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Ty Unnos - Mechanically Jointed Box Beams

Feasibility Study

For

Coed Cymru

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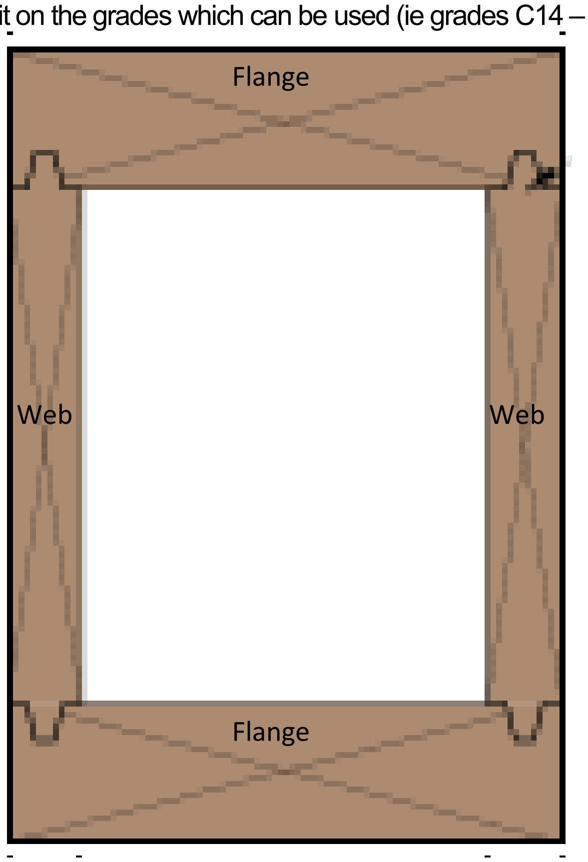
1.0 Introduction

1.1. Mann Williams were appointed by Coed Cymru to produce a feasibility study into the use of Ty Unnos box beams with mechanical fasteners replacing the current glued joints.

1.2. It is anticipated that this would provide an alternative manufacturing method which would be simpler and would require less onerous third party certification.

1.3. Box beams are formed of 2 solid timber webs and 2 solid timber flanges in a box arrangement. The webs are typically 40mm thick and the flanges are typically 40 or 70mm thick. The timber is stress graded typically to C16 although there is no limit on the grades which can be used (ie grades C14 – C50).



1.4. The existing box beam design, with structural glued joints between the webs and flanges, has a CE mark as a construction product. Part of this certification requires the completion of a factory production control manual and audits by a notified body such as BM TRADA. It is our understanding that the majority of this is process relates to the structural gluing process.

1.5. This report is primarily related to the effect of changing the box beam construction on the structural capacity of the beams. No observations have been made in relation to the impact on cost or visual quality to the box beams.

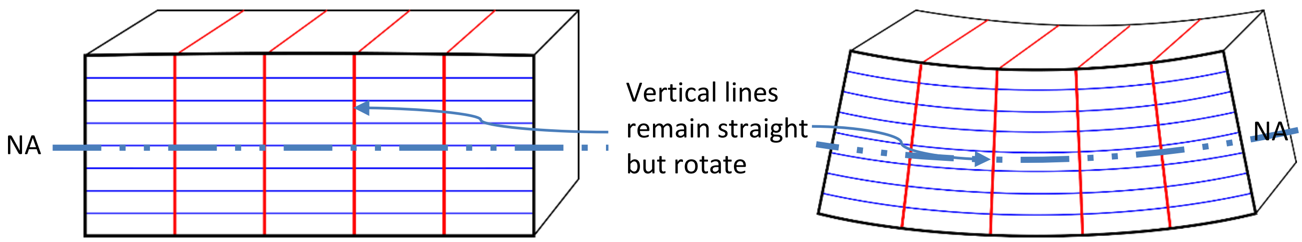
2.0 Analytical Principles

2.1. The analysis of timber box beams is based on calculating the distribution of stresses within the timber elements. This is similar to the design of all structural elements under bending. The typical assumptions made in regards to bending are:

