Tension testing of green oak connections – FRAME 2003, St Fagans

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1 – Introduction

A number of timber framing companies were invited to fabricate connections to a given overall geometry, the exact form of the joint was constructed to their specification. The connections were to be loaded in tension until a peak load was reached, at which point the connection was deemed to have ‘failed’. This was to take place at the timber framing conference FRAME 2003 and forms a part of a 3 year PhD research project at the University of Bath *‘developing a design rationale for traditional pegged connections in green oak construction’*.

The rig used to load the connections was an adaptation of setup used at the university. The load was applied with a hydraulic jack system, via a load cell. The load cell and two displacement transducers were linked through a data logging device which allowed the load and displacement at any time during the test to be observed. The general setup is shown in figure 1.1

Figure 1.1 – ‘Mobile’ tension testing rig

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2 – Joint Submissions

Seven different timber framing companies submitted a total of eleven different samples. A brief description of each is given in table 2.1. The moisture contents (mc) were recorded using a electrical moisture meter. The tenon mc was recorded on the face of the tenon and the mortice mc recorded inside the mortice on the wall.

Table 2.1 – joint descriptions

Fabricator	Description	MC tenon	MC mortice
1 – Rick Lewis	'Dry' joint, 7/8" peg in 13/16" hole, 1 3/8" edge spacing (to centre of hole)	14.0	25.2
2 – Rick Lewis	As above but 'green'	23.9	23.5
3 – T J Crumps	Two 1" pegs through ¾" holes, undercut mortice, 3 ½" edge distance	27.0	25.6
4 – Jim Blackburn	Top wedged, half dovetail, two ¾" pegs, at 50 mm spacing and 80 & 54 mm edge distance	27.6	18.8
5 – Carpenter Oak & Woodland Ltd.	¾" peg at 1 1/8" edge distance	16.9	13.4
6 - Carpenter Oak & Woodland Ltd.	1" peg at 2 1/4" edge distance	15.1	13.7
7 – Carpenter Oak	As no 5	16.0	18.9
8 – Martin Silburn	Bottom wedged, half dovetail with wedged through tenon and two ¾" pegs	14.9	13.6
9 – Carpenter Oak & Woodland Ltd.	Wedged through tenon with two pegged sided wedges	16.3	14.2
10 – English Oak Buildings	¾" peg at 1 1/8" edge distance	15.9	18.4
11 – English Oak Buildings	¾" peg at 1 1/2" edge distance	13.5	14.2

3 – Results

In each case the transducers on either side of the 'stud' were averaged to give the displacement at any given load. The results are shown in graph form, with the gradient of the load displacement graphs representing the stiffness of the connection. Figures 3.1 – 3.11 show the joints post failure with a brief description of each failure mode.

3.1 – Photographs and failure description

Figure 3.1

1 – Rick Lewis; 1.62 t

Peg yielded, crushed and pulled out between mortice and tenon. As the load increased the mortice wall split where the grain sloped and 'ran' off the timber.

2 – Rick Lewis; 1.47 t

Failure mode very similar to 1 except slope of grain very significant in the thicker mortice wall causing splitting of this section

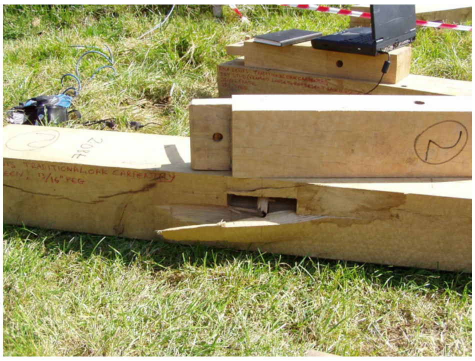

Figure 3.2

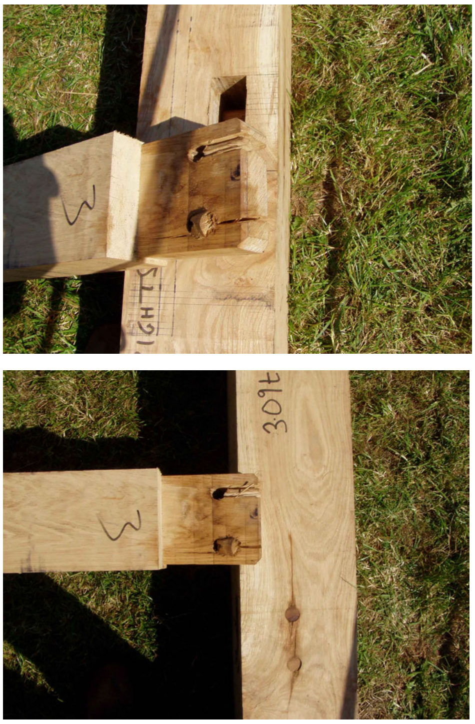

Figure 3.3

3 – Crumps; 3.18 t

Joint remained fairly stiff until approx. 2 t where the relish failed on one of the pegs. The other peg yielded soon after.

