LVL Portal Frame Structures in New Zealand

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Abstract

Laminated Veneer Lumber (LVL) portal frame structures have proven to be both practical and cost effective in many cases in Australasia but still struggle to gain a foot hold in the commercial and industrial market due to the dominance of more commonly available steel framed solutions. This paper discusses the design and fabrication of a large LVL portal frame structure in New Zealand, by New Zealand contractors, using a mixture of standard and made to order products from the Carter Holt Harvey Woodproducts (CHH) LVL product range.

1. Introduction

Portal frame type structures are a popular and economical solution for large span commercial and industrial buildings. When Carter Holt Harvey, New Zealand's major supplier of timber based solutions in the residential market, required a new building for a Planer Mill in northern New Zealand they had to look no further than their own range of LVL and timber based products. The versatility of the Marsden Point LVL press allowed CHH's engineers to create a frame with composite built up box beams that have cross banded (x-band) LVL webs and LVL flanges over high moment areas whilst using solid 105 mm thick LVL sections in reduced moment regions. Using 18.2 m long solid LVL sections we were able to dramatically reduce both the fabrication time and cost. In combination with I-beam purlins at 10 m bays the continuous 33 m span LVL portal frames created a spacious open area to operate the planer and provide ample storage and distribution facilities. New Zealand contractors were used in both the fabrication and erection of this 12,210 square metre building. This paper details the logic behind member selection and touches on some of the important practical issues in fabrication and erection of LVL based systems.

2. Design

Key design decisions about the building needed to be made early including the structural form of the primary support members, the loading and member selection.

2.1 Structural Form

A moment resisting portal frame configuration was chosen for its ability to resist lateral loads and provide large open areas for the production and storage of radiata pine timber that is processed in the planer mill. The building layout, including bracing bays, was determined as a function of the machinery layout to suit the planer equipment. The building consists of two separate sections, one 66 metres wide and 110 metres long with a centralized internal support (Figure 1).

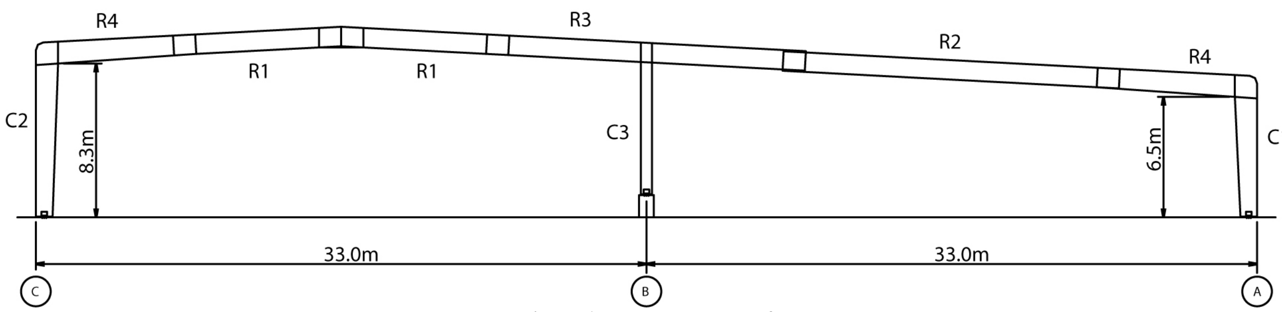

Figure 1. Portal Frame, PF2

The second region 99 metres wide and 50 metres long consists of portal frames with prop columns at third points providing 33 metre clear span, refer figure 2. A full portal frame was provided on the end wall of the 99 metre section to allow for further expansion at a later date with a fully framed end wall was used on the 66m end to take advantage of the reduced costs over a full frame.