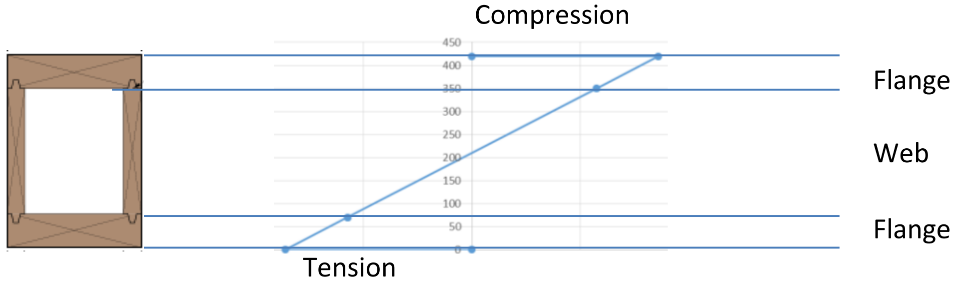
- Material is homogenous and isotropic - constant stiffness in all directions
- Transverse sections which are plane before bending remain plain after bending.
- Beam is initially straight and all longitudinal filaments bend in circular arcs
- Deflections are small in relation to the beam geometry
- Each layer of the beam is free to expand or contract

2.2. By following these assumptions it is possible to calculate the distribution of stresses in any beam under bending. This will vary from a maximum compressive stress in the top face to a maximum tension stress in the bottom face. The point at which the stress is zero is referred to as the neutral axis.

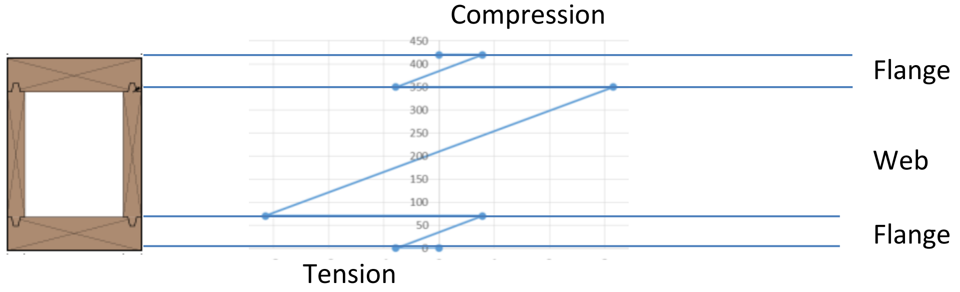
2.3. For compound beams, beams built up of more than one section, there are two interpretations of the assumption that plane sections remain plane after bending. This assumption states that any lines in the member which are vertical prior to bending remain strait after bending, but rotate, as shown in the sketches bellow.



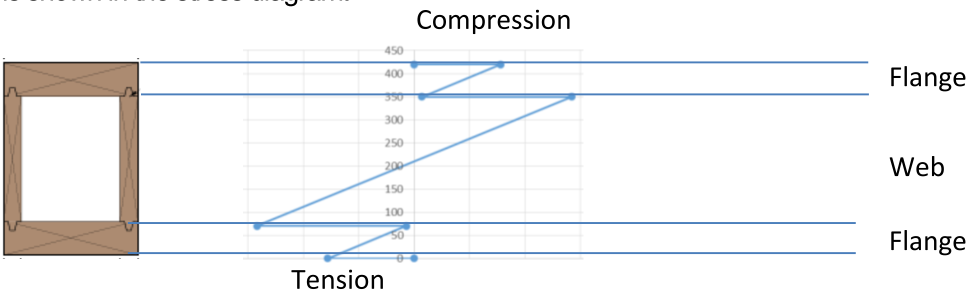
2.4. For compound beams this can relate to each of the sections individually or for the beam as a whole depending on the joint between the components. If the components are fixed so they can't slide past each other it relates to the beam as a whole. One flange of the beam would be in tension and one would be in compression as shown in the stress diagram.



2.5. If the components are able to slide past each other it would relate to each individual component. Each component of the box beam would have a tension and compression face as shown in the stress diagram.



2.6. In reality there is a continuum between these two extreme cases. The degree to which a given compound beam goes to one extreme is related to the stiffness of the longitudinal connections between the components. A compound section with perfectly rigid joints would behave as a whole beam and a compound section with no joints would act as individual components. A compound section with joints between these two extremes will act partially as a whole section and partially as separate components. This is shown in the stress diagram.

