SHOT FIRED DOWEL FLITCH BEAMS

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Abstract: Flitch beams are a form of sandwich construction using steel and timber elements. They are used in the construction of domestic dwellings when relatively high loads and long spans predominate but available depth of section is restricted in some way. Traditional flitch beams use a bolted connection to hold the elements together, which is a time consuming method of fabrication requiring the pre-drilling of holes in the steel and timber elements. It also presents problems in design detailing. Bolt slippage and fabrication tolerances result in disproportionate stress transfer due to uneven strain affecting the stiffness and strength properties of the beam.

This paper details the findings from a series of laboratory tests and parametric studies on flitch beams constructed from either Kerto S Laminated Veneer Lumber (LVL) or C24 grade timber using a shot-fired dowel connection. The tests showed that during the elastic range proportional stress transfer took place. However, at higher load levels there is uneven stress transfer due to localised buckling of the steel in the top chord and a weakening of the timber elements of the beam due to splitting at the nailing points.

Keywords: composite beams, strength and stiffness, timber structures, connections.

1. INTRODUCTION

As far back as 1859 the advantages of Flitch Beams were being explored (Desai, 2003). Flitch beams consist of one or more pieces of flat steel plate sandwiched between two or more solid rectangular timbers which are bolted together at intervals along the length resulting in the creation of a steel-timber composite beam. The composite beam combines the benefits of timber construction (ease of working, readily available resource, simple connection of ancillary components) with the strength and stiffness of structural steelwork (Bainbridge, 2001) resulting in a timber composite option where relatively long spans and heavy loads predominate.

2. TRADITIONAL FLITCH BEAM FABRICATION

One of the disadvantages of traditional flitch beams is the bolted connection; which requires the pre-drilling of holes through the steel and timber elements and the subsequent bolting together of the beam. Not only is this method of fabrication time consuming but it also has implications on the design and detailing of the beam.

It is reported that laterally loaded timber joints constructed from bolts experience an initial slip as a result of the bolthole clearance whereby load transfer across the joint is only achieved once the bolt is brought into bearing contact with the wood (Davis, 2000). There is also a ‘bedding in’ stage where the initial load results in localised crushing of the cut wood surface.

Full composite action of a flitch beam is as a result of full stress transfer due to even strain of the beam elements. However, even strain may not take place in traditional flitch beams as there will be an initial slip δ on load application due to bolthole clearance (see Figure 1).

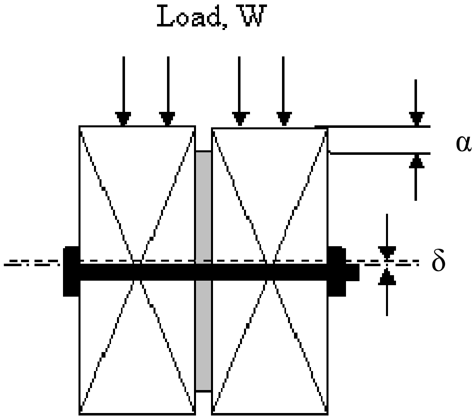

Figure 1: Traditional flitch connection

The initial slip will be determined by the bolthole clearance and quality of fabrication. Fabrication tolerances, such as misalignment of the boltholes, lack of straightness of the boltholes, variation in the bolthole diameter and the initial position of the bolts in the holes can further increase the variability in load distribution between fasteners (Blass, 1995)

To allow for fabrication tolerances, the steel plate element of the flitch beam will, in normal circumstance, not be the same height as the timber element but a distance α (normally of at least 10mm) will be allowed between the elements. This tolerance ensures that the steel does not stand proud of the timber elements which could occur due to poor fabrication or shrinkage of the timber, causing a problem when erected. However, a greater depth of steel would be desirable as it would improve the strength and stiffness properties of the beam.

