of the wall. Figure 4-2 shows what these different responses look like.
The shear response caused mainly internal stresses in the wall, while the rocking response mainly caused stresses in the connection. Figure 4-3 and Figure 4-4 show the deflected wall at the end of the second test.

Figure 4-3: ICLT Panel Deflection After Testing

Figure 4-4: Lateral Deflection of ICLT Panel
At the beginning of the test, the bottom of the wall was flush with the bottom of the steel channels. After testing was performed, the bottom of the wall on the side of the actuator had lifted relative to the steel channels. Similarly, the bottom of the wall on the side away from the actuator was lower than the bottom of the steel channels, as seen in Figure 4-5.

![Figure 4-5: Shifting of Wall Relative to Steel Channels](image)

The shear response of the panel was easy to see after testing. The individual horizontal members had shifted relative to each other, as seen in Figure 4-6 and Figure 4-7.
Figure 4-6: Shifting of Horizontal Members

Figure 4-7: Shifting of Horizontal Members
Prior to testing, all the horizontal members were flush at the end of the wall. Similarly, in Figure 4-5, it can be seen that the vertical members have also shifted relative to each other.

The American Society of Civil Engineers (ASCE) has published recommended story drift limits for structures. In ASCE 7-05, *Minimum design loads for building and other structures*, this recommendation is stated in Table 12.12-1, which says story drift for low rise wood structures should be limited to 0.025h. For the 8’ tall ICLT panel tested, the story drift limit would be 2.4 inches (61 mm). From Figure 4-1, this deflection results in an applied load of 13.6 kips (60.5 kN). The ICLT wall has a much higher load capacity than this, but to no avail, as the story drift limit will have already been exceed. Possibly for structures with more relaxed drift limits, more lateral load capacity could be utilized.

### 4.3 Comparison

When comparing the lateral capacity at the story drift limit, it can be seen that the ICLT wall panel was stronger than the panel tested at the University of Ljubljana, but not as strong than the panel tested by FPInnovations. Even though the panel isn’t as strong as the FPInnovations panel, the result is significant because the ICLT panel uses no adhesives and still out-performed the Ljubjana panel.

To reiterate, the ICLT panel has significantly higher strength capacity than either of the traditional CLT panels, but exceeds story drift limit before reaching full capacity. This is likely due to the dovetail connections. In traditional CLT panels, the failure would most likely occur as a shear failure between plies, as the individual wood members are not interconnected.
4.4 Failure Mode

There are several explanations for the amount of movement that occurred in the ICLT panel. During testing set-up, it was determined that in order to have the holes in the steel at the top and bottom of the wall to line up on each side, the steel should be aligned and drilled first. Once the steel was in place, the holes in the ICLT panel were then drilled. This proved to be more difficult than expected, and the holes ended up being drilled slightly larger than the threaded rods to facilitate placement of the rods.

After testing, the wall panel was deconstructed to observe what failure, if any, the individual members experienced. No signs of ultimate failure were detected. Instead, localized crushing failures where the dovetail joints were bearing perpendicular to the grain of the neighboring member were observed, as seen in Figure 4-8 and Figure 4-9.

![Figure 4-8: Slight Crushing Perpendicular to Grain](image)
Both figures show different views of the same dovetail joint and localized crushing perpendicular to grain. In Figure 4-9, the crushing failure can be seen along the left side of the dovetail joint by the small notches. Upon inspection of the individual members after testing, the strength of the wall was dependent on the strength of the wood perpendicular to grain, and the number of locations where this crushing occurred.

Using the results of the testing performed, an R-value can be determined. For the most common building systems, the International Building Code (IBC) and ASCE 7 define which R-value to use. There are two common methods used in the United States for determining R-values. The first is the Equivalency Method which is outlined in the International Code Council Evaluation Service (ICC-ES) AC 130. In this method, the performance criteria of new building systems (maximum load, story drift, ductility) is compared to lumber-based nailed shear walls.
For 80 of the most common building systems, R-values are listed in the International Building Code (IBC) and ASCE 7. These values are based mainly on judgment and past performance of the building systems. Many of the recently developed systems have never been through an actual earthquake, so their actual performance is still uncertain. It is because of this that the Federal Emergency Management Agency (FEMA) has developed the FEMA P695 document. This document outlines the procedure for evaluation of building system response parameters. This document was created to standardize the methodology for setting design criteria.