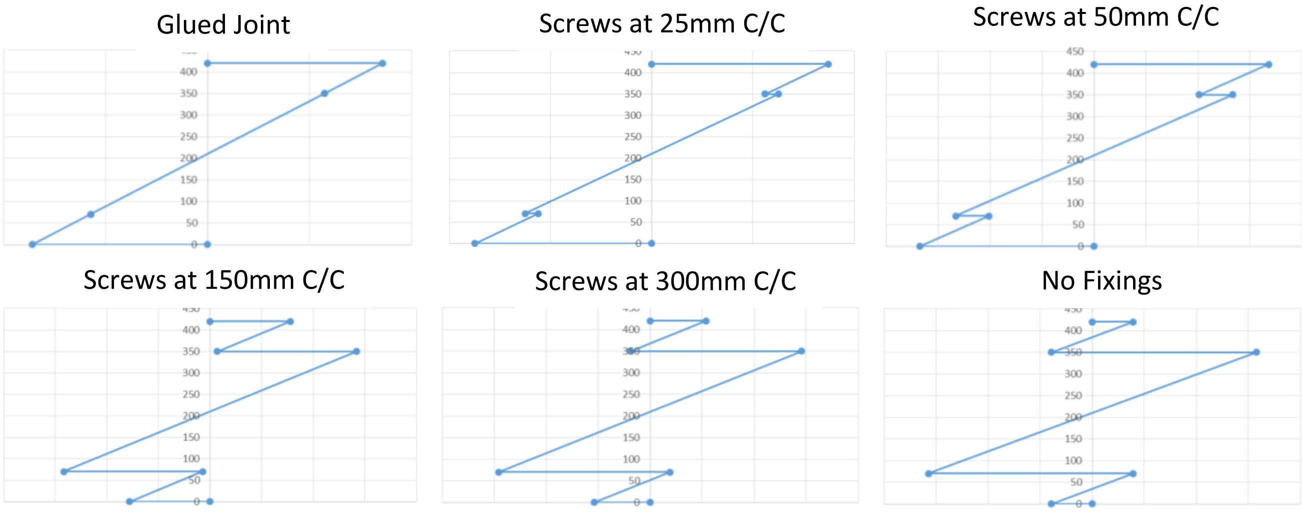


2.7. The steps in the stress diagram between the web and flanges show the degree of slip at this interface which is related to the connection stiffness. As the stiffness of the connection increases the step in stress decreases.

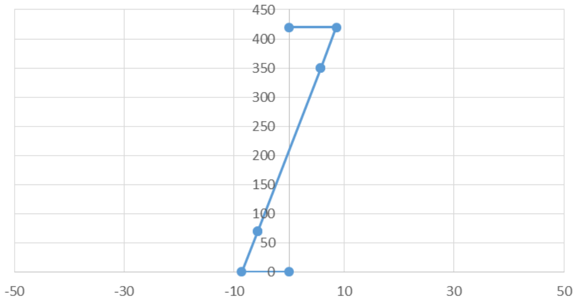
2.8. For the glued box beams the joint is significantly stiffer than the surrounding timber and the beam will act as a whole section. In contrast connections made with mechanical fasteners are less stiff than the surrounding timber but are stiffer than a joint with no fixings and there is more slip along the joint.

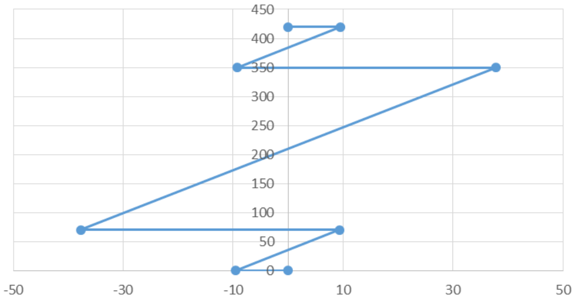
2.9. The stiffness of this mechanical joint is dependent on the diameter of the fastener, the density of the timber and the spacing's of the fasteners. As the diameter of fastener and density of timber increases and as the fastener spacing decreases the stiffness increases and the degree of slip decreases.

2.10. The following stress diagrams show the continuum from a glued jointed box beam to a box beam with no joints through various screw jointed box beams. All of the screwed box beams have the same fastener diameter and timber density but the spacing's are varied. The increasing step in the stress diagrams shows the reducing joint stiffness.