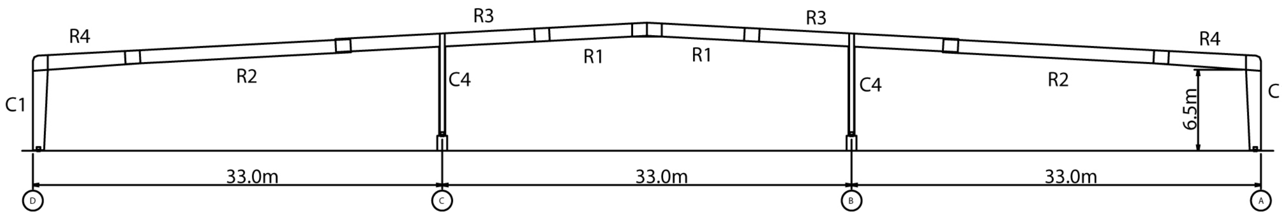

Figure 2. Portal Frame, PF3

To achieve the required clearance above machinery along the grid line C the ridge line is centred between grids B and C. This provides a symmetrical frame for PF3 and allows for the use of 'like' members within both portal frames PF2 and PF3.

2.2 Loading

The building is being constructed in Whangarei located in the North Island of New Zealand, approximately 160 km north of Auckland, New Zealand's largest city. Design loading was completed in accordance with joint Australian and New Zealand loading standards (1, 2, 3, 4) and design capacities determined in accordance with the New Zealand timber structures standard (5) and Limit States Design Information published by Carter Holt Harvey (6). Whilst many buildings in New Zealand are subject to heavy snow loads and earthquake loads the site at Whangarei is subject to minimal seismic activity and practically no snow loading. For most components and connections the building design was critical for wind loading even though the large number of openings on one of the side walls and one end wall provided low internal pressure coefficients (+0.2, -0.3).

2.3 Member selection

The selection of suitable members for the building design was a function of three interrelated issues, structural integrity, material availably, and the level of fabrication expertise required.

Structural Integrity

The consideration of member selection requires the structural components to be adequate to support the design action effects in bending, compression, tension and shear. The members must also be able to be economically connected together, where the transfer of bending moments through moment resisting connections can be optimized by an increased lever arm length within the connection.

Material Availability

LVL was chosen for its flexibility in type (long band or x-band), variability in length, thickness and veneer mix. The nature of LVL is ideal for large volume structural applications where the veneers are peeled and graded to provide a low coefficient of variation whilst removing the concentration of naturally occurring defects such as knots.

CHH Woodproducts New Zealand currently offer four different LVL veneer mixes into the residential and commercial construction market in New Zealand. Ranging in stiffness, from highest to lowest, the products are branded hyONE, hySPAN, hyCHORD and hy90. Specific design information is available for each product type (6) for engineers whilst span tables are readily available for the more conventional residential design situations such as floor joists, lintels, etc. The selection of the most appropriate veneer mix for use in building design is based on the availability of suitable veneer, the capability of manufacture, and most importantly the price of supply of the total project including fabrication of components. The structural components within the portal frame members were manufactured from a hySPAN mix while the secondary framing components such as mullions and girts were selected from lower cost products such as hy90 and hyCHORD where suitable.

All LVL made for the project was produced at CHH's New Zealand LVL plant, located at Marsden Point, just 30 km south of Whangarei. The LVL press is a continuous process that allows longitudinal veneers to be layed up in thicknesses ranging from 27 mm through to 120 mm. X-banded LVL can be manufactured by utilizing the x-band feeder. The Dieffenbacher continuous LVL press has a press length of approximately 50 metres with a current manufacturing length maximum of 18.3 m limited only by the existence of the end wall of the building. The usable slab width is around 1220 mm excluding saw kerf from cutting (typically expressed as 1200 mm with saw kerf). The I-beam purlins (hyJOIST) were manufactured at CHH's Australian LVL plant based in Nangwarry, South Australia.

