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ENHANCING MULTI-STOREY BUILDINGS WITH CLT CORES USING LVL TECHNOLOGY: DESIGN AND TESTING

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ABSTRACT: Mass timber (MT) construction is gaining popularity worldwide for multi-story buildings. However, it's important to note that despite this trend, these buildings still rely on concrete or steel cores for additional strength and stability. No one has yet succeeded in creating a timber core solution, and there is no published evidence of a timber core solution with the necessary stiffness to withstand wind or earthquake loads beyond ten levels. Preliminary research and calculations at the University of Auckland indicate that a hybrid product that uses radiata pine LVL to make radiata pine CLT can be made considerably stronger and more than ten times stiffer than conventional radiata pine CLT; allowing timber building cores up to twenty levels. This paper will present results of an initial experimental study carried out to verify the feasibility of using LVL-CLT shear cores in multi-storey timber buildings. The experimental study consists of testing two of different scaled configurations of LVL-CLT panels for stiffness and comparing these results with the stiffness of a tested ordinary radiata pine CLT panel. Based on our initial stage of testing and research, the use of LVL-CLT for shear cores is both a viable and recommended solution to enhance structural performance under seismic loads. Its performance during our initial testing confirmed as per the New Zealand Building Code, an expected average rolling shear failure stress at the glue lines of 2MPa under load via a hydraulic press. If the LVL-CLT core system is proven successful, it will offer a viable sustainable alternative to traditional concrete core construction.

KEYWORDS: Timber, LVL, CLT, shearwall, stiffness, multi-storey

1 – INTRODUCTION

The adoption of mass timber (MT) construction in multi-storey buildings is gaining momentum globally. Cross laminated timber can be used successfully for high rise buildings but to date, concrete or steel lateral load resisting systems remain prevalent for wind and earthquake resistance due to the lack of suitable timber solutions with the necessary stiffness. While developing a joint solution for CLT panels, it was discovered, quite serendipitously, that CLT made with radiata LVL is much stiffer than normal radiata pine CLT. Those initial investigations indicate that LVL-CLT panels could be considerably stronger and stiffer than conventional radiata pine CLT panels (Oswald, Wang & Chapman, 2022a) (Oswald, Wang & Chapman, 2022b) (see figures 1). Preliminary calculations by the authors indicate that panel stiffness can increase by over 1000%. This level of stiffness has the potential to enable the usage of LVL-CLT panels for high-rise cores. An important question is 'can LVL planks be successfully glued together to form a reliable form of CLT'. To answer this, three number LVL-CLT specimens for investigating glueline strength were made and subjected to load testing using a hydraulic press. The specimens combine three short LVL planks and the grain direction of each plank layer is at a 90-degree angle to the adjacent layer. The testing of the gluelines of these specimens is the main topic of this paper. Important to consider in this project is the crucial research on resilient design, CLT, and timber connections, as noted by Chan et al. (2023) and Shirmohammadli et al (2023).

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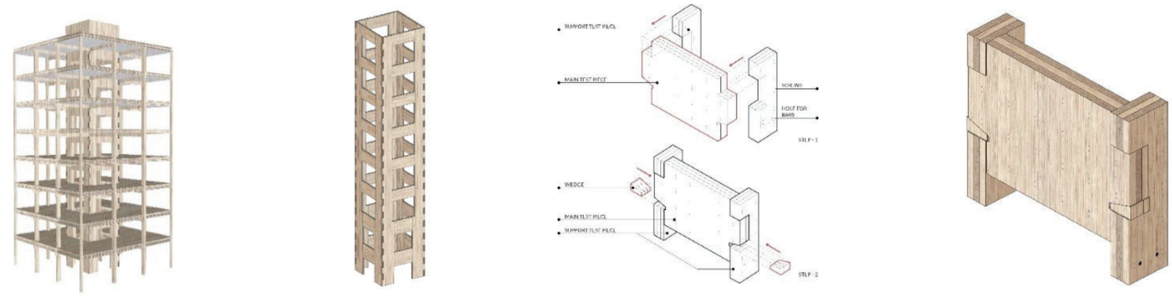

