# JOINTS IN GLULAM USING GROUPS OF EPOXY GROUTED STEEL BARS

**D J Gaunt, Scientist, Forest Research, Rotorua, New Zealand**

## Abstract

Epoxy-grouted threaded steel dowels were used to make connections between 800 mm deep glulam members and fabricated steelwork in structures erected for the Olympics 2000 games in Sydney. This paper describes tests done to check the adequacy of these connections. The results show that the strengths of groups of bars may not simply be an integer multiple of the strengths observed on single bars. The results also show that with good timber selection and detailing the strength of the connection can be dramatically improved.

## Introduction

Hunter Laminates against competition from Australian glulam manufacturers won the contract to provide glulam for the prestigious Sydney 2000 Olympic development. The structure was designed by Ove Arup (Sydney) and utilised 800mm deep, 180-280mm wide by 10m long glulam members in three barrel vault style halls and a 70m dome structure. The connection between glulam members relied on epoxy grouted threaded rods and substantial steel connection pieces. Under the terms of the Hunters contract, a series of (prototype) evaluations of the complete connection assemblies was called for.

Previous tests on single fixings undertaken by and on behalf of Hunter Laminates and also by (Buchanan *etal* 1993) had failed the metal joint components and shown tension strengths in excess of 600kN per fixing. However the effect of multiple fastenings had not been explored.

Three types of testing will be examined in this paper namely:

- Prototype Tension Testing
- Prototype Bending Testing
- Metal Component Testing

## Glulam Fixing Details

Figure 1 shows the standard glulam joint fixing details and dimensions. The installation of the epoxied rods was carried out at Hunters plant in Nelson. The pilot holes relied on a steel jig for position and were drilled by portable electric drill, the hole alignment was monitored by eye.
In order to epoxy in the rods, the beams were laid on the flat with the rods sealed in place with silicon sealant. The adhesive used was a West System Epoxy as supplied by Adhesive Technologies, specially modified to give the flow characteristics of the Araldite K80 adhesive. A pink dye was also added to the hardener to make it readily apparent that hardener had been included in the mix.