For the design of composite beams designers often adopt the transform-section method. In traditional flitch beam fabrication, slippage, due to bolthole clearance and fabrication tolerances, may result in an uneven stress distribution due to disproportionate strain and consequentially a reduction in safe working load. Slippage can also add to the initial deflection at the on-set of loading. In most circumstances flitch beams are used for carrying loads over relatively long spans and as a result serviceability is often the limiting design criteria. A proposed improved connection method is the use of shot fired dowels which do not require the pre-drilling of holes and therefore reduce fabrication time and alleviate fabrication tolerances.

3. TESTING PROGRAM

For mass fabrication of shot fired dowel flitch beams it is important to optimise the number of fixings used so that production costs are kept to a minimum. Accordingly the laboratory testing programme examined the following options with regard to the use of shot fired dowels, beam elements and dowel patterns:

1. C24 grade timber or Kerto S LVL only.
2. C24 grade timber or Kerto S LVL and steel plate sandwich configuration clamped together with finger tightened screw clamps.
3. C24 grade timber or Kerto S LVL and steel plate sandwich configuration connected with shot fired dowels of varying patterns and densities.

Several test specimens were constructed each consisting of one length of 3mm thick grade 43 flat steel plate and two lengths of C24 grade timbers or Kerto S LVL. Each test specimen was a sandwich configuration comprising the three flitch elements with the steel plate being sandwiched between the two timber elements. An ITW Spit P200 gun was used to shot fire 3.6mm diameter 60mm long dowels through one timber element and the steel element, penetrating the second timber element to a depth of approximately 12mm or more depending on embedment depth in the first timber. This was done on alternate sides of the beam for the specified nailing requirement. Alternating the side of application ensures full fixity of both timber elements and means that dowels could be spaced in accordance with EC5 (BSI, 2004) guidance.

Testing of the flitch beams was carried-out over two effective spans of 1.8 metres (C24 grade timber and Kerto S LVL) and 2.1 metres (C24 grade timber only) and although these are relatively short spans the depth of section was scaled appropriately to be representative of longer spans. Testing beams with no nails was to demonstrate the method of stress transfer, whether it was via the connection or simply through load sharing as a result of the beam elements being the same height.

Initial designs to EC5 (BSI, 2004) stipulated that a minimum number of 5 nails would be sufficient to carry the maximum design shear force to be exerted on the test beams. The beams were to be loaded in excess of the maximum design loads, to ultimate failure, so nailing patterns were specified as follows, (see also Figure 2):

- No dowels, elements clamped together with finger tightened screw clamps.
- 5 dowels per side
- 8 dowels per side
- 13 dowels on one side and 14 on the other
- 18 dowels per side

4. TESTING METHOD AND RESULTS

The stiffness tests were performed in accordance with EN 408:1995. A minimum of three beams of each fixing method were tested with displacement measurements taken at incremental loading until failure occurred. The average test results of each dowel pattern were then plotted and in the case of C24 grade timber adjusted to account for variations in density (Figure 3).

From the average trend line the EI value for each beam of varying dowel pattern was calculated. The EI value was calculated over the elastic part of the curve at approximately 40% of the ultimate loads.