Fabrication expertise

Prior to this project there was very little available LVL fabrication expertise in New Zealand. Many of the larger LVL buildings erected in New Zealand have been fabricated in Australia by a timber engineering consultancy and prefabricator called Timberbuilt. The lack of prefabrication facilities in New Zealand means that buildings are either manufactured out of other materials such as steel (or Glulam) or alternatively many LVL based solutions are made from Australian material with Australian designers which limits the potential growth of the New Zealand market.

2.4 Design Specifics

The key design areas where designers can exert considerable influence on the cost of portal frame based solutions are in the purlin design and the design of the portal frames.

Purlin Design

The first step in the design of the structure was to determine the bay spacing which is limited by the readily available material and sections for use as purlins. In general for purlins that span 6.0 m or less LVL or solid machine stress graded (MSG) timber can provide economical solutions. However, for spans above 6.0 m I-beam sections can prove to be both economical and easy to install. Lateral torsional restraint can be provided by intermittent blocking pieces that provide torsional resistance to the purlins whilst lateral restraint is provided to the top and bottom of all purlins. The use of pierce fixed sheeting is recommend as it provides continuous restraint to the top edge of the purlin reducing the amount of lateral restraint required in the critical wind uplift case. There is some conjecture about the number of rows of lateral restraint offered to a purlin system given that the more lateral restraints the smaller the purlin. It is best to try and provide two or a maximum of three rows of restraint for purlins spanning around 10.0 m which provides an economical mix between the cost of the purlins and the cost of the time and materials to install the lateral restraints.

The relatively new range of hyJOIST, composite LVL and plywood I-beams, have sections with 90 mm wide flanges that are reasonably laterally stable and cost effective. The HJ360 90 hyJOIST was chosen based on its suitability relative to the design loading for the purlins not subjected to localized pressure zones. A 400 deep I-beam is also available in the hyJOIST range however both the HJ360 90 hyJOIST and the HJ400 90 hyJOIST share the same shear capacity and are both structurally adequate for wind uplift with two rows of lateral restraint. For regions close to the windward edge where eddy currents provide localized pressure zones the HJ360 90 hyJOIST was not suitable with two rows of lateral restraint so a 'non standard' I–beam has been designed. Ideally a wider flange would have been chosen to cater for the increased loading however the I-beam assembly machine is capable of handling a maximum 90 mm wide flange subsequently a 360 mm deep I-beam with 90x45 hySPAN flange was designed and found to be structurally adequate to support the implied loads. By keeping the purlin depth the same but increasing the moment capacity (due to the increased flange size) two rows of lateral restraint can be used within this highly loaded region. Purlins are connected into the side of the portal frame rafters to provide a level of lateral restraint to the rafter sections.

Portal Frame Design

The two portal frames, PF2 and PF3, were individually designed to share common components. The advantage of using the same components is that it increases the level of repetition, providing the ability to set up processes and carry them out in bulk. This is advantageous in both the manufacture of the LVL and the fabrication of components.

The portal frame sections were chosen on their suitability to the applied loads where box beams were used in high moment areas such as over the prop columns and between the eave and first point of contriflexure (for nearly all load cases). Rafters were spliced at points of contriflexure, dictating the length of members. The maximum length component being 18.2 m long (rafter R2) which was very close to the maximum available supply length from Marsden Point. The section chosen for rafter R2 was a solid 1050 x 105 hySPAN (refer Figure 3 for rafter and column sections).