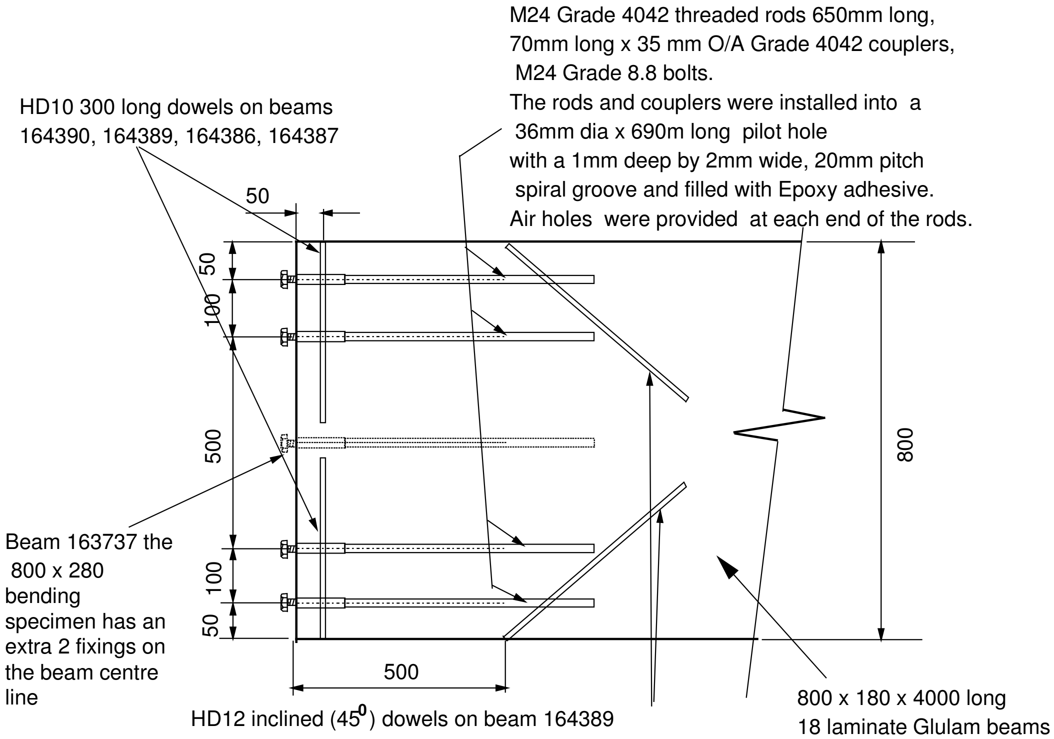

**Figure 1**: Typical Glulam Fixing Details

## Prototype Tension Testing

The tension test frame (see Figures 2 & 3) was set up on the Timber Engineering strong floor, which is a 300mm thick slab reinforced top and bottom, each way with 20mm reinforcement. Two hydraulic jacks were linked together to ensure they both applied the same load. The capacity of this setup was limited to 1200kN by the capacity of the hydraulic jacks. The test setup for testing all the eight fixings at once was as drawn in Figure 2. Figure 3 shows the arrangement for testing one set of four fixings. In this case the two hydraulic jacks were arranged to be equidistance about the fixing centre line albeit with the beam centre line eccentric to the applied load. Continuous load deflection plots were taken for each test.

The actual test procedure for each beam was as follows:

- Beams 164079 & 164080 had the fixings in centre of the beam and were tested as per Figure 2. These beams were cycled from zero to 220 kN (1.0 times service tension) three times then once to 330kN (1.5 times the service tension) then to failure.
- Beams 164386, 164387, 164388 were initially proof tested with all eight fixings as per Figure 2 then on each side where possible with four fixings as per Figure 3. These beams were not cycled just gradually loaded to failure.
- Beams 164389, 164390, 164941 were tested on each side where possible with the four fixings as per Figure 3. These beams were not load cycled, just gradually loaded to failure.

