THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

Research on ductility of connections at Napier University, Edinburgh

Dr. Ben Zhang

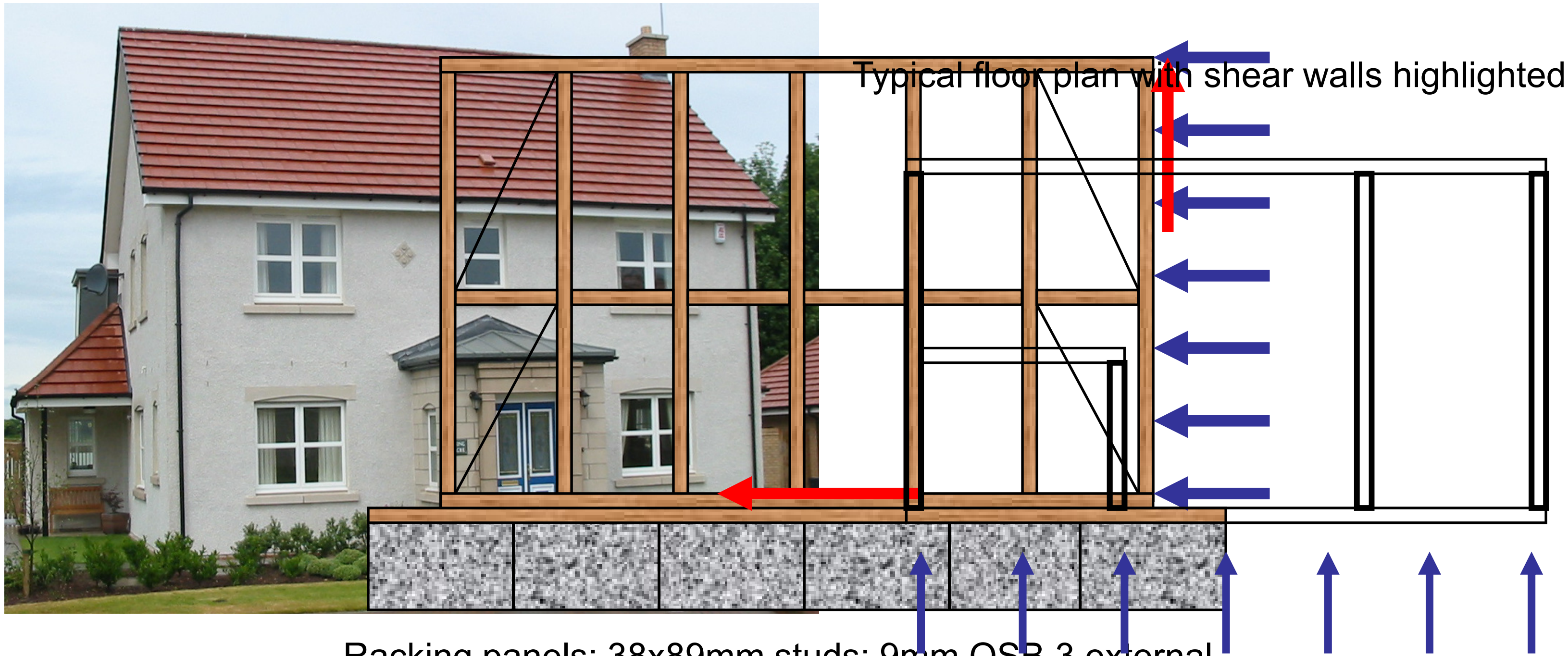
Timber Connections — Topic 1

Development of Hybrid Racking Panel System: Sole plate to substrate connection detailing — concrete/masonry-to-timber connections