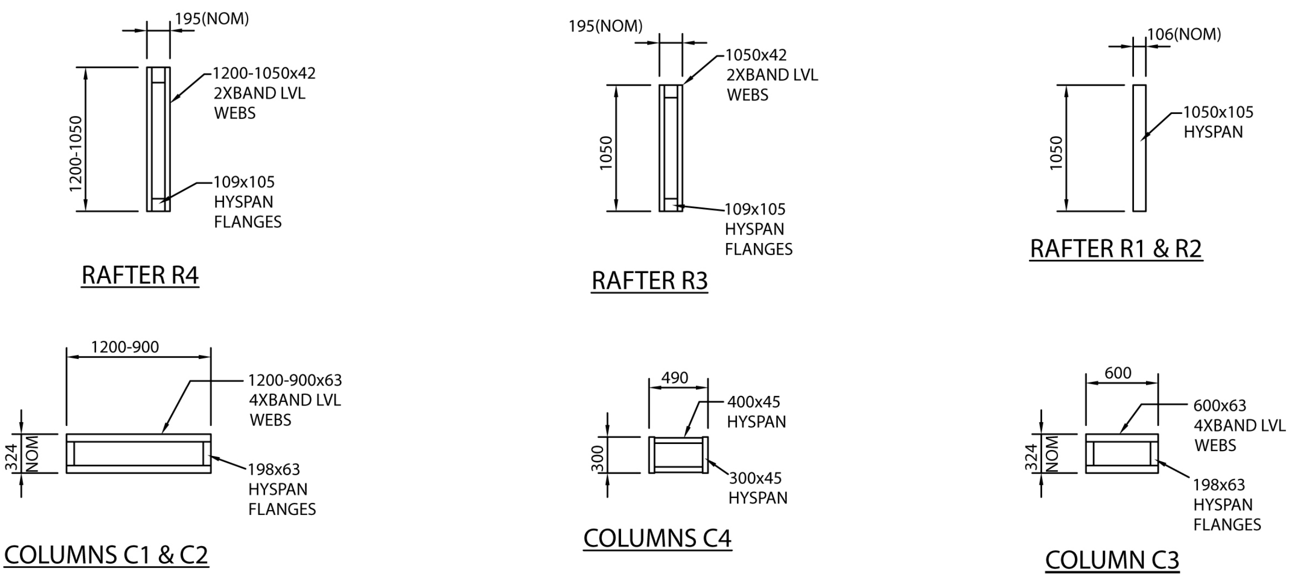

Figure 3. Rafter and Column Sections

This section maintains a depth to breadth ratio of 10. Timber sections with a depth to breadth ratio greater than 10 can experience cupping and are often subject to lateral torsional buckling problems due to their high degree of slenderness. The flexibility of the Marsden Point LVL Mill allowed for the production of this section which is also advantageous from a fabrication perspective because the sections are required only to be square cut at each end. The use of a solid section in this region compared with the increased stiffness box beam over the columns has the advantage of drawing less moment to this region. Flybraces were used to provide lateral restraint to the compression edge for wind uplift. 1050x105 hySPAN was also used in the ridge region where the sections needed only to be plumb cut on one end and square cut the other and can be easily spliced on site using x-banded ridge gussets.

The rafter component over the prop columns, C3 and C4, was designed to be a box section with 1050x42 mm 2 x-band webs and 109x105 hySPAN flanges. Box sections are an advantageous form of construction where the hollow nature of the box allows material to be put where it is structurally most advantageous and they generally provide a laterally stable section. The 109x105 hySPAN flanges were taken from the remnant of the 105 mm thick slab maximizing the use of the slab. The 109 mm depth was used to provide a 3 mm tolerance between the webs and 105 mm wide rafters (which typically measure 106 mm) during erection. The webs were chosen to be x-banded because with such a high depth to breadth ratio (25) dimensional stability can become a problem. The use of x-banded veneers close to the outside of the section effectively eliminates any cupping problems.

Timber based box beams are not a new form of construction with many buildings constructed using plywood box beams for portal frames. X-banded LVL was selected as being preferable to plywood for the webs for a number of reasons. Firstly, the use of a continuous web removes the need to splice sheets over the vertical stiffeners, hence the stiffeners effectively perform a function of eliminating web buckling only. Secondly, LVL can be produced in varying thickness where plywood stocks in New Zealand are typically manufactured to a maximum of 32 mm thick with a maximum stress grade of F11. Thirdly, the nature of the number of parallel plies in the X-banded LVL means that the webs have a much higher contribution to the overall strength and stiffness of the section with 53% of the load in bending taken by the webs of the section in question. Since every second veneer in plywood is x-banded the contribution of many of these veneers to the bending and stiffness is negligible where with the 2 x-banded LVL there are only 2 x-bands out of 12, meaning there is 35 mm of parallel plies per web.