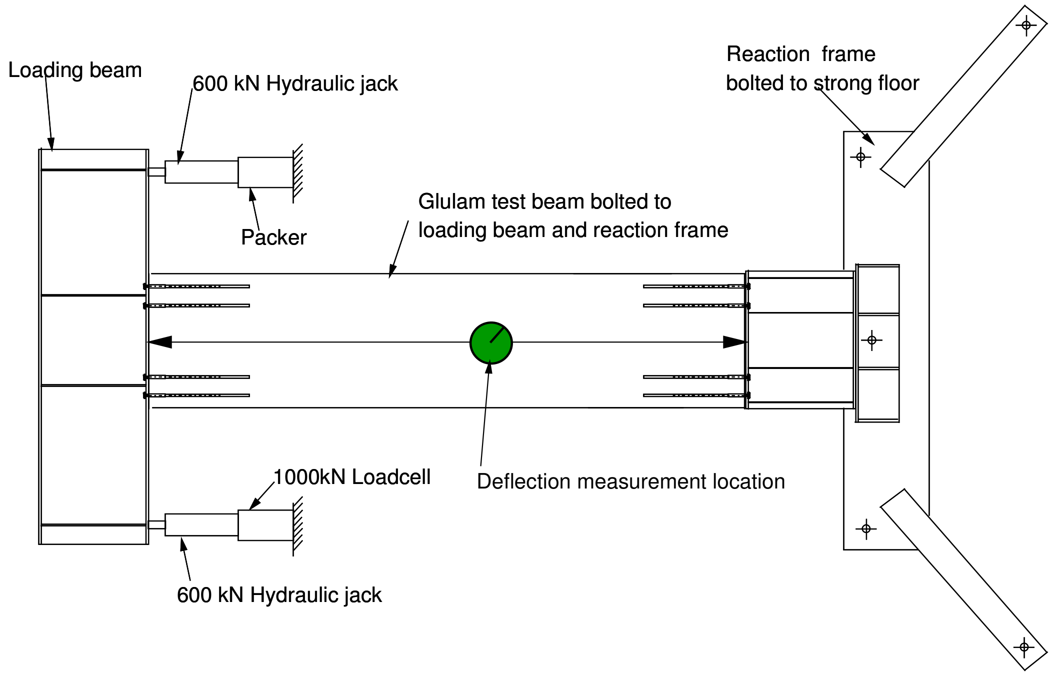

**Figure 2** Eight Fixing Tension Test Frame

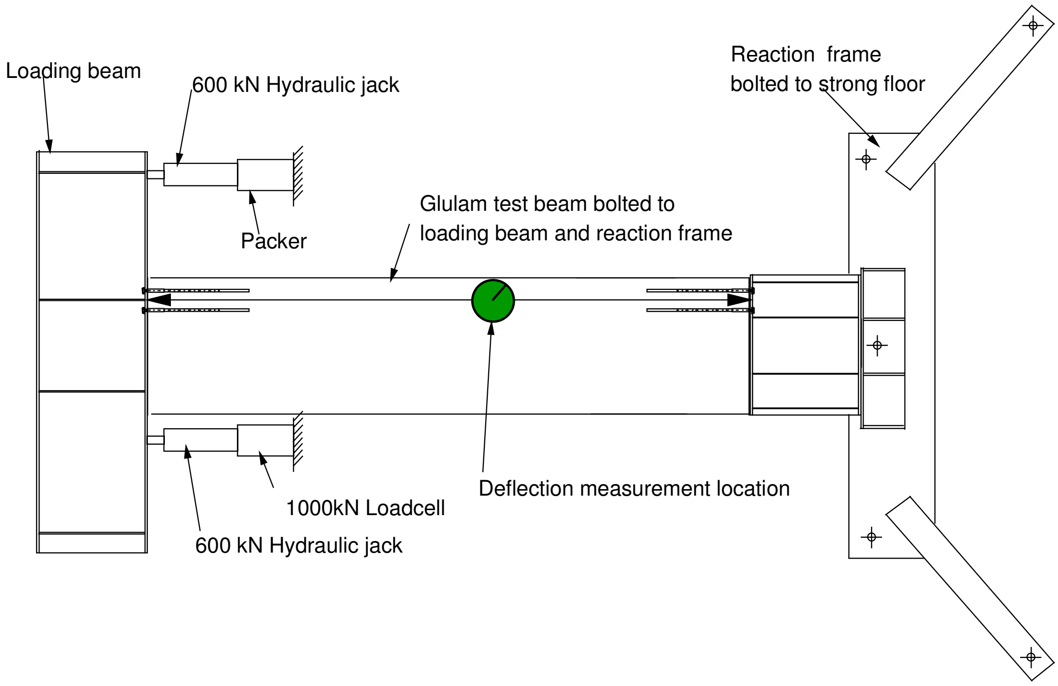

**Figure 3** Four Fixing Tension Test Frame

### Prototype Tension Test Results.

- Beams 164079 & 164080 completed the cyclic testing without showing any signs of distress and failed at loads of 610 & 585 kNm respectively. The failure was a vee shaped wedge being pulled out of the beam at one end.

- Beam 164386 was proof loaded to 1200kN on all eight fixings without showing any signs of distress then tested on each side group of four fixings giving failure loads of 785 & 650 kN. The failure was a large (half beam depth by 1.2m) corner section being pulled off the sides of the beam.

- Beams 164387 & 164388 were proof loaded to 1200kN on all eight fixings without showing any signs of distress. The beams were then tested on one side group of four fixings only giving failure loads of 850 & 850 kN respectively. The failure was a smaller corner section being pulled of the side off the beams. The section was bounded by the ends of the threaded rods and the cross dowels.

- Beam 164389 was tested on each side group of four fixings giving failure loads of 875 & 990 kN. The failure was a smaller corner section being pulled of the side off the beams. The section was bounded by the ends of the threaded rods and the cross dowels.

- Beam 164390 was tested on each side group of four fixings giving a failure load of 1062 with failure being a smaller corner section pulled of the side off the beam. And a failure load of 1143 kN with the failure mode being extensive splitting along the rods accompanied by withdrawal of the rods. There was no corner section pulled of in test.