Mr Kenneth Leitch et al

Industry Partners

Timber Platform Frame - Racking resistance



Typical floor plan with shear walls highlighted

Timber Frame House

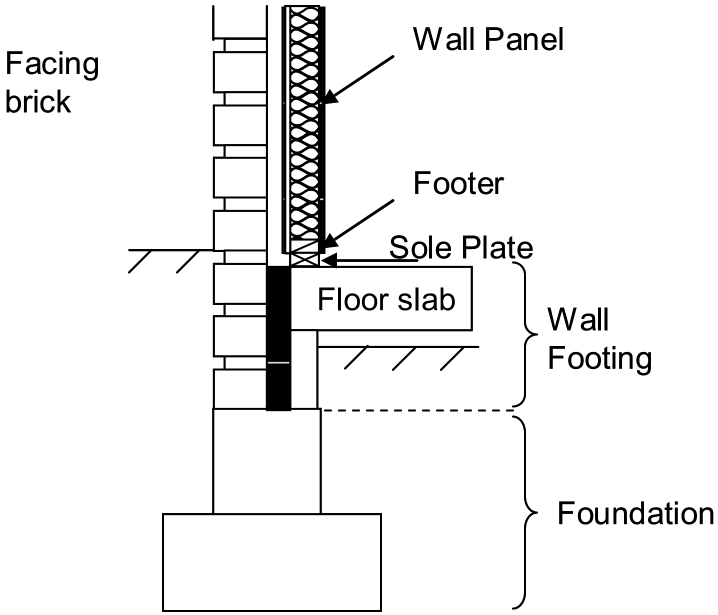
Racking panels: 38x89mm studs; 9mm OSB 3 external sheathing & 12.5mm plasterboard internally

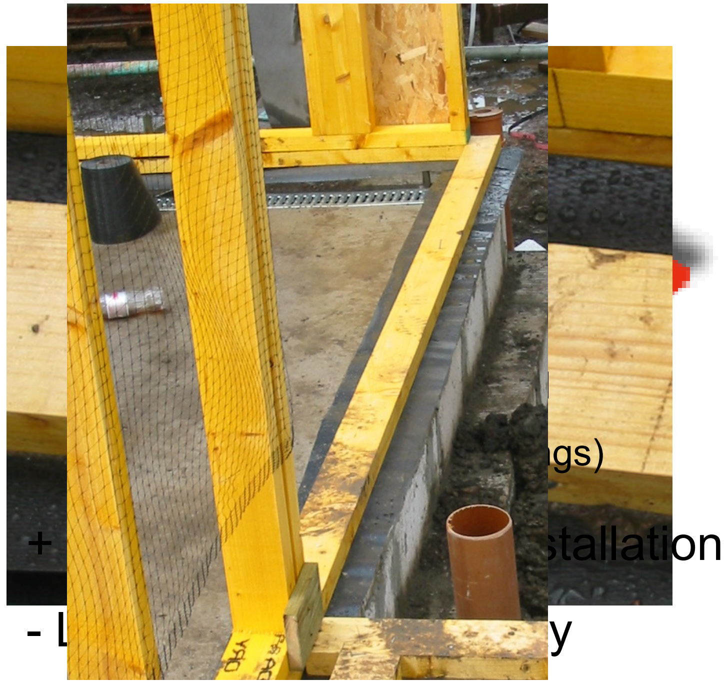
CTE
THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY
EDINBURGH

Site Practice - Soleplate connection

Improvements in Racking performance, must be matched by a robust specification of the soleplate connection.





THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

Range of industry standard fasteners tested

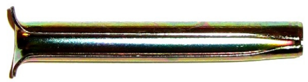
Masonry screw

MSC 36070

MSC 36082

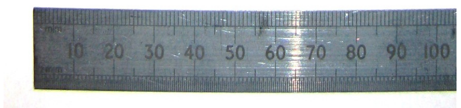
BTB4C82

KF7.5X100 — *All purpose masonry screw*



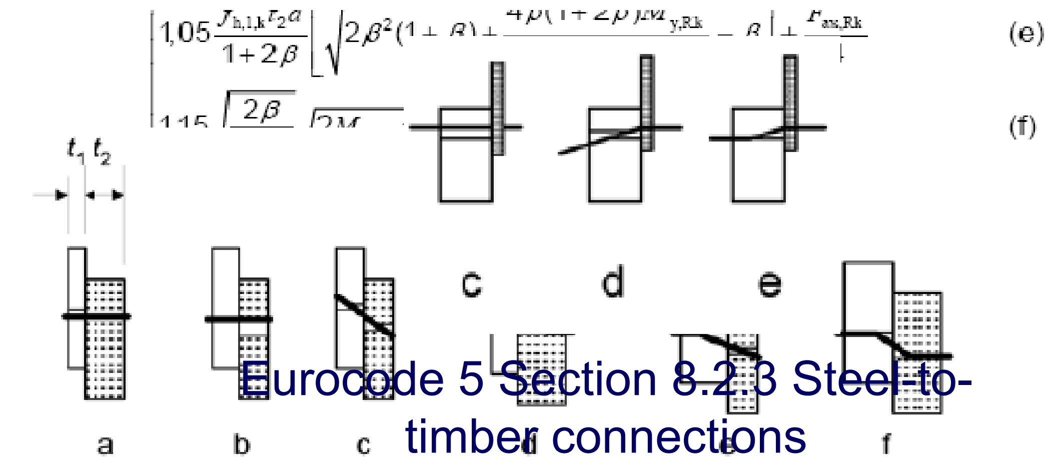
EXPN8x70 — *Express nail**

KMN72 — *Low Velocity Shot Fired Dowel*



Calculation of connection capacity as per EC5

$$F_{v,Rk} = \min \begin{cases} f_{h,k}\, t_1\, d \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,k}\, d\, t_1^2}} - 1\right] + \dfrac{F_{ax,Rk}}{4} & \text{(c)} \\ 2{,}3\sqrt{M_{y,Rk}\, f_{h,k}\, d} + \dfrac{F_{ax,Rk}}{4} & \text{(d)} \\ f_{h,k}\, t_1\, d & \text{(e)} \end{cases}$$