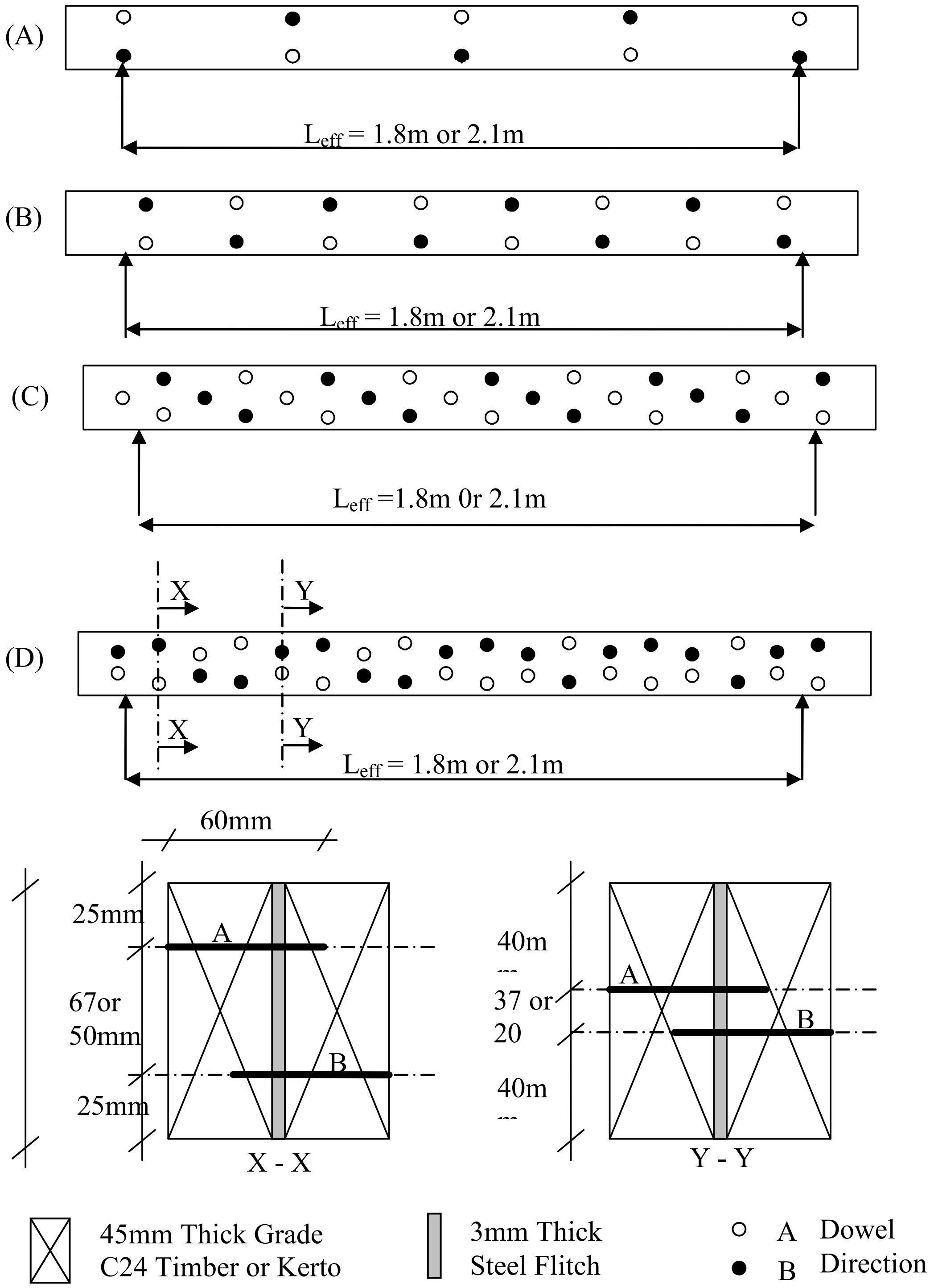

Figure 2: (A) 5 dowels per side; (B) 8 dowels per side; (C) 13 dowels on one side & 14 on the other and (D) 18 dowels per side