Figure 4 shows the typical failure patterns we encountered while Appendix A lists a description of the beams along with the test results

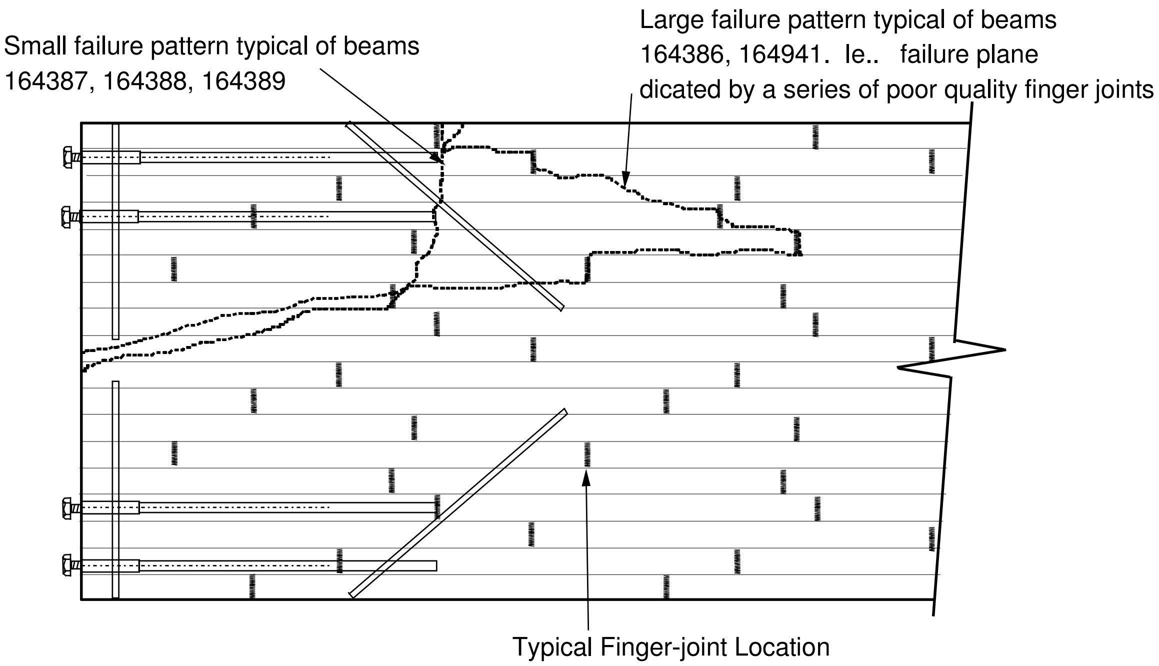

**Figure 4** Typical Tension Failure Modes

**Prototype Tension Test Discussion**

The failure loads for all the tests were well in excess of the service loads specified by Ove Arup.
At no stage was there a failure in the metal joint components.
The strength of the multiple fastening joint was observed to be less than an integer multiple of the strengths previously observed on single bars.
In order to best appreciate the development of the tensile fastenings the results of have been plotted in Figure 5. It can be noted that a considerable increase in strength that was achieved.