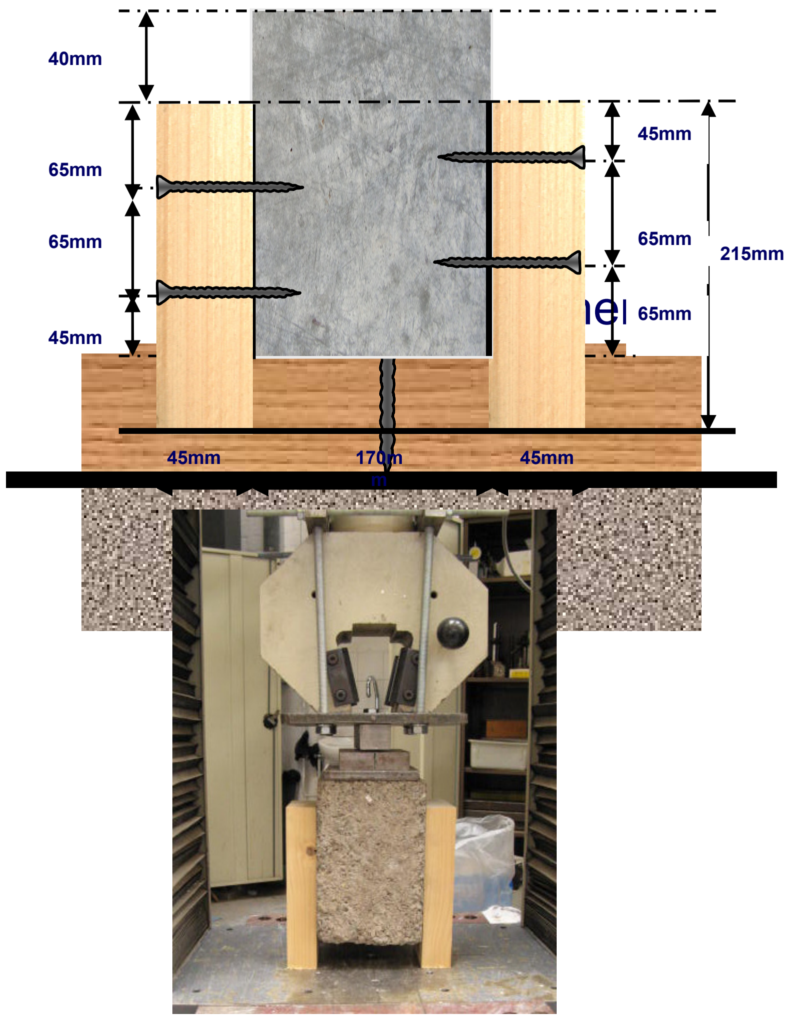


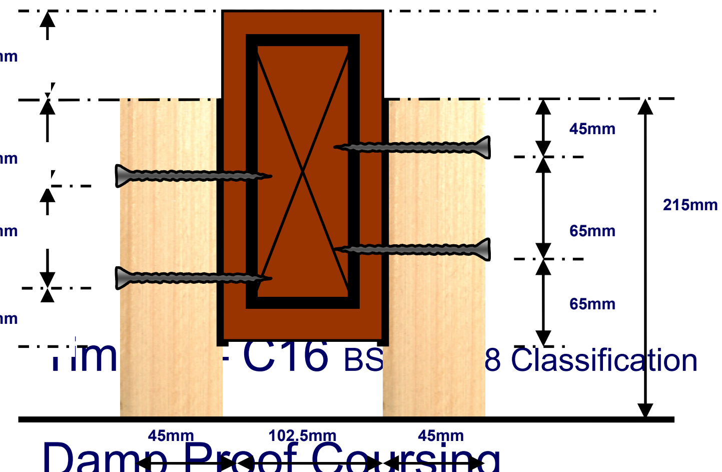
Eurocode 5 Section 8.2.3 Steel-to-timber connections

Eurocode 5 Section 8.2.2 Timber-to-timber connections

- Equation's based on Johansen's Yield theory (1949)
- Assumes that connection elements and dowel behave as rigid-plastic materials
- Allow characteristic load carrying capacity as well as failure mode of dowel type connection to be determined