2.11. The stress at any point in a beam is a function of the moment, beam width and the square of the beam depth. If the stiffness of the joint decreases the stress in the flange for a given moment reduces and the stress in the web increases. As the flange is further from the neutral axis than the web the increase in web stress is significantly more than the reduction in flange stress. The two stress diagrams below are at the same scale and show the stress distributions for a beam with glues joints and a beam with no fixings for the same moment. The peak stress in the beam with no fixings is approximately 4 times higher than the peak stress in the beam with glued joints.





2.12. These are the analytical principles which underpin the analysis of compound beams with connections which are not perfectly rigid. This is based on an analysis methodology laid out in Appendix B of BS EN 1995-1-1. The method in which this has been used to calculate beam capacities and allowable spans is explained in section 3.0.

3.0 Calculation Methodology

3.1. BS EN 1995-1-1 provides a methodology for designing glued compound timber beams and an analysis method for determining the stress distribution in mechanically jointed beams. These two methods have been used in conjunction to calculate moment capacities and allowable spans for compound mechanically jointed box beams.

3.2. The methodology for calculating the stress distribution in mechanically jointed beams is described in section 2.0. This is based on the principles described in Annex B of BS EN 1995-1-1. For the analysis the distribution of stresses has been calculated in accordance with the method described in Annex B of BS EN 1995-1-1.

3.3. Section 9 of BS EN 1995-1-1 gives a methodology for designing glued compound timber elements. For this report we have designed the box beams according to a modification of the glued thin-webbed beam methodology with the stress distribution from Annex B.

3.4. The glued thin-webbed beam methodology prescribes 6 stress checks based on the bending moment and 1 stress check based on the shear load.

3.4.1. The first 2 bending checks are two compare the extreme fibre stresses against the allowable timber bending stress.

3.4.2. The third bending check is to compare the average stress in the compression flange against the allowable timber compression stress.

3.4.3. The fourth bending check is to compare the average stress in the tension flange against the allowable timber tension stress.

3.4.4. The fifth bending check is to compare the peak compression stress in the web against the allowable timber compression stress.

3.4.5. The sixth bending check is to compare the peak tension stress in the web against the allowable timber tension stress.

3.4.6. The shear check gives a method for determining the allowable shear force based on the web dimensions and allowable shear stress.

3.5. For this analysis the six bending checks have been used in conjunction with the bending stress distribution calculated from appendix B. The shear check has been replaced with an equation in appendix B. This calculates the applied shear stress which has been compared to the allowable timber shear stress. In addition a check was made of the load carried by the mechanical fasteners, the load in each fastener was calculated according to an equation in Appendix B and compared with the allowable fastener load.

3.6. This general methodology has been used for a series of beam geometry and loading configurations. Two beam sizes, TU-BB 8 (270x210x40) and TU-BB2 (420x210x70) have been used with 6 joint configurations, glued, screwed (at 25mm C/C, 50mm C/C, 150mm C/C and 300mm C/C) and no fixings.

3.7. For each of these geometries the moment capacity and the allowable spans under three different frame centres and three different load conditions have been calculated.

3.8. In each case an iterative process was used to determine the maximum span at which all of the design checks were valid. This was required because the moment capacity of mechanically jointed beams is related to the span of the beam.

3.9. For all of the beams it has been assumed that they are C16 timber and that the mechanical fixings are pairs of 7.5mm diameter 75mm long screws (one into each web). The beams have been assumed to be simply supported and loaded by a uniformly distributed load. It has been assumed that he beams are in service class 1 and that the applied loading is medium term.

3.10. The three load conditions used in this report are based on domestic floor, light industrial floor and roof loadings.

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4.0 Calculation Results

4.1. Moment Capacity

4.1.1. The following table shows the calculated moment capacities for box beams with glued joints, screwed joints and joints with no fixings. These are the moment capacities at the maximum allowable span for a consistent loading arrangement. All moment capacities are in kNm.