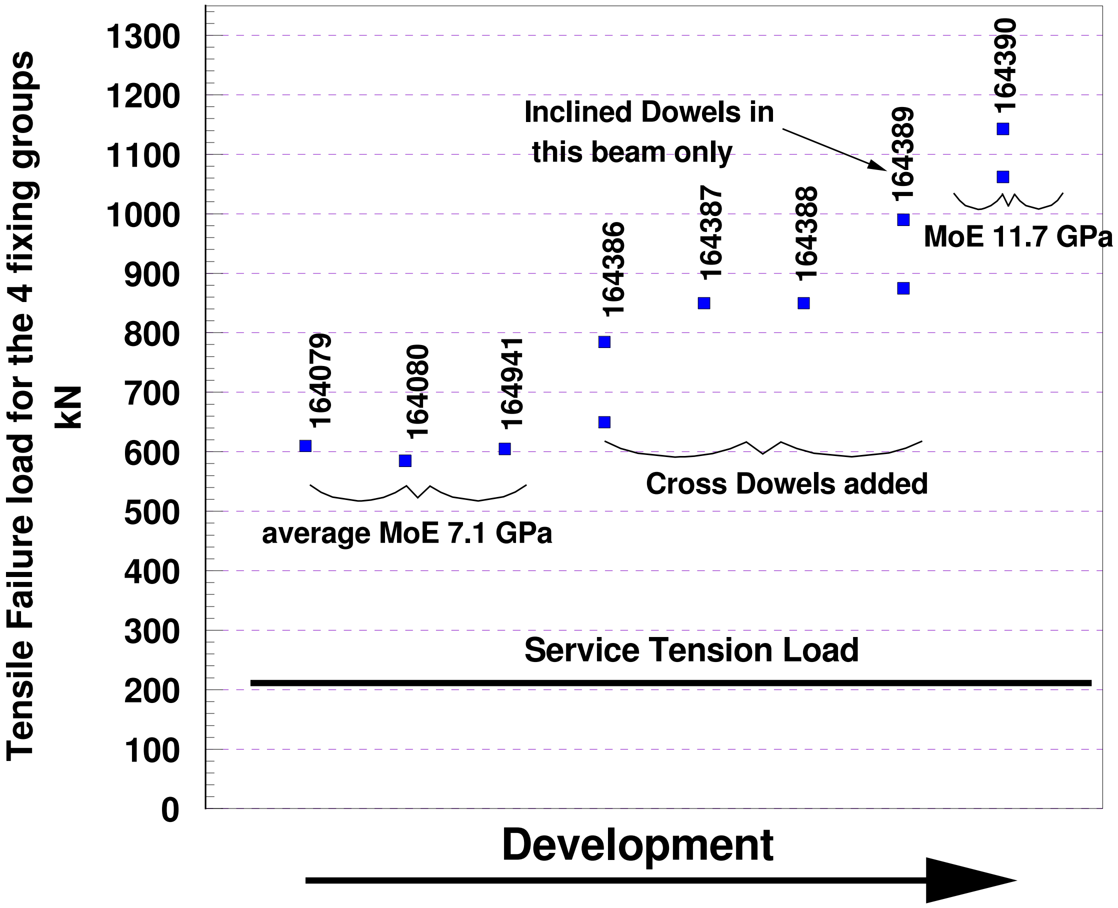

**Figure 5** Plot of Increasing Tensile Capacity with Modifications

The reasons for this the increases in strength are likely to be a combination of several factors namely:

1. The general improvement in timber quality
   From the original visually graded lamination stock, in-grade tests on this material gave an MoE of 7.1 MPa and a characteristic tension strength of 12 MPa, through to the final use of machined graded lamination stock material that was in edge laminated and all finger-joints proof loaded. An in-grade assessment of this material yielded an MoE of 11.67 MPa and a characteristic tension strength of 27 MPa. A paper titled the "Production of radiata glulam for Olympic facilities", by G.B. Walford presents the timber quality issues associated with this project.
2. The addition of the cross dowels resulted in larger sections of timber being torn off the beams with resultant higher tension loads.
3. The additional of the inclined bar appeared to have only a small positive effect.
4. The majority of the failures centred around the ends of the threaded rods, indicating stress concentrations in a zone of reduced timber cross section.
5. In some of the earlier beams, failures were noted in the finger joints and along the glue lines.

**Prototype Bending Testing**

The bending test frame was set up utilising the tension frame as Figure 6. Continuous bending moment load versus deflection plots were taken for each test, the moment being calculated from the distance between the applied load and the opposite end of the timber section..
The actual test procedure for each beam is as follows:

- Beam 163736 (800x 180) was cycled from zero to 130 kNm (1.0 times service moment) seven times then once to 195kNm (1.5 times the service moment) then to failure.

- Beam 163737 (800x 280) was cycled from zero to 150 kNm (1.0 times service moment) seven times then once to 225kNm (1.5 times the service moment) then to failure.