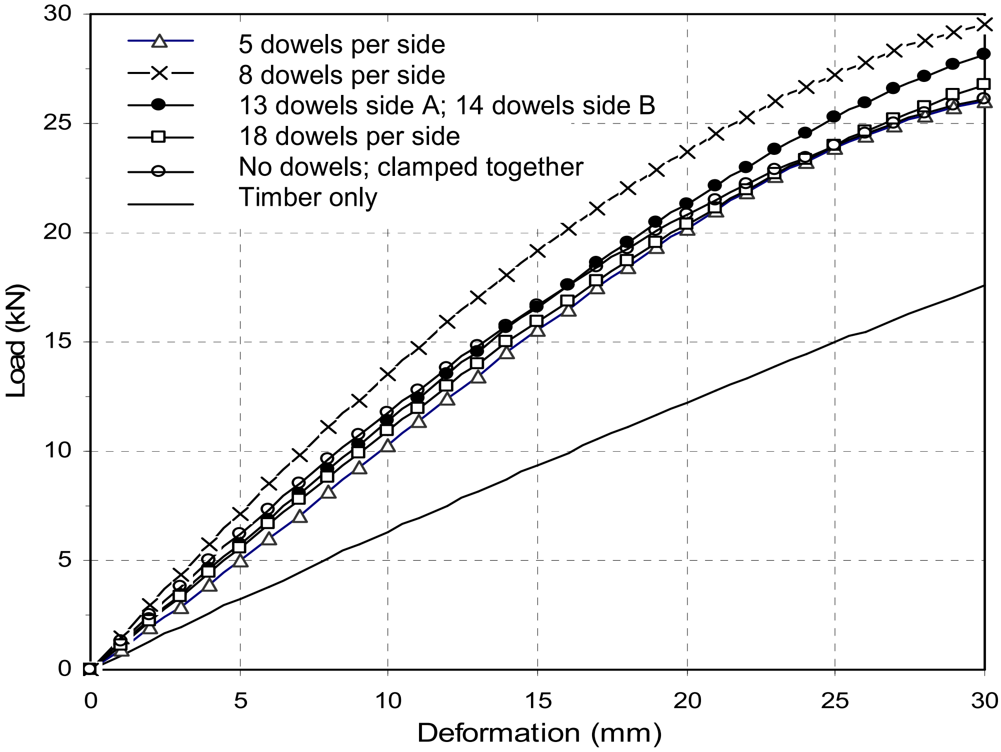

Figure 3: Grade C24 beams over 2.1m effective span load against deflection plots adjusted for density

Figure 4 shows the consistency in stiffness of flitch beams constructed using C24 timbers tested over a 1.8m span. This consistency was also demonstrated in the beams constructed from C24 tested over 2.1m and in beams constructed using Kerto S LVL tested over 1.8m. Deviations in the results can be credited to variations in timber material properties. What the results show is that the nailing pattern has little or no effect on the stiffness of the beam.

The recorded loads at failure were used to determine the bending strength of each flitch beam in accordance with EN 408:1995. The average bending moment carrying capacity for each beam type, segregated in accordance with the employed fixing method, was then calculated using the characteristic strength to allow for sample deviation. Figure 5 shows the variations in bending strength of the flitch beam types constructed using Kerto S LVL.

A consistency in results of the Kerto S LVL and C24 flitch beams was demonstrated taking into due consideration the variability in material properties. What the test results served to demonstrate was that no particular dowel pattern enhanced the bending moment carrying capacity, in fact it was noted during the testing programme that dowels can in some instances serve to weaken the timber elements of the beam by introducing points of weakness through splitting of the timber.