	Glued	25mm c/c	50mm c/c	150mm c/c	300mm c/c	No Fixings
TU-BB8	18.79	14.54	8.11	4.14	3.56	3.09
TU-BB2	43.36	42.79	15.67	7.24	6.09	5.17

4.2. Maximum Allowable Spans – Domestic Floor Loading

4.2.1. The following table shows the calculated maximum allowable spans for box beams with glued joints, screwed joints and joints with no fixings. These are for beams loaded with domestic floor loading (Dead load = 0.75 kN/m^2, Live load = 2.0 kN/m^2) at three different beam centres. Deflection has not been considered in any of these calculations. All spans and beam centres are in m.

	Beam Centres	Glued	25mm c/c	50mm c/c	150mm c/c	300mm c/c	No Fixings
TU-BB8	1.2	5.60	5.29	4.19	2.59	2.32	2.10
270x210x40	2.4	3.99	3.40	2.54	1.90	1.77	1.67
	3.6	3.26	2.52	2.00	1.55	1.33	1.20
TU-BB2	1.2	8.57	8.67	5.96	3.46	2.32	2.72
420x210x70	2.4	6.06	5.70	3.51	2.50	2.32	2.16
	3.6	4.95	4.01	2.71	2.11	1.99	1.82

4.3. Maximum Allowable Spans – Light Industrial Floor Loading

4.3.1. The following table shows the calculated maximum allowable spans for box beams with glued joints, screwed joints and joints with no fixings. These are for beams loaded with light industrial floor loading (Dead load = 1.0 kN/m^2, Live load = 3.0 kN/m^2) at three different beam centres. Deflection has not been considered in any of these calculations. All spans and beam centres are in m.

	Beam Centres	Glued	25mm c/c	50mm c/c	150mm c/c	300mm c/c	No Fixings
TU-BB8	1.2	4.67	4.19	3.15	2.17	2.00	1.85
270x210x40	2.4	3.30	2.57	2.03	1.61	1.38	1.23
	3.6	2.69	1.85	1.38	0.90	0.86	0.82
TU-BB2	1.2	7.09	7.14	4.40	2.88	2.62	2.39
420x210x70	2.4	5.01	4.10	2.75	2.13	2.01	1.87
	3.6	4.10	2.98	2.19	1.49	1.35	1.25

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4.4. Maximum Allowable Spans – Flat Roof Loading

4.4.1. The following table shows the calculated maximum allowable spans for box beams with glued joints, screwed joints and joints with no fixings. These are for flat roof beams loaded with roof loading (Dead load = 1.0 kN/m^2, Live load = 0.6 kN/m^2) at three different beam centres. Deflection has not been considered in any of these calculations. All spans and beam centres are in m.

	Beam Centres	Glued	25mm c/c	50mm c/c	150mm c/c	300mm c/c	No Fixings
TU-BB8	1.2	7.63	7.47	7.05	3.57	3.00	2.57
270x210x40	2.4	5.40	5.02	3.91	2.49	2.24	2.04
	3.6	4.41	3.89	2.91	2.07	1.91	1.78
TU-BB2	1.2	11.59	11.67	10.22	4.85	3.97	3.32
420x210x70	2.4	8.20	8.31	5.53	3.32	2.94	2.64
	3.6	6.69	6.66	4.04	2.73	2.50	2.30

4.5. Span Comparisons for Mechanically Jointed Beams

4.5.1. The following table shows comparisons between mechanically jointed beams, glued Ty Unnos beams and solid timber of the same grade.

4.5.2. This table shows beams at 2.4m centres spanning 3.5m under domestic loads

	Size	Cross Sectional Area	% efficacy (compared with smallest cross sectional area)
Mechanically Jointed Ty Unnos Box Beam	TU-BB2 (420x210x70) with 7.5mm screws at 50mm c/c	0.052 m^2	40.4%
Glued Box Beam	TU-BB9 (210x290x40)	0.0336 m^2	62.5%
Solid C16 Timber 1	210 deep x 200 wide.	0.042 m^2	50%
Solid C16 Timber 1	420 deep x 50 wide.	0.021 m^2	100%

4.5.3. This table shows beams at 1.2m centres spanning 4.0m under flat roof loads

	Size	Cross Sectional Area	% efficacy (compared with smallest cross sectional area)
Mechanically Jointed Ty Unnos Box Beam 1	TU-BB2 (420x210x70) with 7.5mm screws at 275mm c/c	0.052 m^2	16.2%
Mechanically Jointed Ty Unnos Box Beam 1	TU-BB8 (270x210x40) with 7.5mm screws at 100mm c/c	0.032 m^2	26.3%
Glued Box Beam	TU-BB9 (210x210x40)	0.027m^2	31.1%
Solid C16 Timber 1	210 deep x 75 wide.	0.016 m^2	52.5%
Solid C16 Timber 1	420 deep x 20 wide.	0.0084 m^2	100%

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4.6. Comparison of Timber Grades

4.7. The following table shows comparisons between different Ty Unnos box beams constructed from different timber grades. The table shows the maximum beam span in meters under domestic loading at 2.4m beam centres.