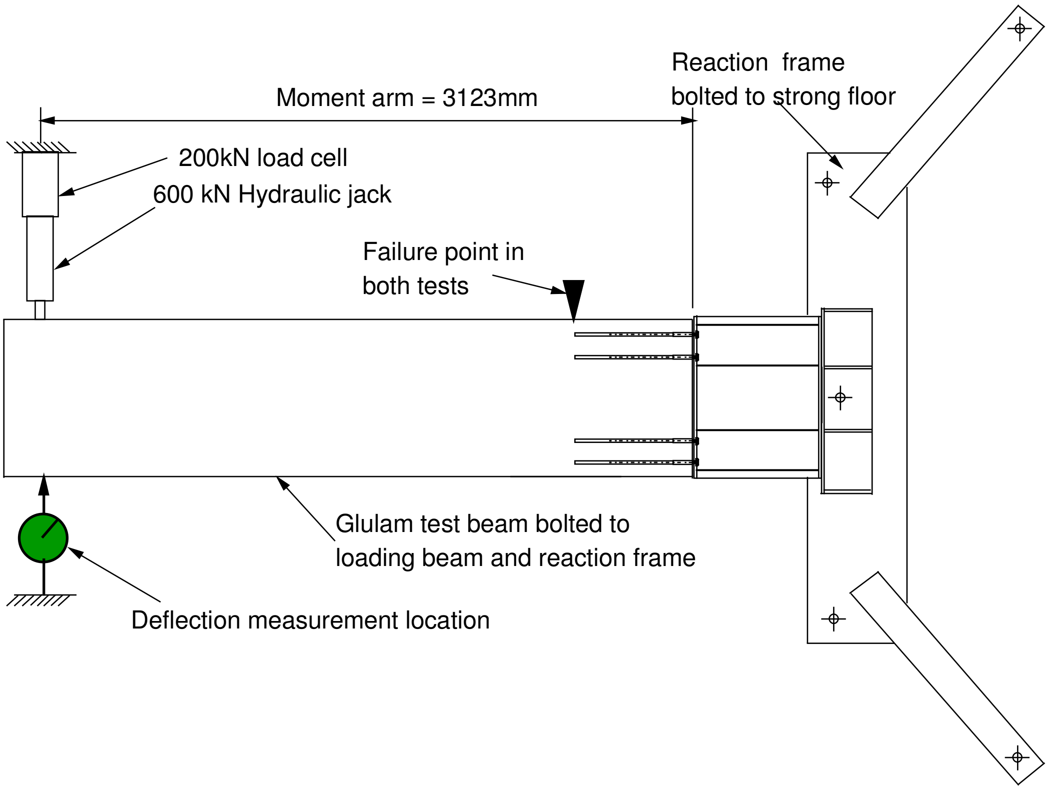

**Figure 6** Bending Test Frame

### Bending Test Results And Discussion

- Beam 163736 completed the cyclic testing without showing any signs of distress and failed at a bending moment of 434 kNm. The failure initiated with a crack in a clear-wood section of the outer tension laminate adjacent to the end of the threaded rods. The final failure pattern spread from the initial crack throughout the tension section of the beam, back towards the beam end. The failure stress in the beam was calculated at 22MPa.
- Beam 163737 completed the cyclic testing without showing any signs of distress and failed at a bending moment of 475 kNm. The failure mode and pattern was very similar to beam 163736. The failure stress in the beam was calculated at 16MPa.

These two beams were made early on in the project when the timber quality issues were not fully understood which may in part explain the low timber failure stresses. However the failure moments were three times greater than the service moments specified by Ove Arup.

### Metal Component Testing

By way of a check on the metal components two tensile tests were undertaken on the assembled component ie.. the threaded rods, couplers and bolts (Figure 6). These tests were done in the 550kN Baldwin Universal Test Machine at a rate of loading of 50 kN/minute.

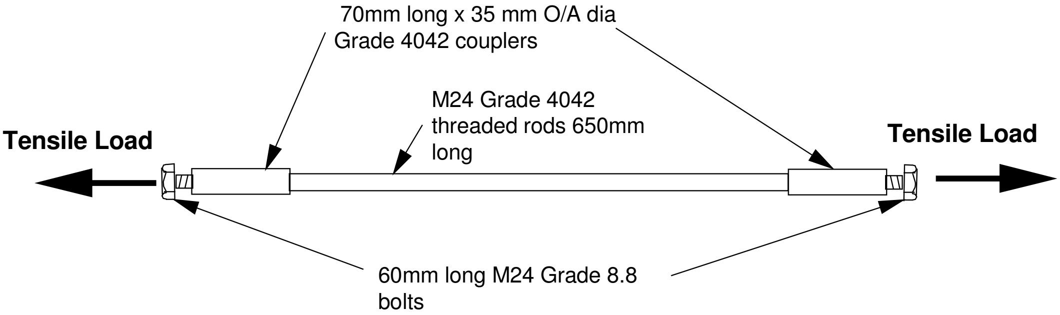

**Figure 6** Tensile test geometry of metal components

The results of these tests are listed in Table 1.