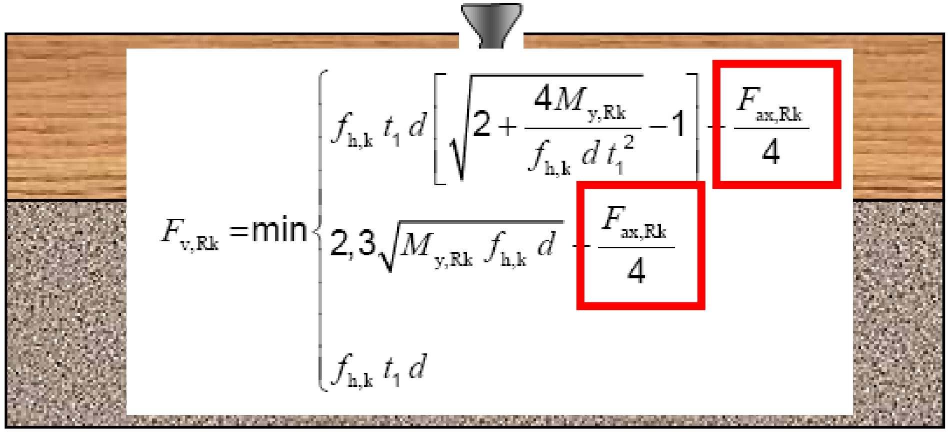
Connection composition and Test set up



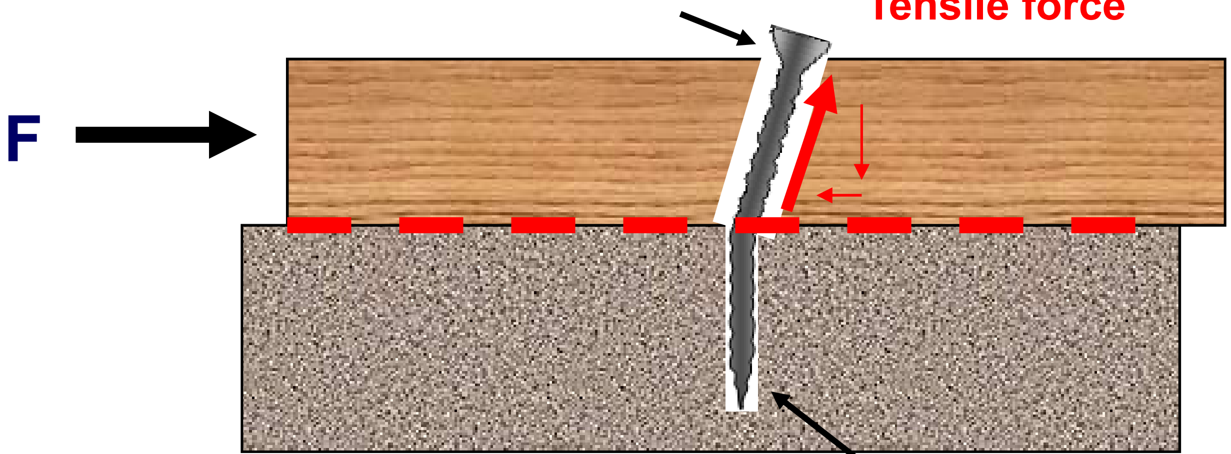


Damp Proof Coursing

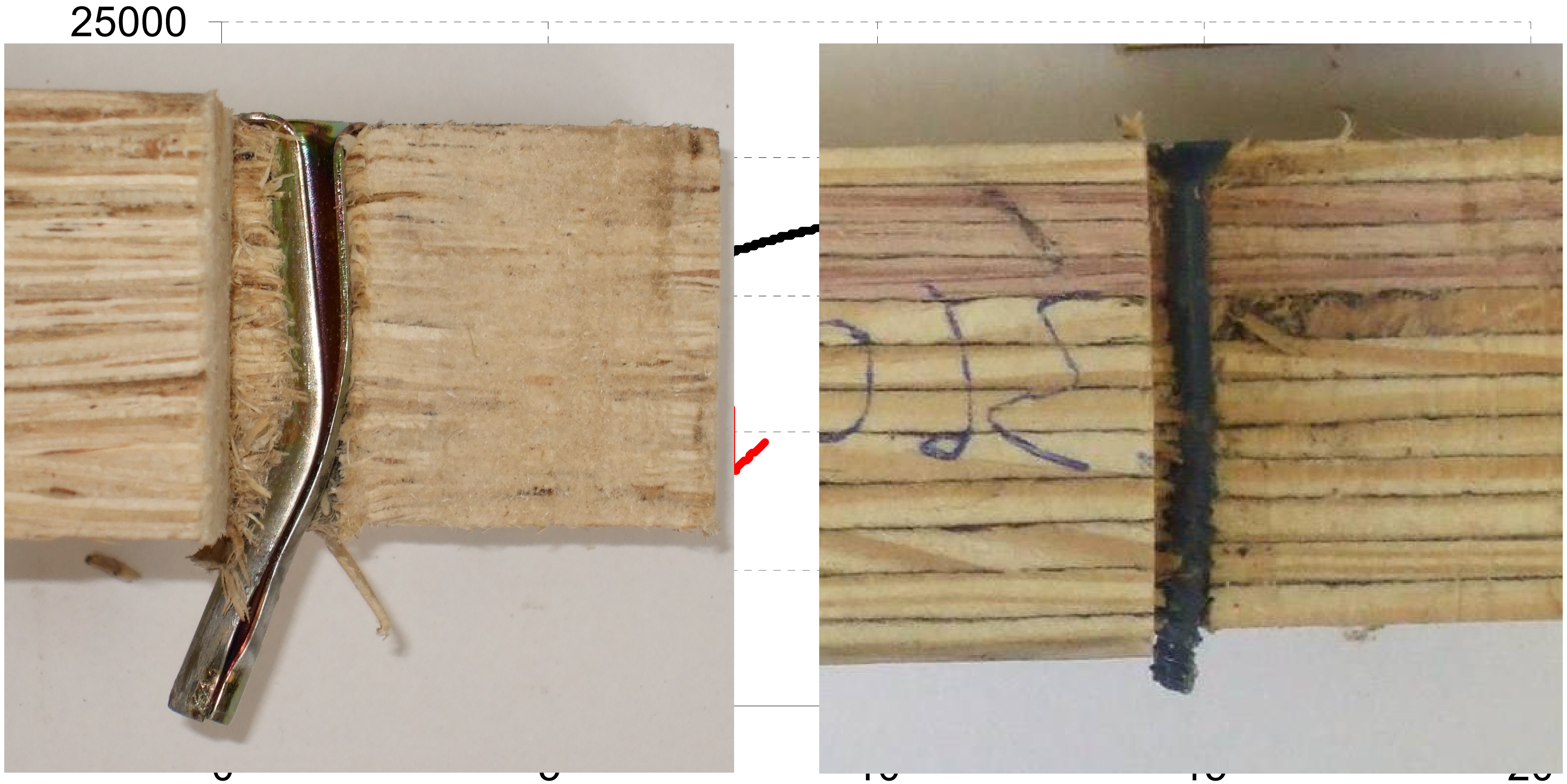
Subs … creed,
Brick



$$F_{v,Rk} = \min \begin{cases} f_{h,k}\, t_1\, d \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,k}\, d\, t_1^2}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} \\ 2{,}3 \sqrt{M_{y,Rk}\, f_{h,k}\, d} + \dfrac{F_{ax,Rk}}{4} \\ f_{h,k}\, t_1\, d \end{cases}$$



Performance of fasteners: Test results



EXPN8x70 Ductile failure

BTB4C82 Brittle failure

Remarks

- Eurocode 5 only provides the equations for timber-to-timber, panel-to-timber and steel-to-timber connections (see 8.2.2 and 8.2.3 of EC5-1-1). There are no design