Development of a Frame for Wide Openings in Residential Construction

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Summary

An increasing demand for wider and taller openings within the confines of a limited wall area in modern housing in New Zealand means that steel frames are often chosen to replace what has traditionally been timber framing. To provide a wood based solution for wide openings, high strength laminated veneer lumber (LVL) and plywood solutions have been developed to provide both lateral bracing for seismic and wind resistance, as well as to support vertical loads.

This paper describes static and dynamic testing on timber framed box columns supporting a beam over the opening, with a range of material combinations used to clad the columns. Creep tests on completed frames identified problems with long-term creep deformations that were solved by modifying connection details. The results from two and a half years of creep test show the improved performance of the system. The project has resulted in a set of published span tables that allow the use of LVL by utilising the portal action to reduce deflections and compete with steel.

Keywords

Laminated veneer lumber, housing, timber framed openings

Background

New Zealand houses have traditionally been built from light timber framing, with walls 2.4m high and 90mm wide timber. Lightweight nailed wall frames and nail-plated roof trusses are typically manufactured in a frame and truss plant. There is as much pre-fabrication as possible, with simple nailed connections and proprietary light steel brackets on site. Changes in house design have resulted in most garage doors now being 4.8m wide x 2.1m high. The beam (lintel) over an opening of this size cannot be made with commonly available pine sections (up to 300mm x 50mm) so the solution has been either a steel section (a small channel or UB section) or a flitch beam (6 or 10mm steel plate between two pine side pieces). These solutions are expensive, heavy (usually requiring cranage), difficult to modify on site, and add another trade to the building process.

Most garages consist of a 6m x 6m internal space – enough for two cars and some storage. A 4.8m wide door leaves a panel 600mm wide either side of the door. This is then the only wall space available for bracing panels to resist lateral wind and earthquake loads. Bracing for houses in New Zealand is determined from earthquake and wind zone analysis [1]. The resistance of bracing walls is determined from standard cyclic racking tests to a prescribed method known as the P21 test [2]. Our assessment of the market was that house designers and builders wanted a cost and time effective wood based solution to provide wind/earthquake bracing capacity, and a reduced depth of lintel.

Research programme

Testing was carried out in the laboratories of the New Zealand Forest Research Institute (FRI) [3], [4], [5]. Figure 1 shows the chosen lintel and wall construction detail, which fits the construction of a conventional house. Hy90 is a 90mm thick LVL beam manufactured by CHH futurebuild, and Laserframe is machine-graded pine. Usually a lintel stops above the trimmer stud, but in this research the lintel was extended over the framed side panels. Sheet materials are nailed to the lintel and side framing to connect the members and provide some bending moment transfer to stiffen the frame. The objectives of the research were to determine:

1. The stiffness enhancement of a 300mm x 90mm Hy90 LVL lintel utilising the support walls at each end.
2. The bracing resistance determined from a P21 test programme for the lintel and wall frames.

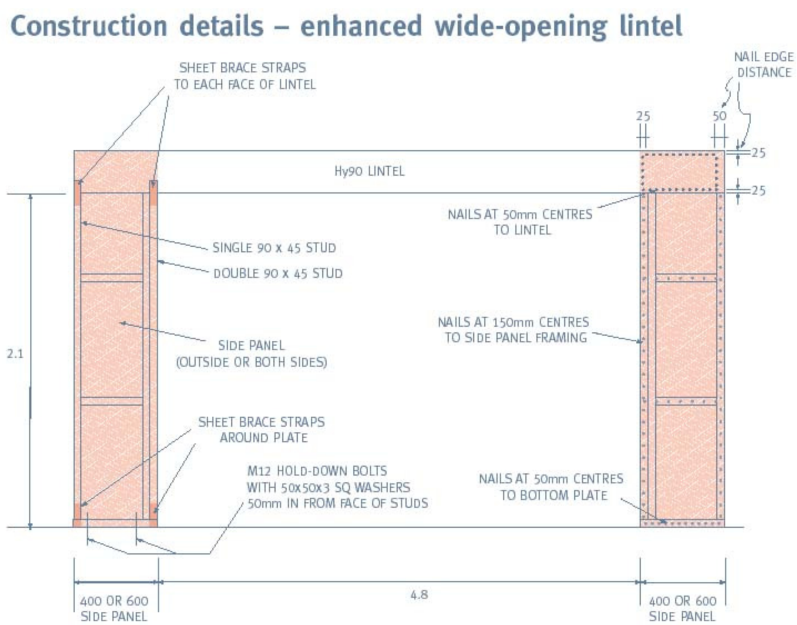


Figure 1 – construction details (ref page 18 of Hy90 brochure [6]