Figure 1: Building core (Left two images) and previous test specimens for potential CLT-LVL core panel corner connections

2 – BACKGROUND

This research project builds upon the foundational work of Qun Wang's thesis, [5], *Viability of High-Rise Timber Buildings with an Integrated Central Core: Structural Performance Tests and Comparisons with Existing Multi-Storey Timber Buildings.* Wang's study explored the feasibility of utilizing the Integrated Timber Central Core (ITCC) system, as a structural solution for high-rise timber buildings (Fig 1). The ITCC system consists of a core structure that extends the full height of the building, acting as a cantilever to resist lateral loads. This core is composed of core columns and core beams constructed from LVL-CLT panels [5]. These panels are made from radiata pine LVL but follow a CLT-inspired manufacturing process, where alternating layers are oriented at a 90-degree angle to enhance strength and stability.

Wang's research provided key insights into the structural behaviour of LVL-CLT, revealing that it fails in a ductile manner rather than exhibiting the sudden brittle failure seen in conventional CLT. This ductility is a critical advantage in structural applications, as it improves the resilience of timber buildings under load. Additionally, Wang's thesis involved the development and testing of a LVL-CLT core panel corner connections. The study found that the key-shaped corner joint developed in this research could support an exceptionally high shear force of 290kN significantly exceeding the required 116kN shear strength for a 20-story timber building with a central core [5]. Furthermore, the joint's maximum shear strength was consistently recorded at around 580kN, highlighting its reliability and performance under load. These significant findings provide a strong foundation for further exploration into the structural capabilities of LVL-CLT.

Inspired by Wang's work, this project seeks to expand upon the potential applications of LVL-CLT in modern architecture. Through additional testing and in-depth analysis, we aim to further validate the effectiveness of this system, optimize its structural behaviour, and demonstrate its viability for large-scale timber construction. By refining manufacturing techniques and exploring new design configurations, this research will contribute to the ongoing development of sustainable, high-performance timber structures.

2.1 ALTERNATIVE APPLICATIONS

In addition to structural testing, this research will explore alternative applications of the LVL-CLT system for architectural contexts. Given the material's high strength-to-weight ratio and potential for weight savings, its applications are expected to be primarily structural. We will investigate opportunities within both residential and commercial construction, assessing how the system can be adapted to different building typologies. Potential applications may include load-bearing walls and flooring systems, that take advantage of the material's strength, weight, efficiency and ease of assembly. By analysing various design scenarios, we aim to determine how LVL-CLT can enhance both the performance and sustainability of buildings, reducing reliance on current materials and technologies while maintaining structural integrity. As part of our research into the application of the LVL-CLT system in architectural contexts, we have explored three viable applications. The first application is primarily replacing a typical concrete core system with a LVL-CLT core to achieve superior strength under seismic load as well as being a regenerative, sustainable alternative. The second application focuses on the strength of the LVL-CLT core to reduce the need for load bearing walls internally. Thus, allowing for flexible floorplans, which would be beneficial not only for office buildings but potentially for residential buildings as well. Finally, the last application would be replacing CLT panels with LVL-CLT panels to achieve greater results in structural performance which ultimately results in stronger, safer structures that are more resilient to climatic challenges.

3 – PROJECT DESCRIPTION

The experimental study involves testing six 6-meter-long panels in bending to assess their stiffness characteristics and identify the variables that affect these properties. Each panel is 126 mm thick and 1150 mm wide. Four panels are made from LVL-CLT, using radiata pine LVL boards that are 290 mm and 390 mm wide, while two panels are conventional radiata pine CLT panels made from 140 mm wide timber boards.

The initial testing phase is for rolling shear strength at the glue lines and is the focus of this paper. There are 3no. test joint specimens. Each specimen has two LVL parts measuring 800 mm long x 248mm wide x 42mm thick; and a central LVL part sized 398mm long x 248 mm wide x 42mm thick. These test joint specimens have been developed and manufactured by the authors, at the Structures Testing Laboratory on the University of Auckland's Newmarket Campus. This phase of testing will provide valuable data to refine the testing methods and inform the larger-scale panel tests.