Figure 3.4

4 – Jim Blackburn; 4.05 t

As the dovetail pulled out, so to did the wedge. Pegs crushed and pulled out between m & t.

Figure 3.5

5 – COWCo.; 1.44 t

Failure mode as 1 except straighter grain in the mortice wall caused mortice wall to split but crack did not run out of the timber.

Figure 3.6

6 – COWCo.;3.13 t

As above

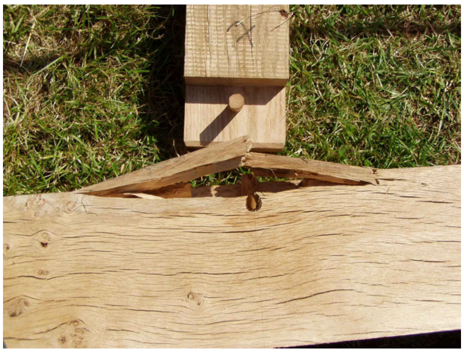

Figure 3.7

7 – Carpenter Oak; 1.61 t

Peg yielding, crushing and pulling out then mortice wall splitting. ‘Wavy’ grain led to mortice wall lifting and ‘bursting’.

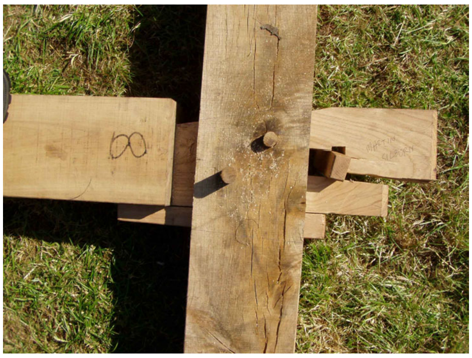

Figure 3.8

8 – Martin Silburn; 8.64 t

Very stiff connection. Brittle failure occurred in combination of tension and shear of the plane between the pegs.

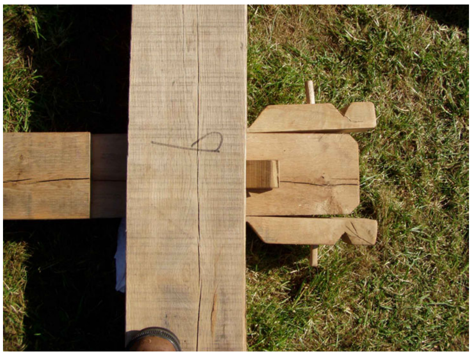

Figure 3.9

9 – COWCo.; 9.91 t

Maintained a high load for a very large displacement. Wedge in tenon pulled through between m & t. When Load released 8 x8 'beam' member split along entire length.

Figure 3.10

10 – English Oak Buildings; 1.15 t

Very similar failure as seen before. Peg yielded and pulled out between m & t.

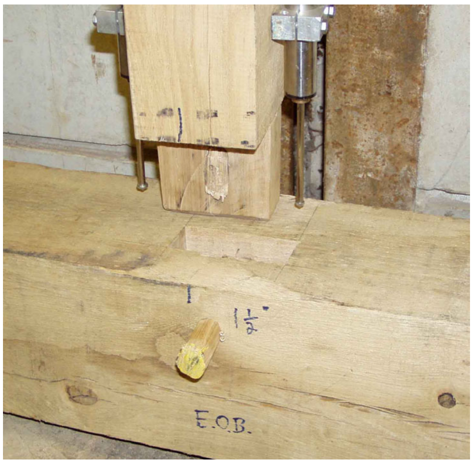

Figure 3.11

11 – English Oak Buildings; 1.20 t

Failure mode as above.