Note that for clarity, details shown on the left of the figure apply to the right and vice versa

Table 1 shows the first range of sheet materials tested for the wall construction as per Figure 1 for a 4.8m span, with 400mm and 600mm side wall widths and a lintel depth of 300mm. The P21 testing regime requires three replicates of each wall type to be tested. Where three replicates were not tested the intention was to conservatively predict the P21 values using the results from other similarly constructed lintel wall frames.

Sheet material options		
Type	**Outside**	**Inside**
1	7mm plywood	none
2	7mm plywood	9.5mm fibre-reinforced gypsum plaster board
3	None	9.5mm fibre-reinforced gypsum plaster board
4	7.5mm fibre cement	none
5	7mm plywood	9mm plywood

***Table 1:** Lintel wall combinations and test required*

Testing regime

Prior to constructing each test assembly the framing timber was machine stress graded and then sorted by its average stiffness so that each wall frame had a similar range of stiffness framing timber.

The testing regime was:

1. Construct lintel and walls without connecting straps and sheet materials.
2. Determine the stiffness of the lintel by incrementally loading at five points (evenly spaced to simulate the load from roof trusses) while recording the deflection relative to the floor, then unload the wall.
3. Complete the wall construction by fixing sheet materials as per Table 1.
4. Re-determine the stiffness of the lintel by incrementally loading at the five points while recording the deflection relative to the floor.
5. Apply the P21 wall test up to ± 10mm horizontal deflection with the five vertical loads applied. Bring the frame back to zero load and deflection.
6. Re-determine the stiffness of the lintel by incrementally reloading at the five points while recording the deflection relative to the floor.
7. Apply the P21 wall test up to ± 70mm horizontal deflection at ± 10mm increments with the five vertical loads applied.

Results

A significant increase in stiffness of the frame was obtained compared with the simply supported lintel (Table 2). For simplicity, individual tests have been averaged. The table also details the P21 bracing test results for both the wind and earthquake situations.

No. of	Wall	Sheet material options		Lintel stiffness improvement		Total bracing capacity (kN)	
tests	Width (mm)	Outside	Inside	(no racking)	(after 4 +/- 10mm cycles)	Earthquake	Wind
3	400	7mm plywood	None	**52.3%**	**59.3%**	**1.77 (U)**	**4.03 (S)**
1	400	7mm plywood	9.5mm p/board	**46.7%**	**58.0%**	**2.55 (U)**	**4.10 (S)**
3	400	None	9.5mm p/board	**35.9%**	**37.8%**	**1.25 (U)**	**3.27 (S)**
3	400	7.5mm f/cement	None	**50.4%**	**51.9%**	**1.36 (U)**	**4.37 (U)**
1	400	7mm plywood	9mm plywood	**63.3%**	**76.0%**	**3.85 (U)**	**7.80 (S)**
1	600	7mm plywood	None	**50.2%**	**67.6%**	**3.35 (U)**	**7.45 (S)**
1	600	7mm plywood	9.5mm p/board	**73.9%**	**81.1%**	**4.75 (U)**	**12.3 (S)**
1	600	None	9.5mm p/board	**51.2%**	**60.2%**	**2.00 (U)**	**6.20 (U)**
1	600	7.5mm f/cement	None	**77.0%**	**69.3%**	**2.10(U)**	**8.90 (U)**
1	600	7mm plywood	9mm plywood	**90.0%**	**100.3%**	**6.00 (U)**	**11.1 (S)**