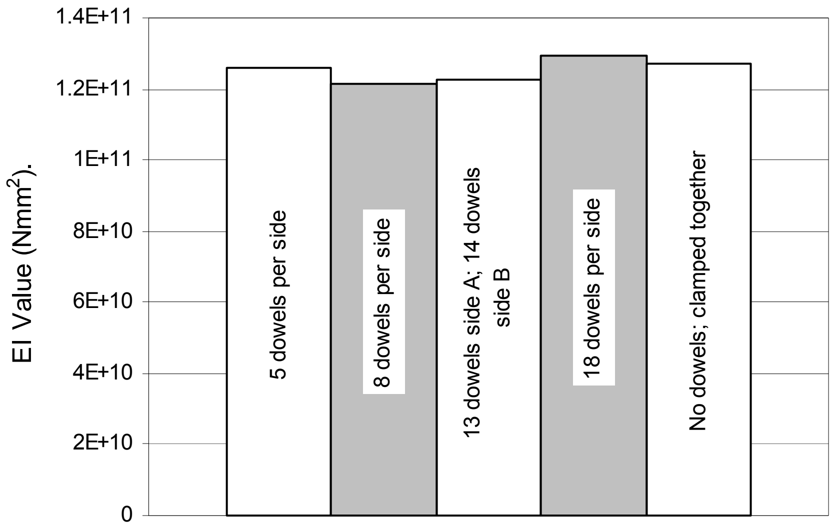

Figure 4: EI Value variations of C24 flitch beam over 1.8m effective span

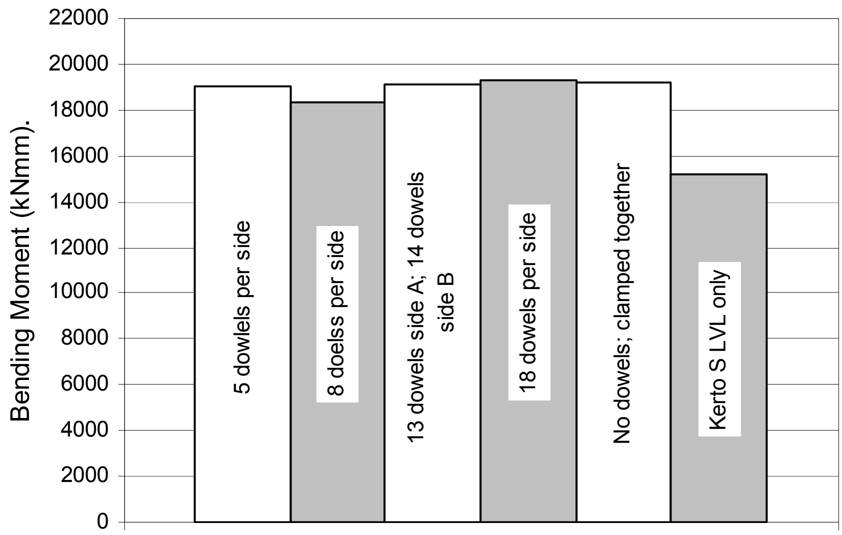

Figure 5: Bending moment capacity variations of Kerto S LVL flitch beam over 1.8m effective span

4. ANALYSIS & COMPARISON OF RESULTS

As expected the test results have confirmed that the stiffness and flexural strength of flitch beams, with the steel plate and timber being of the same depth and length, are relatively the same regardless of the dowel pattern. This is due to the fact that the elements of the flitch beams tested are forming a load sharing system whereby stress transfer occurs as a result of even strain.

Table1 shows the correlation in results between test out-put EI, for a particular fixing method and element configuration, and calculated EI values. Average test set specimen dimensions have been used to determine EI on each occasion.

Table 1: EI value comparison

Set	Test EI Values		Calculated EI Values		Mean Percentage Difference	Characteristic Percentage Difference
	Mean	Characteristic	Mean Properties	5th %'ile Properties		
	Nmm^2	Nmm^2	Nmm^2	Nmm^2		
Set 1	1.25E+11	1.07E+11	1.28E+11	1.03E+11	-2%	4%
Set 2	1.88E+11	1.60E+11	2.04E+11	1.64E+11	-9%	-2%
Set 3	1.33E+11	1.14E+11	1.53E+11	1.41E+11	-15%	-24%

Note:

- A negative percentage difference is as a result of the test results being less than the calculated result.

Set Reference:
Set 1 – C24 Flitch Beam Over 1.8m Effective Span (Dowel Only)
Set 2 – C24 Flitch Beam Over 2.1m Effective Span (Dowel Only)
Set 3 – LVL Flitch Beam Over 1.8m Effective Span (Dowel Only)

From the test results two columns of information are presented: the mean test values and the characteristic test values. To give a true comparison the mean test values have been compared with the EI values calculated using mean material properties and the characteristic test values have been compared with EI values calculated using 5^{th} percentile material properties.