3.2 – Load/displacement graphs

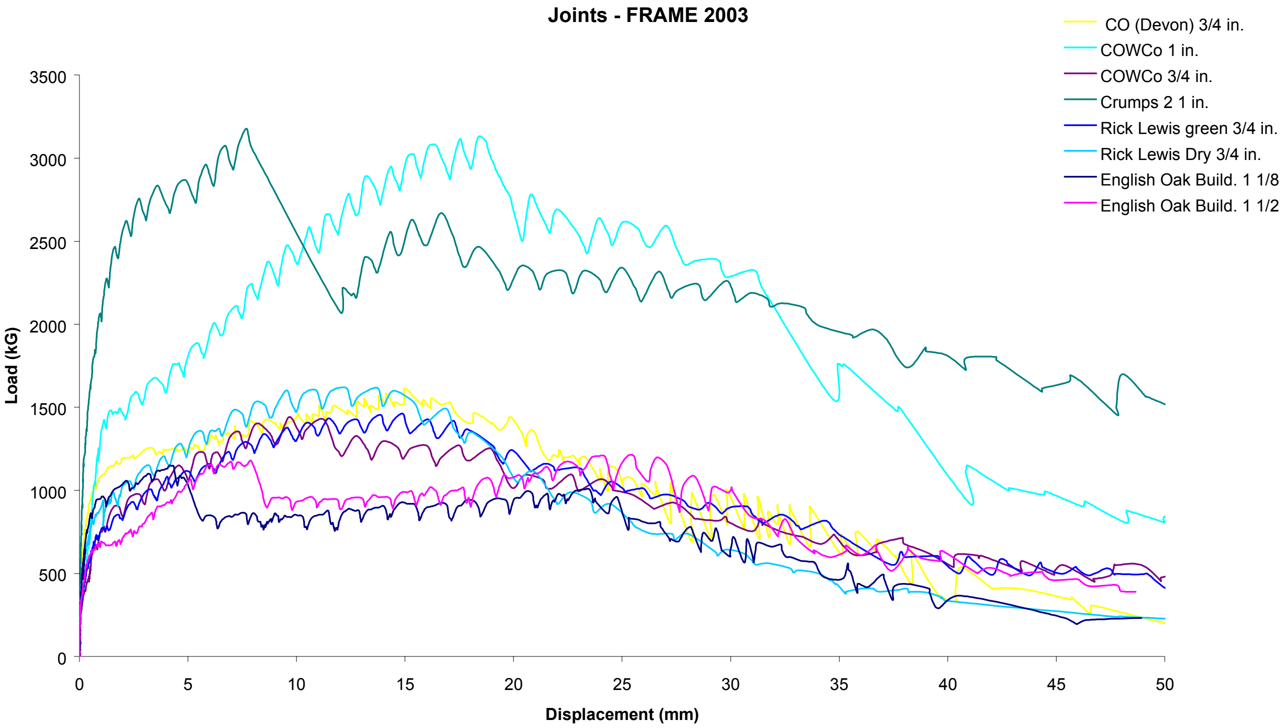

Figure 3.12 – Load/displacement graph for the pegged connections

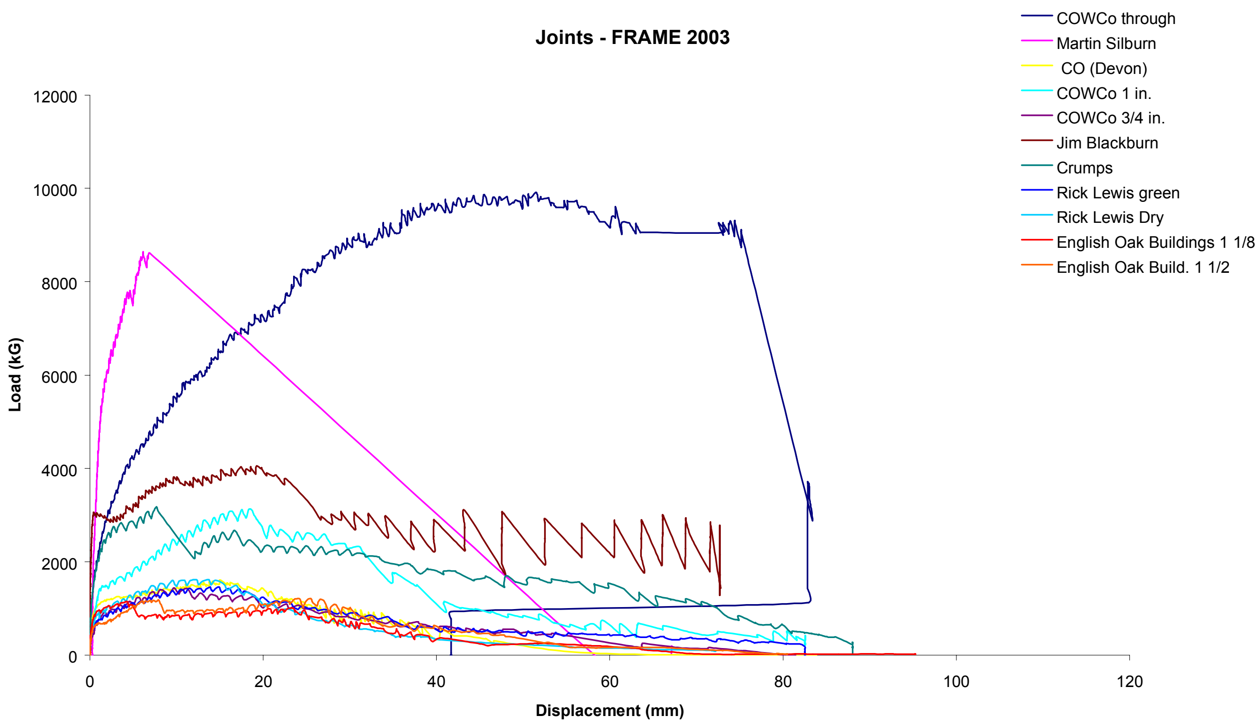

Figure 3.13 – Load/displacement graph for all eleven connections

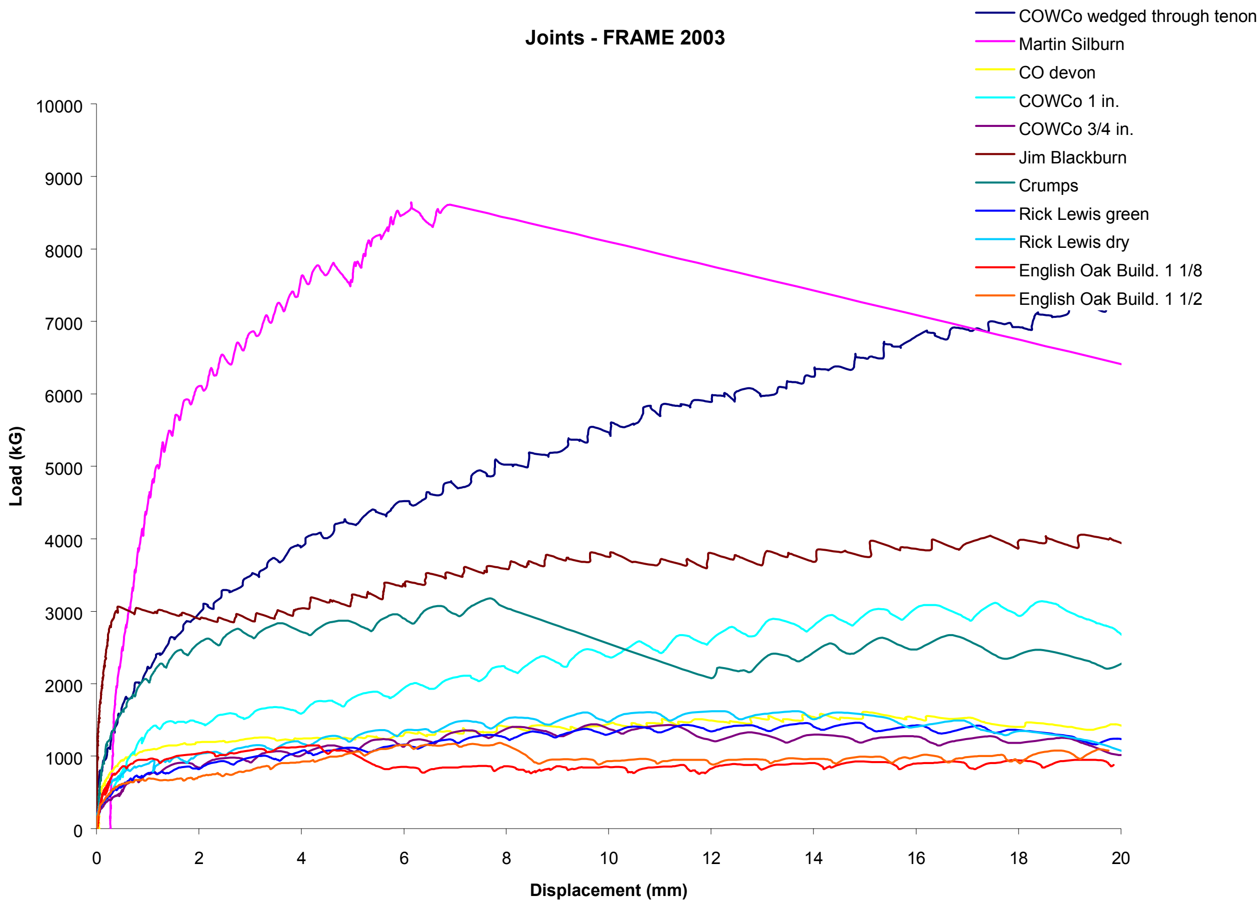

Figure 3.14 – Load/displacement graph showing initial stiffness

3.3 – Tables of Results

Table 3.1 – maximum loads and load displacement properties

Fabricator	Load at 1 mm disp	Load at 5 mm disp	Maximum 'failure' load	Disp at max load
1 – Rick Lewis	0.89 t	1.21 t	1.62 t	12.2mm
2 – Rick Lewis	0.77 t	1.11 t	1.47 t	14.9mm
3 – T J Crumps	2.04 t	2.80 t	3.18 t	7.69mm
4 – Jim Blackburn	3.00 t	3.23 t	4.05 t	19.2mm
5 – Carpenter Oak & Woodland Ltd.	0.75 t	1.07 t	1.44 t	9.65mm
6 - Carpenter Oak & Woodland Ltd.	1.38 t	1.80 t	3.13 t	18.4mm
7 – Carpenter Oak	1.09 t	1.23 t	1.61 t	15.0mm
8 – Martin Silburn	5.03 t	7.9 t	8.64 t	6.0mm
9 – Carpenter Oak & Woodland Ltd.	2.25 t	4.20 t	9.91 t	51.5mm
10 – English Oak Buildings	0.95 t	1.03 t	1.15 t	4.15mm
11 – English Oak Buildings	0.69 t	1.04 t	1.21 t	7.8mm

Table 3.2 – joints in order of stiffness (considering 1 mm displacement)

Fabricator	Load at 1 mm disp
8 – Martin Silburn	5.03 t
4 – Jim Blackburn	3.00 t
9 – Carpenter Oak & Woodland Ltd.	2.25 t
3 – T J Crumps	2.04 t
6 - Carpenter Oak & Woodland Ltd.	1.38 t
7 – Carpenter Oak	1.09 t
10 – English Oak Buildings	0.95 t
1 – Rick Lewis	0.89 t