Table 2: Lintel stiffness improvement and bracing capacity

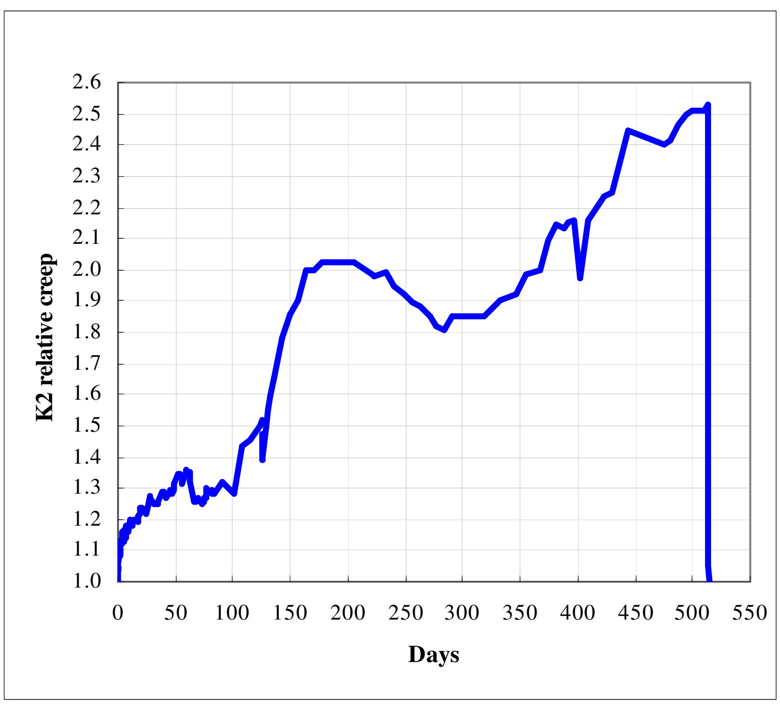
The letter (U) indicates the capacity was limited by the ultimate limit state and the letter (S) indicates it was limited by the serviceability limit state. During the P21 testing the most common method of failure was a tension failure of the sheet material at the underside of the lintel. It was significant that both the fibre-cement and plaster-board sheet materials failed below +/- 40mm deflection. Plywood tension failures were observed at or above a +/- 40mm deflection.

Creep performance

Three different walls were loaded for a week during which time water was sprayed on the jointed area to simulate construction moisture. It was determined that the stiffness retention was best with the plywood lined walls. One wall frame was then erected in a storage shed for a long creep test (figure 2). The frame was built with 600mm side panels, a 300 x 90 Hy90 lintel, with 12mm plywood on one face and 7mm on the other all nailed at 150mm centres. It was loaded with 834kg concrete weights at third points and the deflection was measured at the beam midpoint relative to the floor.

Figure 2. Long term creep test at FRI barn

Figure 3 shows the creep deflection measured relative to the floor over a period of 17 months. The first increase in the slope of the graph followed 3 hours of wetting at 126 days to simulate construction moisture. The initial concept was to evaluate the stiffness gains that could be achieved by mobilising only a standard 150mm nailing pattern.



However the graph indicates that there is an ongoing creep deflection occurring in the frame. It was assumed that the nail grouping at the lintel to side panel connection was being stressed above its elastic capacity. This was supported by the findings of Collins [7] that long-term creep is predictable when the nails are stressed at or below design code values.

The frame was unloaded and re-nailed using additional nails at a 50mm spacing (ie three times the initial nailing) and re-loaded. From Figure 4 it can be noted that from the time that the knee joint was re-nailed using the additional nails the creep deflection has settled to a seasonal cycle. The conclusion is that the standard nail pattern was over-stressed by having too few nails.