Max Span (m)	C14	C16	C24
TU-BB8 Glued	3.57	3.99	4.72
TU-BB8 50mm c/c	2.27	2.54	2.67
TU-BB8 150mm c/c	1.75	1.90	2.05
TU-BB2 Glued	5.42	6.06	7.17
TU-BB2 50mm c/c	3.55	3.51	3.67
TU-BB2 150mm c/c	2.56	2.50	2.69

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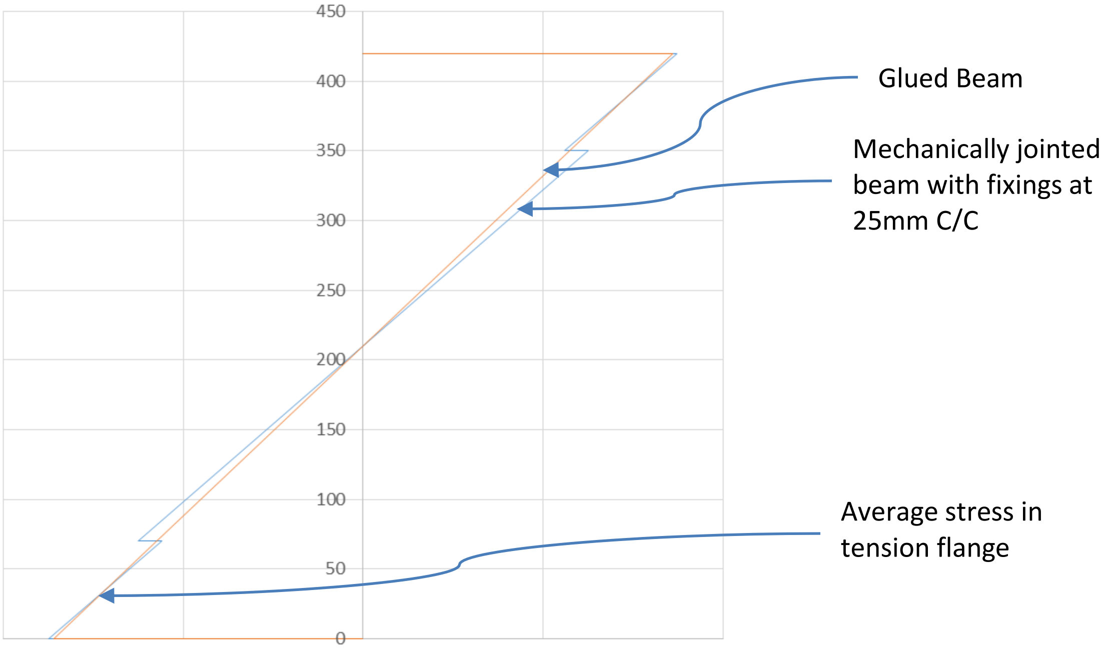
5.0 Discussion

5.1. The results of these calculations generally agree with the expectations discussed in section 2.0. The calculated capacities for mechanically jointed beams generally lie between the results for a beam with perfectly rigid joints and joints with no fixings.

5.2. There are a couple of exceptions to this. The maximum allowable spans for a mechanically jointed beam with fixings at 25mm C/C are greater than the glued beam in two cases. However this also fits with the principles of analysis discussed in section 2.0. In both cases the design is being limited by check 4 which is the average stress in the tension flange. From the stress diagrams below it can be seen that the average stress in the tension flange is the same for both but that the peak stress in the outer fibre and the stress in the web is higher for the beam with mechanical fixings. Therefore the moment capacity of the mechanically jointed beam is higher than the glued beam.