Although a relatively good correlation between test results and calculated results is demonstrated by flitch beams constructed of C24 grade timber, the material properties used in calculations are in accordance with BS EN 338:2003 where the mean E value is $11000Nmm^{-2}$ this value is higher than the mean E value from the tested timber beams which was $9840Nmm^{-2}$. If the E value from the tested timber beams was used in the mean EI calculation for Set 2, then the percentage discrepancy would be of the order of +9% as opposed to -9%.

The correlation between calculated EI values and test EI values of flitch beams constructed using Kerto S LVL, are not as consistent as those of flitch beams constructed using C24 grade timbers and this is the converse as to what would be expected due to the higher degree of uniformity of Kerto S LVL. Although poorer correlation is demonstrated this is attributed to the fact that the Kerto S LVL E values used in calculating EI are from the manufacturers specification which states a mean E value of $13500Nmm^{-2}$ and 5^{th} percentile E value of $12000Nmm^{-2}$(Finnforest Building Systems, 2004), the mean E value from tests conducted on plain Kerto S LVL beams was $12350nmm^{-2}$.

If the mean test value of $12350Nmm^{-2}$ was used in the mean EI value calculation for Set 3, the percentage discrepancy in results would be of the order of +6% as opposed to -15%. It would be appropriate to compare the mean test EI results with the calculated EI results determined using mean property values when deciding upon the correlation because of the consistency of Kerto S LVL. It is, therefore, concluded that the correlation in results is good considering the variability of material.

It is also concluded that during elastic deformation of the flitch beam, full stress transfer is taking place as a result of load sharing through even strain because the elements of the beam are of the same height. With the above in mind a method of connection is still required to provide lateral restraint during service to prevent the slender steel element buckling out of plane and also to hold the beam elements together for ease of construction.

At high stress levels buckling of the steel plate results in uneven stress transfer which in turn results in a reduction of ultimate failure load. Table 2 contains the mean and the factored ultimate failure load of the tested beams for each fixing method. A factor is applied to allow for sample variation. Table 2 also contains the ultimate failure load calculated in accordance with EC5 (BSI, 2004).

The ratio of experimental load to calculated load shows that the ultimate failure load of the experimental beams constructed using shot-fired dowels are up to 16% lower. Experimental results will have a lower failure load mainly due to disproportionate stress transfer as a result of the steel buckling in the top chord due to compression. There may also be a further reduction of bending strength in flitch beams with a dowel fixing due to the intrusion of dowels cleaving apart the timber fibres creating points of weakness.

Table 2: Ultimate strength effectiveness of flitch beams

Set	Experimental		Calculated	Ratio of Experimental to Calculated
	Mean Ultimate	Characteristic Strength	Characteristic Strength	
	N	N	N	
Set 1	26071	19658	18590	1.06
Set 2	28696	24937	25350	0.98
Set 3	36451	31676	37720	0.84

Set Reference:
Set 1 – C24 Flitch Beam Over 1.8m Effective Span (Dowel Only)
Set 2 – C24 Flitch Beam Over 2.1m Effective Span (Dowel Only)
Set 3 – LVL Flitch Beam Over 1.8m Effective Span (Dowel Only)

5. CONCLUSIONS

Test results demonstrated that when the flitch beam elements are of the same height and length they act in load sharing even when they are not connected together. However, a method of connection is required so that the timber element can provide lateral restraint of the slender steel element to prolong the onset of buckling in the top chord and also to hold the beam elements together during construction.

The use of shot fired dowels provides an adequate connection for the elements of a flitch beam to act in a load sharing system. In design calculations, the designer should allow for a decrease in design strength to take account of the reduction in failure load arising from disproportionate stress transfer as a result of eventual lateral buckling of the steel and also from splitting of the timber due to the intrusion of the dowels. The number of dowels specified should be in accordance with the minimum shear requirement and spaced adequately to reduce splitting of the timber.

It can therefore be concluded that the use of shot fired dowels is a relatively quick and cost efficient method of fabrication and the structural properties of the beam are of a standard high enough to allow economic application.

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