The remaining 150x42 2 x-band section from the manufactured 1200 slab was used as girts in the side wall of the building, again utilizing the full width of the slab. The webs of the box section protrude by 1200 mm each end to allow for rigid connection to the solid R1 and R2 rafter components (Figure 4). These moment resisting connections are made using high density machine driven nail rings. The connection between the flange and web joint was achieved using a composite glued nailed connection. Ø3.33x90 machine driven nails were used with four rows of nails at staggered 65 mm centres based on the design loading for the flange-web connection. Resorcinol formaldehyde glue was also used in the connection but more as a 'belts and braces' approach where the use of the glue will also remove any component of nail slip that may have created deflection issues. Rafter R4 is also a box beam with 109x105 hySPAN flanges, however this rafter is tapered from 1050 to 1200 at the eave.

This utilizes the full width of the slab, draws more moment to these rafters due to the relative increase in stiffness and provides more area to obtain a suitable moment resisting connection at the eave.

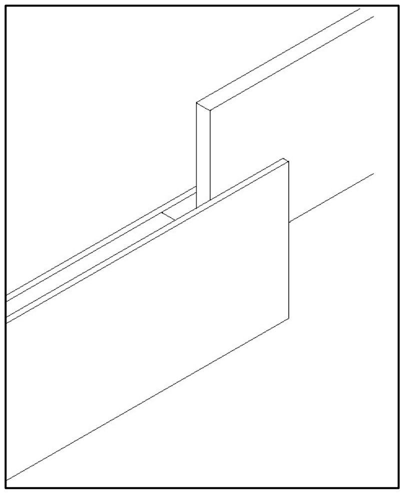

Figure 4. Box rafter to solid rafter

The columns along the outside of the building were chosen to be box sections with protruding webs that encase the rafters that they connect to. The sections are made up of 1200-900x63 mm 4 x-band hySPAN tapered webs with 199x63 hySPAN flanges. Some material economies could have been made by using 42 mm 2 x-band webs with 109x63 flanges with a gusset attached to each side, however, this would have added time to the fabrication schedule through additional cutting of the gussets and the gusset installation. A 4 x-band mix was selected for use as the webs to enable closer nailing along the grain. The presence of x-bands provides a high resistance to splitting at the eave connection. Practical experience and preliminary testing dictate that a minimum number of four x-bands is required to provide across the grain nail spacing along the grain in a 63 mm thick x-band section.

Two types of prop columns were used with column C3 in portal frame PF2 being made up of 600x63 4 x-band hySPAN webs with 199x63 hySPAN flanges whilst column C4 in portal frame PF3 is made up of 2/400x45 and 2/300x45 hySPAN sections. Column C4 is a traditional prop column, with a pin jointed connection at the base and to the rafter. Column C3 is connected to rafter R3 using a moment resisting connection to provide additional resistance to lateral movement under permanent load due to the asymmetrical nature of the gable frame.

3. Component Fabrication

This project is the largest square area LVL based portal frame system to be fabricated in New Zealand. The company completing the fabrication, Stanley Group, had previous experience in the fabrication of their own 25 m LVL portal frame building but no experience in the fabrication of large section composite LVL beams. Whilst there is some information readily available about the design of composite sections (design guides for plywood box beams are available on many industry websites) there is no real information on fabrication techniques and pit-falls in the manufacture of these large members.