4 – EXPERIMENTAL SETUP

The experimental setup for testing the LVL-CLT has been carried out by the authors at the University of Auckland's Newmarket Campus, within the Structures Testing Laboratory. The initial phase of testing began in October 2024 with the development and manufacturing of three identical test joints made from Laminated Veneer Lumber (LVL). Each joint featured a three-part design, consisting of two outer LVL pieces measuring 800mm x 248mm; and a central LVL piece measuring 398mm x 248mm, oriented in the opposite grain direction to the outer layers (Fig 2).

The preparation process started with measuring and cutting the LVL panels to the required dimensions using a drop saw. Once cut, precise measurements were taken to determine the placement of screws that would secure the specimens while the glue set. To ensure structural integrity and adhere to established methodology, the screws were spaced no more than 150mm apart and with a maximum clamping area of 15,000sq.mm, following the guidelines outlined in *Investigation and Analysis of Press Glued Connections for Timber Structures* by Marcus Schiere, Steffen Franke, and Bettina Franke.

For assembly, Wurth SCR-SK-WO-A2-rw40-6x100mm screws were used to hold the central piece in place. Given

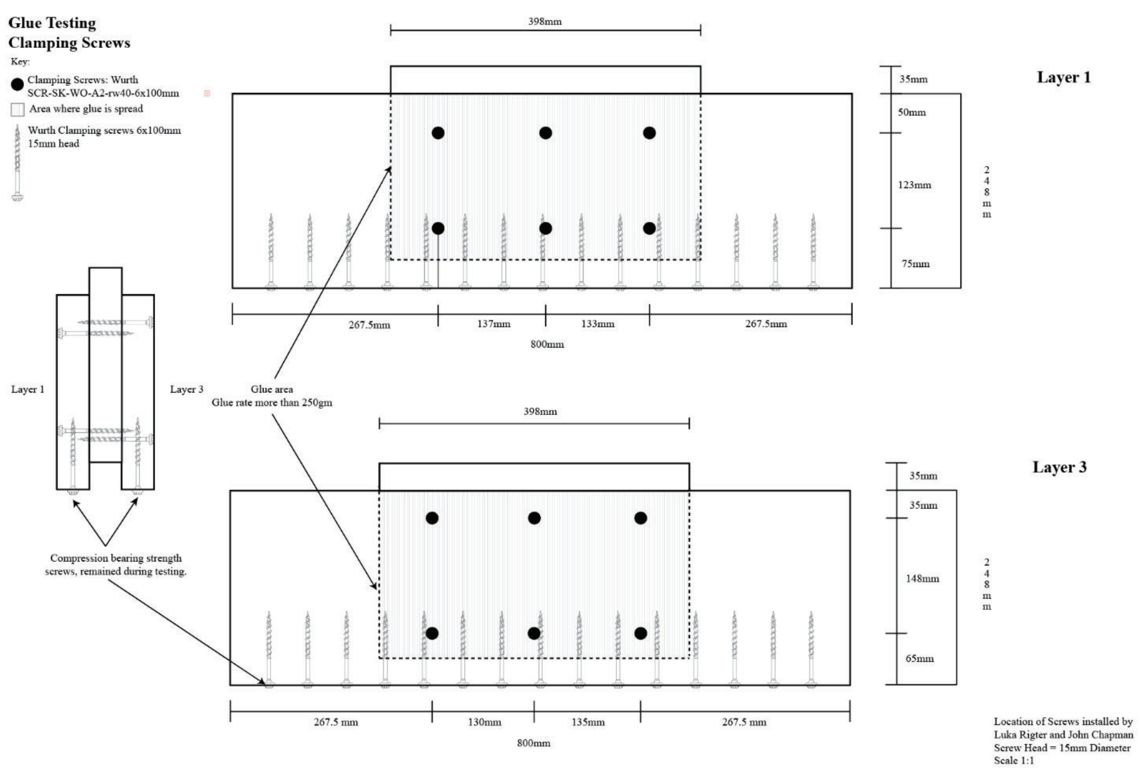

Fig 2: Glue Testing with Clamping screw setup for sample tests.