5.3. The results show that box beams with 7.5mm diameter fixings at 25mm centres have very similar capacities to glued box beams. For a 270x210x40 beam with fixings at 25mm the capacity is 77% of the capacity of a glued beam. For a 420x210x70 beam with fixings at 25mm the capacity is 98% of the capacity of a glued beam.

5.4. The results show that box beams with 7.5mm diameter fixings at 300mm centres have very similar capacities to box beams without fixings. For a 270x210x40 beam with fixings at 300mm the capacity is 115% of the capacity of a beam with no fixings. For a 420x210x70 beam the capacity of the beam with fixings at 300mm the capacity is 118% of the capacity of a glued beam.

5.5. These results suggest that depth of the box beam has an impact on the efficacy of the fixings when the fixings are at close centres. It suggests that deeper mechanically jointed box beams generally require less fixings to achieve the same percentage of glued beam capacity.

5.6. The results of the analysis show that for long lightly loaded spans with fixings at close centres the limiting design check is check 4, i.e. the average stress in the tension flange. This is the same as for all glued beams. For long lightly loaded spans with fixings at larger centres the limiting design check is the capacity of the fixings. For short heavily loaded spans the limiting design check is the shear check. This is generally as would be expected from engineering principles.

5.7. From the load testing completed on box beams during the development of Ty Unnos it has been noted that the box beams performed significantly better than predicted by calculation. We have not been able to review the detailed results from this testing as we have not had access to the raw data.

5.8. Anecdotal reports from the testing suggest that the box beams performed as though they were C27 timber. From these anecdotal reports of the testing results it is likely that if further testing is undertaken we could demonstrate bending moment capacities significantly greater than the values calculated. It is our view that this is because the check of average tension stress in the flange is not appropriate for a Ty Unnos box beam. The tension capacity of timber is approximately 2/3 of the bending capacity. This is despite the fact that by definition bending stresses are a combination of tension and compression stresses. Any timber section in bending will have portions of the material in tension but there is not requirement to check these against the allowable tension capacity. If the capacity of a beam is calculated without this check then the resulting average tension stress in the flange is the equivalent of C24 timber.

5.9. If this is the case then it is likely that testing of the mechanically jointed beams will not show such a significant increase in comparison to the calculated values. This is because the average tension stress in the flange is not a limiting design check for most of the configurations.

5.10. In order to determine the box beam capacity by testing it is likely that we would need to test 30 No beams of each size. It is possible that with a greater general catalogue of testing data that we would be able to demonstrate an improved calculation method to replace the current method.

5.11. The comparison of Ty Unnos beams to solid timber beams shows that thin deep solid timber sections are theoretically the most efficient. However these are not available in softwood and would require significant noggins or similar to provide lateral stability. Compared with shallower timber beams Ty Unnos beams use a comparable volume of timber.

5.12. The comparison between Ty Unnos box beams using different timber grades shows that increasing the timber grade increases the allowable span. However it also shows that this effect is reduced for mechanically jointed beams. This is likely to be because the capacity of the mechanically jointed beams is being limited by the mechanical fastener capacity and the glued beams are being limited by the average stress in the tension flange. The mechanical fastener capacity is related to timber density which is 21% higher for C24 timber than C14 timber. In comparison the allowable tension stress is 75% higher for C24 than C16.

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6.0 Conclusions

6.1. The proposed calculation method for mechanically jointed beams appears to provide a good model for the structural capacities of these elements.

6.2. It appears to be possible to produce mechanically jointed box beams with capacities close to the capacities of similar sized beams with structural glued joints.

6.3. The capacity of a mechanically jointed beam is very sensitive to the spacing and size of the fasteners.

6.4. Mechanically jointed beams are more efficient for larger beam sections and for longer more lightly loaded spans.

6.5. For a mechanically jointed beams to have a moment capacity 50% of the equivalent size glued box beam it will require screws at approximately 50-100mm cts.

6.6. Box beams with fixings at 300mm cts or greater do not have any appreciable benefit over beams with no fixings.

6.7. Further testing of box beams with glued joints to determine structural capacities is likely to provide a significant increase in structural capacities in comparison to calculations.

6.8. Further testing of box beams with mechanical joints to determine structural capacities is likely to provide a lesser increase in structural capacities in comparison to calculations.