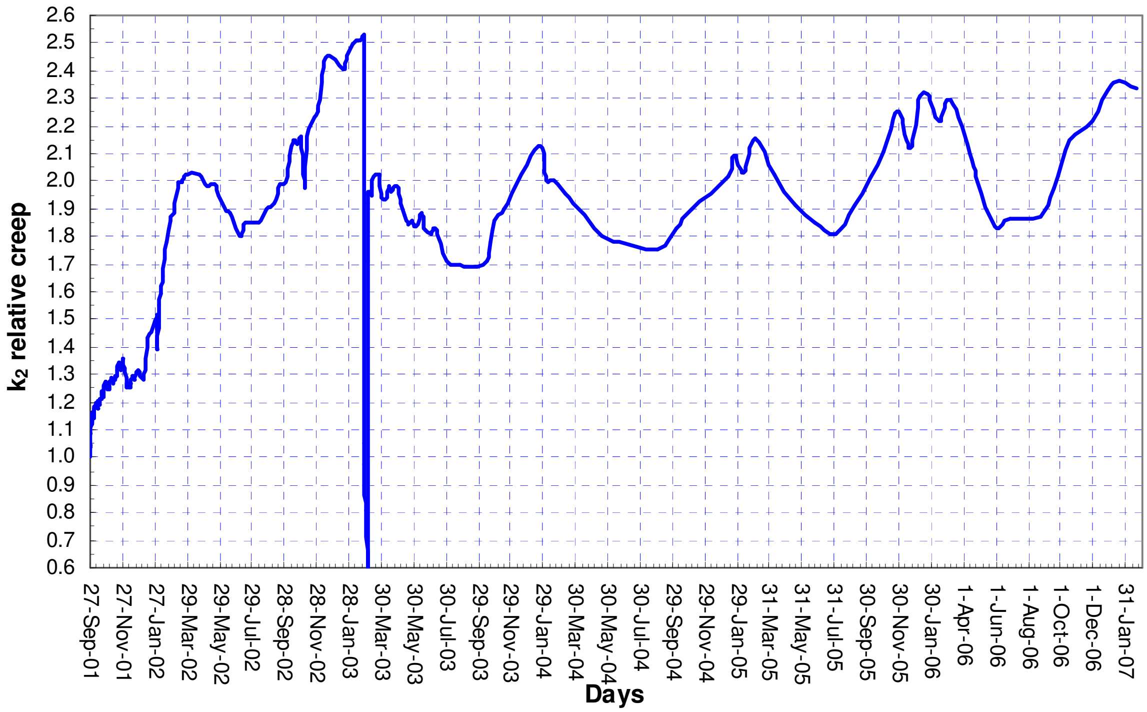


Figure 4. Creep – 50mm nail spacings

Observations

<u>Stiffness Improvement</u>

1. The 600mm walls give a greater stiffness improvement than the equivalent 400mm walls. This in part could be explained by the lower bending and shear stiffness of the 400mm walls and the lower moment capacity of the 400mm wall portal knee nail group.
2. The plasterboard gives the lowest stiffness improvement, with the fibre-cement and 7mm plywood giving a similar and greater stiffness improvement.
3. In virtually all cases the stiffness improvement was greater after the lintel wall frame was racked +/- 10mm in the P21 test.

P21 Bracing Resistance.

1. The 600mm walls provide a greater bracing resistance when compared to the 400mm walls. Again this could partially be explained by the lower bending and shear stiffness of the 400mm walls and the lower moment capacity of the 400mm wall portal knee nail group.
2. The 400mm walls provide a low bracing resistance.
3. The plaster-board and fibre-cement probably should not be relied upon for providing bracing resistance in this design situation as shown by the failures occurring before the ±40mm deflections were achieved. In this situation cladding material is required to have a significant tension strength which these materials could not provide. Fibre cement did not respond well to the wetting regimes.
4. Plywood tension failures were observed at or above the ± 40mm deflections.

Discussion

Analysis of light timber framing is difficult because of the assumptions required to get meaningful joint stiffnesses. This research programme used a pragmatic test and see approach and the analysis followed. The results were assessed by the CHH technical team to prepare information to include in a brochure "Hy90 lintels for residential construction" [6] that was published in April 2003. The stiffness improvements were used as a basis for selecting reliable increases in 'roof load width' for a particular depth of Hy90 lintel over the simple span load case. In most cases this resulted in a lintel one depth smaller than by considering the lintel in isolation (eg 300mm rather than 360mm).

The applied load on each case was used to derive a joint bending moment analysed taking into account the relative stiffness of the beam and column sections. This moment was compared firstly to the plywood bending capacity, and then the nail group capacity. Where the nail group capacity (assessed using the data in the NZ timber design code NZS3603) [8] was exceeded by the applied moment the stiffness improvement was down-rated appropriately.

The 'garage door solution' is rapidly gaining exposure in New Zealand's specifier (engineer, architect and architectural designer) community. This is due to a combination of the simplicity of specification, the cost effective nature of the solution, and the increasing acceptance of LVL and plywood as high-performing and reliable building materials. New Zealand's largest home builder has adopted the solution as a standard detail for all their plans, while smaller building companies are seeing the solution as a time and cost-saving solution.

Conclusions

Initial testing, concept development, revised creep testing and structural analysis have combined in this project to prepare an engineered wood solution that is rapidly gaining acceptance in New Zealand. A part of the market that was losing to steel is being regained through a simple concept that has a researched technical basis.

Acknowledgements

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