2 – Rick Lewis	0.77 t
5 – Carpenter Oak & Woodland Ltd.	0.75 t
11 – English Oak Buildings	0.69 t

4 – Discussion

The stiffness of the joints, illustrated by the load at 1 mm displacement, is far more indicative of the performance of the connection in situ. This shows that Martin Silburn's connection would be more suitable than 9 – Peter Eyles (COWCo) even though 9 carried a higher peak load. At peak load 8 had displaced 6 mm and at the same load 9 had displaced 27 mm.

However, the other characteristic to consider is the ductility of the connections. Consider Martin's connection loaded in a frame. If the load approached the ultimate failure load (if, say, inadequate safety factors in design) then the failure would be instantaneous with no warning. This is very undesirable in structures. With this in mind, the most suitable may well be Jim Blackburn's half wedged dovetail, which exhibits a 'hardening' or stiffening after the initial loss of stiffness giving warning of impending failure.

The simple pegged connections exhibit an initial stiffness followed by a loss of stiffness, then another increase before complete failure. This behaviour is caused by the peg; initially the peg carries the load elastically, eventually the peg yields, failing in combined bending and shear. Following this the peg is pulled between the tenon and the mortice walls and effectively wedges the connection. In a structure the joint will have been deemed to have failed after the initial elastic failure.

It is worth noting that in the life of a timber frame this loading is short term loading. Under a sustained load for many years the behaviour will be different. Creep and relaxation in the timber will mean that under any given displacement the stress in the timber will reduce.

The load/displacement plots have a slight wave and are not smooth. This is due to the manner in which the load is applied. In between pump strokes the joint is allowed to relax slightly, during which time the load may well drop off.

5 - Acknowledgments

Many thanks to all who supplied the connections for the weekend of testing; Rick Lewis, T J Crumps (especially Bill), Jim Blackburn, Carpenter Oak (Devon), Martin Silburn, English Oak Buildings and especially Carpenter Oak and Woodland Co., not only for the joints at the weekend but for their continued support in the research project. Thanks to Andrew Holloway and the Green Oak Carpentry Co. for the supply of the first 20 joints in the testing programme.

Also, thanks to Pete Walker, Brian, Buro Happold and Christopher Mettem, who's support makes the project possible.

Thanks to Lui for the organisation and to Lui (again), Rick, Phil and others for the help packing away the incredibly 'mobile' rig!

See you all next year – bigger, better, stronger!

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