Large sections have often been the domain of steel and glulam manufacturers who are accustom to dealing with deep, long members. Practical issues such as the physical size of the members in handling and fabrication need to be considered. Circular saws that cut to depths of up to 130 mm are not readily available off the shelf and need to be obtained for projects using thick members or where sections are to be cut in pairs. Common framing nailers, or 'stick' nailers as they are known, make way for coil nailers during fabrication and erection due to the increased number of nails that can be fired from one coil, reducing the amount of time lost in reloading the nailer. To cater for fabrication of sections up to 18.2 m long and 1.2 m wide sufficient forethought into utilization of workshop area is fundamental. Systems were developed in conjunction with Stanley Group that allowed for these long and deep members to be fabricated within allowable construction tolerances whilst still permitting a cost effective schedule. Components for the rafter and column box sections were individually cut in preparation for fabrication. Fabrication guides were made up for each of the box beam where stops were used to locate critical components. Further critical dimensional checks were applied before assembly to ensure the internal frames and beams were square.

The use of adhesives in the fabrication of the box beams was important to remove the component of nail slip and also to provide a sealed beam to limit moisture getting in the hollow of the box beam during erection. It is important that fabricators understand the use and application of adhesives. Adhesives used in a structural capacity need to be applied in a dry, controlled environment where particular attention needs to be paid to glue spreads and to ensure that sufficient pressure is applied by nails (or screws) to provide a bond. Due to the limited experience of the fabricator with adhesives, connections were designed such that the mechanical fasteners provided sufficient structural transfer. It is also important that when adhesives are used that fabrication occurs on flat, and that beams are left flat to cure.

One of the perceived (and to some extent real) limitations of the specification of timber based structural solutions is the additional detailing involved in both the structural and work shop drawings (WSD's). Standard connections are common place within the steel industry where common connections can be applied to specific members that are detailed and performed by the steel fabricator. At this stage the timber industry does not have the same tools available although it should be noted that a lot of the economies in a design can be made through ingenuity in the connections. The cost of creation of WSD's needs to included for in the fabrication cost with much of the specific design and detailing of connections and composite members completed by the design engineer to ensure the structural adequacy of the system is maintained. CHH are in the process of developing 'standard' connection details for moment resisting connection used in portal frame applications that are due for release mid 2008.

4. Building erection

The erection of this LVL building is set to begin in March 2008 with many of the components fabricated December 2007 through to February 2008. In a similar vein to fabrication, the erection of LVL and other timber based structures has a portion of the unknown to which construction companies tend to include a contingency to account for any perceived difficulties. For the erection of this building a contractor, from Australia, familiar with LVL building erection is being used to provide advice and education to New Zealand building companies on the erection of large LVL systems to eliminate any misconceptions about the erection process.

Typically an LVL based solution of equivalent area is erected in a similar time frame to a steel solution. Riggers are still required to lift roof systems into place except the connections are often performed using pneumatic nailers and nails instead of pneumatic rattle guns and bolts. It can be advantageous to nail off the minimum amount the nail rings whilst the cranes are on site and return later to complete the nailing when the expensive cranes are off site.

It is economical for LVL based systems where the purlins are fixed into the side of the portal frame members to be assembled on the ground in bay multiples and lifted into place. With the purlins framed into the side of the rafters the system is quite stable during lifting. This enables the purlins, lateral restraint and bracing to be installed on the ground limiting the amount of time in scissor lifts, etc, which dramatically increases the productivity on site. In-fill bays then have their purlins and restraint installed. Braced Bays are erected first to allow for squaring up of the frames and to provide resistance to longitudinal wind forces during remaining construction.

5. Conclusions

In this paper the design and fabrication of a large LVL portal frame system in New Zealand was discussed. The design was carried out in accordance with the most up to date New Zealand standards. Design decisions were commercially based where the limited fabrication experience available and the flexibility of CHH's Marsden Point LVL manufacturing facility were considered and appropriate sections were designed, manufactured and fabricated as required. The existence of x-banded LVL allowed for the development of economical structural system the included box sections in high moment regions and solid 105 mm thick LVL sections in less stressed regions. The establishment of fabrication expertise in New Zealand through this project will provide a foundation for the continual development of timber based solutions for large span projects which were previously the domain of steel fabricators and suppliers.

Acknowledgements

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