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that the LVL parts were 42mm thick, there was a potential risk of screw interference if placed incorrectly.

To prevent this, the screw locations on both sides of the test pieces were alternated by 15mm, ensuring there were no conflicts within the specimen. This careful planning and execution were crucial in maintaining consistency across all test samples, laying the foundation for the subsequent structural testing phase.

The next step in advancing the specimens took place at the University of Auckland's Architecture Workshop. The process began by trimming the three test pieces to ensure uniformity using a table saw, followed by planing 1.5mm off the face that would be glued. Once the surfaces were prepared, pilot holes were drilled using a drill press.

Next, we carefully measured the required amount of adhesive, ensuring a glue application rate of more than 250g/m² for each specimen. The glue was evenly spread, and the two 800mmx248mm outer pieces were clamped to the 398mmx248mm central piece using Wurth screws to hold them securely in place. While the minimum required drying time was 120 minutes, we allowed the glue to set for 72 hours to ensure optimal bonding.

This process was repeated to complete the three specimens which are 100% identical down to the process and amount of glue applied. Once fully cured, these samples were tested using a hydraulic press, which would apply loads of up to 1500kN to determine their structural performance. Below is a detailed breakdown of the methodology used for making these specimens, which will also be followed for the main panel tests.

<u>The method for making the 3no. test pieces to check glueline strength is as follows (Images seen in Fig 3).</u>

1. Cut planks to length as per the above test pieces sketch.
2. Plane 1.5mm approx. off both faces of all planks, so planks are 42mm thick.
3. Drill and place compression bearing support screws at 50mm centres for 800mm long parts.

4. Drill holes, apply glue and screw planks layer 1 to layer 2, then layer 3 to layer 2.

5. After glue set, remove all screws.

ADDITIONAL NOTES:

- The compression bearing support screws at 50mm centres for 800mm long parts ensure the pieces fail adjacent to the glue lines in rolling shear, and not due to perpendicular to grain compression failure at the bases of the test pieces. The compression bearing support screws were Wurth Washer Head 80mmLx6mm dia, thread 50mm long.
- Drilled holes for clamping screws: 42mm depth, 5mm dia. Holes are to minimise splitting & for ease of screw removal.

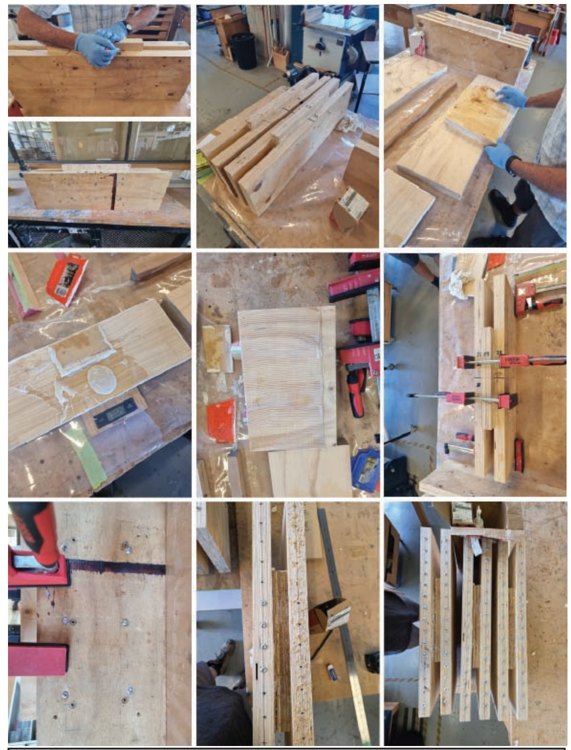

Fig 3: Process of construction for the three specimens

- Clamping Screws: Wurth Washer Head, 100Lx6mm dia, thread 60mm, washer head 14mm dia.

- Glue: Purbond HB S309. Spread 250g/sq,m min. or 0.22l/sq.m., specified cure time 75min.