**Table 1** Component Tensile Test Results

| Test | Ultimate Load kN | Failure mode | Failure Stress MPa | Yield Stress (approx) MPa |
|---|---|---|---|---|
| 1 | 306 | Bolt failure | 974 | 557 |
| 2 | 314 | Bolt failure | 999 | 668 |

## Recommendations

- Improving the wood quality probably provides the best means of improving the tension capacity of this type of fixing.
- Good quality finger-joints along with proof testing will further enhance the tension capacity.
- Good quality glue lines will better control the tendency for the beams to split.
- The additional of small cross dowels will also improve the tension capacity.
- The addition of inclined dowels should improve the tension capacity but may have to be closer to the middle of the fixing group.
- Using threaded rods of different lengths (shorter bars on the outside) should go some way towards dispersing stress concentrations and maximising the timber cross section, thus hopefully improving tension capacity.
- The possibility of using inclined epoxy grouted threaded rods (angled towards the beam centre line) may also offer some benefits.

## References

*Buchanan A.H, Moss P.J, Townsend P.K* "Reinforcing Bars Epoxy Bonded in Glue Laminated Timber", ITEC 1990 Volume 2.

*Cavan S*. "Epoxy Connection Test Results from Exhibition Halls - New Sydney Show Grounds" Hunter Laminates letter dated 29 Sept 1997.

## Appendix A: Prototype test results

| Lab No: | Test Type | Bars Tested | Max Load | Failed Yes / No | Beam Size, mm | Comments | Failure Mode |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 163736 | Bending | 8 fixings | 434 kNm | yes | 800x180 | Taken from the first series of beams made | Tensile failure adjacent ends of bars |
| 163737 | Bending | 10 fixings | 475 kNm | yes | 800x280 | Taken from the first series of beams made | Tensile failure adjacent ends of bars |
| | | | | | | | |
| 164079 | Tension | 4 fixings on centre | 610 kN | yes | 800x180 | Taken from the first series of beams made | Central 'Vee' shaped plug of wood removed |
| | | | | | | | |
| 164080 | Tension | 4 fixings on centre | 585 kN | yes | 800x180 | Taken from the first series of beams made | Central 'Vee' shaped plug of wood removed |
| | | | | | | | |
| 164941 | Tension | 4 fixings on edge | 605 kN | yes | 800x180 | Taken from the first series of beams made | Large section removed with failure along finger-joints |
| | | | | | | | |
| 164386 | Tension | 8 fixings proof loaded | 1150 kN | no | 800x180 | Cross dowels 380 long | |
| 164386 | Tension | 4 fixings on edge | 785 kN | yes | 800x180 | Cross dowels 380 long | Large section removed with failure along finger-joints |
| 164386 | Tension | 4 fixings on edge | 650 kN | yes | 800x180 | Cross dowels 380 long | Large section removed with failure along finger-joints |
| | | | | | | | |
| 164387 | Tension | 8 fixings proof loaded | 1195 kN | no | 800x180 | Cross dowels 380 long | |
| 164387 | Tension | 4 fixings on edge | 850 kN | yes | 800x180 | Cross dowels 380 long | Small section removed, failure across ends of bars |
| | | | | | | | |
| 164388 | Tension | 8 fixings proof loaded | 1185 kN | no | 2/400x 180 | Cross dowels 380 long | |
| 164388 | Tension | 4 fixings on edge | 850 kN | yes | 2/400x 180 | Cross dowels 380 long | Small section removed, failure across ends of bars |
| | | | | | | | |
| 164389 | Tension | 4 fixings on edge | 875 kN | yes | 800x180 | Cross dowel & inclined dowel at bar end | Small section removed, failure across ends of bars |
| 164389 | Tension | 4 fixings on edge | 990 kN | yes | 800x180 | Cross dowel & inclined dowel at bar end | Small section removed, failure across ends of bars |
| | | | | | | | |
| 164390 | Tension | 4 fixings on edge | 1143 kN | yes | 800x180 | F11 edge jointed laminates with cross dowel | Splitting along bars and bars withdrawn |
| 164390 | Tension | 4 fixings on edge | 1062 kN | yes | 800x180 | F11 edge jointed laminates cross dowel | Small section removed, failure across ends of bars |