Neither of the above described methods will work for establishing an R-value for ICLT. The Equivalency Method requires an ultimate strength as well as the corresponding deflection. Because of the limitations of the testing equipment, neither was obtained. The FEMA methodology requires the development of structural models and multiple tests, both of which are beyond the scope of this project.

With the results obtained from testing, behavior comparison with other structural systems is the best way to approximate an R-value for ICLT. The CLT panels produced in Canada, which are slightly stiffer than ICLT panels, typically use an R-value of approximately 4 (Popovski, 2011). Traditional lumber shear wall panels, which have a lower stiffness than ICLT panels, use an R-value of 6.5 (ASCE, 2010). Though not included in the IBC, log walls traditionally use an R-value of between 4 and 4.5. ICLT panels likely behave very similarly to log walls, and fairly similarly to CLT panels. For this, an R-value of 4 is recommended as a conservative estimate.
5 Current ICLT Construction

Several ICLT projects are in various stages of completion around the state of Utah. Although the potential of ICLT allows construction of mid-rise structures, these first projects are smaller in nature. One home in northern Utah is in the design stages, a bathhouse for a campground in south-eastern Utah is about to begin construction, and a garage/home in south-central Utah is wrapping up construction. This home can be seen in Figure 5-1.

Figure 5-1: ICLT Home in Richfield, Utah

Figure 5-2, Figure 5-3, and Figure 5-4 show the connection of the sill plate to the foundation wall and the connection of the ICLT wall panel to the sill plate using lag screws, respectively.
Figure 5-2: Sill Plate Connection to Foundation Wall

Figure 5-3: ICLT Wall Connection to Sill Plate
In the design of this structure, the engineering was performed assuming that the wall was adequate to support any applied loads. It was assumed that the connection would be the source of any possible failure. The spacing of the lag screws at both the foundation wall and roof diaphragm was determined based on the applied lateral loads for seismic and wind. Upon reviewing the results of the lateral testing, this was a correct assumption in that the connection is many times weaker than the wall itself.
6 Conclusions

Interlocking cross-laminated timber panels are a viable means of low-rise construction from a lateral capacity standpoint. The panels show significant strength, making ultimate failure unlikely. The main limitation on ICLT is the amount of drift, which controls the allowable lateral loads applied. The ICLT panels tested never did show an ultimate capacity due to limitations in testing equipment. However, at the story drift limit, the ICLT wall panel had already shown a high capacity.

There are various other tests that should be carried out to determine other aspects of ICLT wall panels.

6.1 Recommendations for Future Testing

From a structural stand point, there are a few other tests that should be performed on a “proof-of-concept” basis. ICLT panels used as walls will also support vertical loads. Although the wall panel is a solid mass of wood and likely not to be governed by vertical capacity, it would be good to understand the behavior of the wall under such loads. Similarly, ICLT lintels, such as over window and door openings, would be good to study further for an understanding of what distributed loads and point loads may be applied. Certainly there would be a necessary lintel thickness and depth required depending on the applied loads.
The other type of loading that would be important for ICLT panels used both as walls and as diaphragms is the out-of-plane capacity of the panel. As a wall, exterior panels would be subject to wind loading, causing out-of-plane bending. More importantly, and more significantly, panels used as roof and floor diaphragms would be subject to a wide variety of live and dead loads out-of-plane. It is very important to understand the behavior of ICLT panels under such loading to limit the span length for such diaphragms.

Beyond these basic proof-of-concept tests, multiple in-plane lateral, out-of-plane, and vertical tests need to be performed in order for ICLT panels to be accepted as a building system by the International Code Council. Other non-structural tests need to be performed as well, such as heat transfer and fire rating.

6.2 Summary

ICLT panels provide a great use for standing-dead beetle-kill pine. Being that such wood is very available and inexpensive, finding a structural use can be both environmentally important as well as structurally. ICLT allows wood structures to be built taller than currently possible, vastly expanding the market for wood structures. Examples such as the Stadthaus apartment building in London show that low-rise structures are possible with this new method. Although ICLT is new and unique, initial testing shows great promise for this innovative new method.
REFERENCES


American Society of Civil Engineers (ASCE). (2010). *Minimum design loads for buildings and other structures*.