The initial test was conducted using a machine with a capacity of 300kN. The goal was to evaluate the structural performance of our specimen under increasing loads and determine its failure point. Expected failure was rolling shear adjacent to gluelines and, based on theoretical calculations, the test specimens' calculated nominal strength in rolling shear was 410kN.

During the test, the machine automatically shut off upon reaching its maximum force of 315kN. At this point, no visible defects or structural failure occurred in the specimen, indicating that it withstood the applied force without compromising its integrity. While this result was promising, it did not allow us to determine the actual breaking point, as the test was limited by the capacity of the machine rather than the failure of the material itself.

To obtain more conclusive results, further testing was necessary using a higher-capacity machine. We conducted a retest with a machine with a maximum load capacity of 1500kN, which allowed us to push the specimen beyond its strength limits and accurately determine its ultimate failure point.

The second round of testing was conducted on February 22, 2025, by the authors. This test utilized a hydraulic press with a maximum load capacity of 1500kN and a maximum displacement of 100mm.

The setup began with verifying the accuracy of the computer calculations and ensuring that all data was correctly recorded for documentation. Once the system was confirmed to be functioning properly, Test A was initiated. The test sample was carefully positioned at the centre of the press to maintain alignment, and a metal plate was placed across the central LVL piece to ensure an even distribution of the force during loading. The press was set to operate at a speed of 2.5mm per minute, ultimately resulting in a breaking load of 373.34kN. Most failure occurred at the 1A and 2A panel due to rolling shear within the timber, which was the prefered outcome; rather than the main failure being at the glueline. The glue for the test was Purbond HB S309. However, approximately 20% of one of the radiata pine LVL boards was within the glueline, as shown in Fig 4, Right image. Test B failed under a load of 370.27kN, with the break occurring on both sides of the middle piece. This test exhibited less than 5% failure at the glueline, suggesting a relatively strong adhesive bond. Finally, Test C failed under a load of 360.71kN, the lowest of the three, with failure localized to one side of the sample. Overall, these three tests yielded results with an accuracy of 0.369% of each test.

Overall, these tests concluded that the glue worked as hoped with the large majority of the failure due to rolling shear within the timber; and with a consistent rolling shear strength. We will take these findings and utilize them to learn how to improve the main tests which will be for the 6m long CLT panels made with LVL planks.

The main setup will take place using LVL ordered through Nelson Pine. The main test panels will be fabricated and tested at the Structures Testing Laboratory in Newmarket within the University of Auckland. We will make four 6m long panel specimens using LVL similar to the process of making the 3no. glue test pieces as outlined earlier. The next chapter will showcase step by step how to manufacture LVL-CLT in the same methodology as CLT as well as a brief method for manufacturing.

4.1 METHODOLOGY OF MAKING LVL-CLT PANELS, GLUING & SCREWING

The methodology of making the LVL-CLT panels for the main test closely follows the process of making CLT as outlined in *'Investigation and analysis of press glued connections for timber structure'* by Marcus Schiere, Steffen Franke and Bettina Franke in 2018 by Berne University of applied Sciences[6]. The aim of the Berne University report is to use screws to generate sufficient pressure between two glued timber elements to achieve full composite action between them. It is intended that the recommendations of the report be followed for making the LVL-CLT panels, without the need of a vacuum or hydraulic press. The testing, that is the subject of this paper, investigates if the proposed gluing and screwing, as recommended by the Berne University report [6], to achieve full composite action between timber elements.

<u>Recommendations; and comments for making the LVL-CLT panels:</u>

Timber member thicknesses: between 30mm and 55mm. - For the LVL-CLT panels, plank thickness is 42mm.

Screw diameter: 4mm to 6mm. - For making LVL-CLT panels, the diameter of the screws selected is 6mm.

Glue: One component Polyurethane adhesive. - For making the LVL-CLT panels, the glue is Purbond HB S309 which is a single-component polyurethane adhesive for the manufacture of engineered wood products.

Glue spreading rate: at least 250g/sq.m.

For Purbond HB S309, the manufacturer's recommended spreading rate is 120-160g/sq.m. However, the minimum spreading rate of 250g/sq.m will be followed, as per the Berne University Report.

Purbond HB S309 density is 1.16kg/cu.m. Thus, for a spreading rate of 250g/sq.m., the volume spreading rate is 216l/sq.m.

Glue area for all of the LVL-CLT panels is 70sq.m. This results in a total glue weight of 17.5kg & total glue volume of 15 litres.

Curing pressure needed: to be at least 0.1N/sq.mm which is vacuum pressing pressure. - For making the LVL-CLT panels, the Wurth screws as described below provide a curing pressure of at least 0.1N/sq.mm.

Screw embedment depth in load bearing material (second member): at least 40mm. - For LVL-CLT planks, screw embedment depth is 42mm (>40).

Screw thread in fastened plate (first member): none - For LVL-CLT planks, smooth screw shaft length which goes through the fastened plate is 40mm. The planks' thickness is 42mm but the 2mm thread within the fastened plate is negligible.

Screw spacings: not more than 150mm. - For making the LVL-CLT panels, the maximum screw spacing is 150mm.

Area per screw: not more than 15,000sq.mm. - For making the LVL-CLT panels, the maximum screw area is 15,000sq.mm.

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Recommended gluing conditions: surfaces smooth, clean, and free of dust or dirt; glue-line thickness according to DIN EN 302; room temperature >20 degrees C; timber temperature > 18 degrees C.

The clamping between planks at gluing is achieved by the fastener head against the surface of the first plank layer, and by the thread within the second plank layer.

For a screw compression of 1698N, the pressure for screw area of 15,000sq.mm. is 0.11N/sq.mm., which is above the required minimum pressure 0.1N/sq.mm. For making the LVL-CLT panels, Wurth screws are used that are equivalent to the above SPAX screw. Wurth screws are 6mm diameter; 100mm long; washer head, 14mm dia.; threaded length, L1, 60mm; smooth shank length, 40mm; tip with milling cutter; hardened steel material; article number 017736010

5 – RESULTS

The first stage of testing was completed successfully, as all three identical specimens failed within a difference of 0.369% of each other. In all three tests the failure occurred by rolling shear within the grain of the outer pieces, but each test failure was slightly different in its nature.

In test A shown to the right, we had previously tested this specimen with the smaller hydraulic press which applied 315kN of force at maximum capacity. Surprisingly this test specimen which had already been subjected to substantial load resulted in the highest breaking point at a total of 373.3kN. The main failure mechanism within this test occurred in panel 1A due to rolling shear as shown in fig 4. Fig 4 shows that that around 15-20% of the failure occurred in the glueline.

The second test specimen B resulted in a breaking failure of 370.3kN, slightly lower than the first test specimen but still a difference of only 0.825%. Compared to test A, the main difference was that the failure occurred in both outer panels as shown in fig 5. There was 2-3% of failure within the glueline.

The final test using specimen C had the lowest breaking failure of 360.71kN. This test only had failure within panel 3C. This panel had almost complete failure in rolling shear, a similar result to specimen B.

Overall, the results from the first stage of testing are extremely positive and successful as the failure of all three test samples resulted in a strength variability percentage of 0.369%, demonstrating consistency across the tests. In each case, failure occurred within the radiata pine itself rather than at the adhesive joints. The main reason for the minor difference in results will likely come down to the quality of the grain within each panel being different depending on quality of timber and location of knots within the grain.

The three tests show that the glue adhesive bond is stronger than the rolling shear strength within the LVL plank plies, withstanding an average rolling shear stress of at least 2.0MPa. These tests show the reliability of the screw clamping procedure as per the Berne University Report. This is a promising outcome for future applications, as it suggests that the bonding method is effective even under high loads with less than 5% of failure for each test sample within the glue.

The recorded test results are as follows:

- Test A = 373.3 kN, glueline fail stress 2.20MPa
- Test B = 370.3 kN, glueline fail stress 2.18MPa
- Test C = 360.7 kN, glueline fail stress 2.13MPa

The outcomes of this initial testing shows great promise for our alternative applications of LVL-CLT within architectural contexts. The LVL material has a reliable rolling shear strength of 2MPa. This means that replacing concrete cores in multi-level building with LVL-CLT cores may result in much superior seismic resistance. Additionally, this shows that a core using LVL-CLT may be strong enough to remove internal load bearing walls resulting in open, flexible floorplans. Below are the graphs generated from the hydraulic press data (Fig 7), along with images taken during testing, after failure, and of the grain structure once the panels were pulled apart (Fig4-6). These visuals provide further insight into the material behaviour and test results.

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Fig 4: Test A: Left image, Test setup within 1500kN hydraulic press. Middle Image, failure of Panel 1A within the timber fibres. Right image, pried open specimen showing the amount of successful glue connection.

Fig 5: Test B: Left image, failure within both panels 1B and 3B located within the timber fibres. Middle image, pried open specimen showing complete glue connection. Right image, other side of the specimen showing successful glue connection.

Fig 6: Test C: Left image, failure within panel 3C within the timber fibres. Middle image, successful glue connection achieved without fixings. Right image, complete glue connection and failure after 360.7kN of force.

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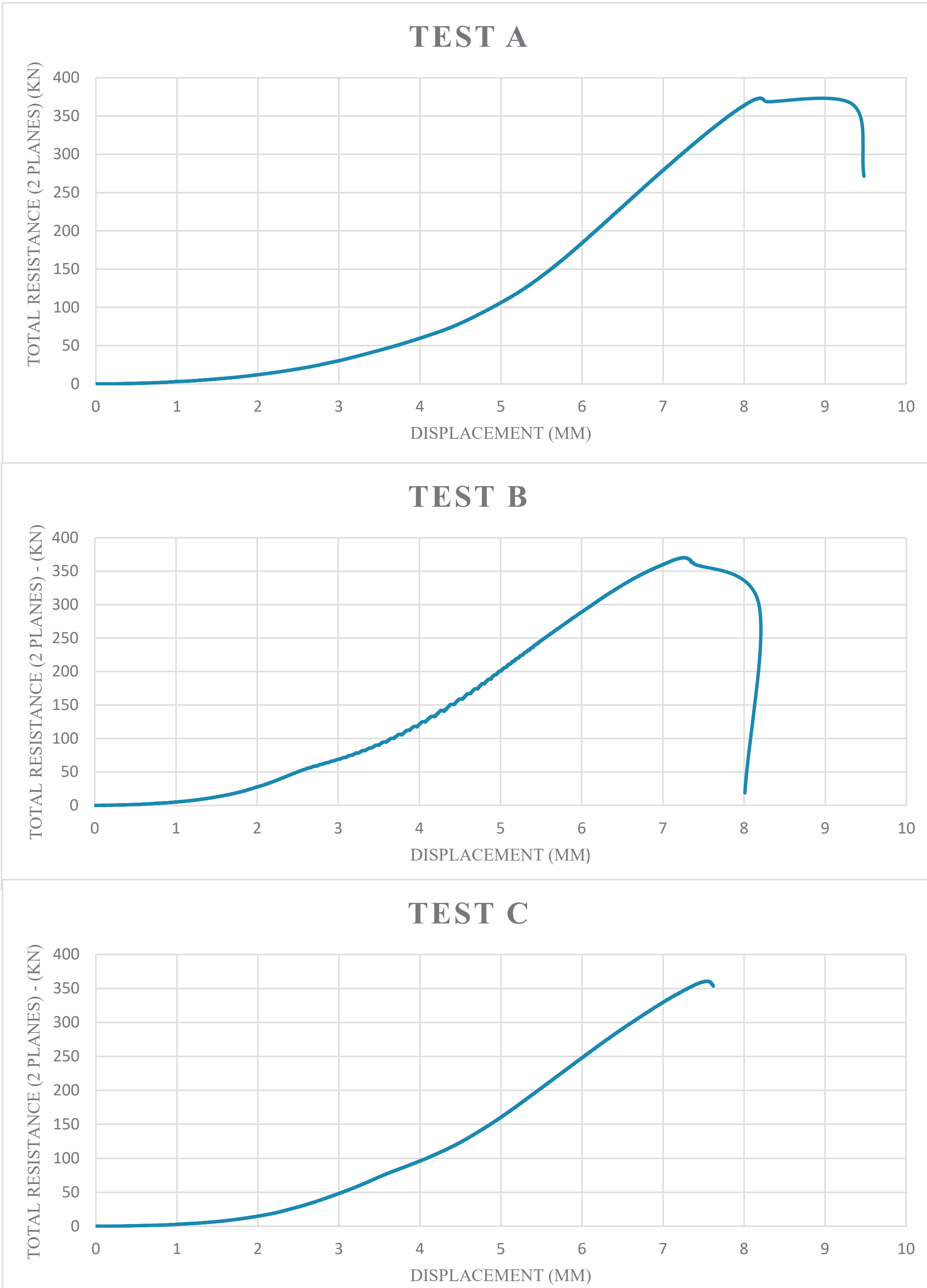

Fig:7 Graphs made from the data gathered from the three tests.

6 – CONCLUSION

Mass timber (MT) is a proven system and material used worldwide for multi-story buildings. However, within these structures they are still using concrete or steel core construction for additional strength and stability. Our goal for this research project is to develop a system using radiata pine LVL in the construction of CLT which will provide the stiffness and strength needed for buildings to 20+ levels. Our preliminary research and calculations completed at the University Of Auckland indicated that our system of LVL-CLT can be made considerably stronger and more than ten times stiffer than conventional radiata pine CLT.

The findings through our testing and research showed great promise that the system will be effective under seismic load and can be a superior alternative to traditional concrete core construction. The primary outcome from this stage of testing was that, for a glued joint, failure occurred within the timber itself rather than within the glue. (Fig 4 – Fig 6). This indicates that the glue performed exceptionally well under high-pressure conditions and that the structural limitations lie within the timber rather than the bonding process. The results demonstrated that the glued LVL joints could sustain an average rolling stress of 2.0MPa (Fig 7) without requiring additional screws or mechanical fasteners for reinforcement. This confirms that the adhesive alone is capable of withstanding significant structural loads, making it a reliable bonding method for future testing.

These results assist our aim of replacing concrete building cores with timber building cores and reducing reliance on internal load bearing walls. The results are a positive step for the next phase of testing and the future of this system.

7 - FUTURE RESEARCH

The next phase of testing will be conducted on a much larger scale. Four number 6m long x 1150mm deep x 126mm thick CLT panels will be made using wide LVL planks and based on the gluing and screwing procedures that have been proven by this current research. The LVL planks are to be F13 grade and supplied by Nelson Pine. Two panels are to be made with 290mm wide x 42mm thick planks; and two panels with 390mm wide by 42mm thick planks. These panels will be tested in bending to assess their stiffness characteristics and identify the variables that affect these properties. Also, two typical CLT panels will be bending tested to compare and contrast results. These panels will be of the same overall dimensions as the LVL-CLT panels but be made of 120mm wide x 42mm thick lumber. All six panels will have three 42mm thick plank layers.

After the above panel testing, the next step involves constructing and testing a full-size LVL-CLT core at the University of Auckland Structures Test Hall. Ideally, the core would then be repurposed in a real building, allowing for long-term study and evaluation.

Additionally, we will be looking into the research conducted around alternative applications of LVL-CLT in an architectural context. The results from the testing indicate significant potential for the use of LVL-CLT in architectural applications. Specifically, replacing concrete cores with LVL-CLT is expected to provide greatly enhanced seismic resistance. Alongside this the results from testing indicate that our LVL-CLT core may be strong enough to reduce internal load bearing walls to allow for greater flexibility in floor plans. Lastly, we are going to explore if typical CLT could be replaced within structures with LVL-CLT. These alternative applications could greatly benefit not only the commercial sector of architecture but the residential sector as well.

Overall, once the main testing is completed, the results will determine the system's viability, and if successful, this construction method may be proposed as an acceptable solution within the New Zealand Building Code.

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