equations for concrete block-to-timber, masonry-to-timber, etc., connections. In particular, the strengths and elastic modulii of concrete blocks, masonry bricks, etc., are similar to those of timber.
- Much research work (analytical and experimental) need to be done on this aspect, e.g. strength, ductility and type of connectors, strength and type of concrete blocks, masonry bricks, etc.
- More design equations should be included in the existing design codes regarding this issue based on the up-to-date research results if they exist.

Timber Connections — Topic 2

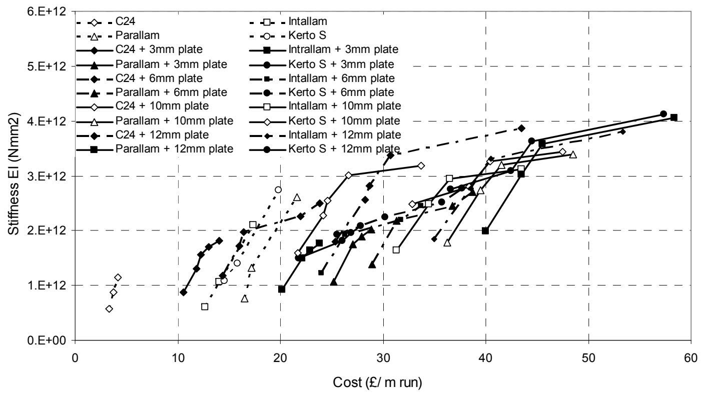
Shot Fired Dowel Flitch Beams

a) Garage door opening

b) Bay window opening

Examples of onerous load span conditions

Dr Robert Hairstans et al



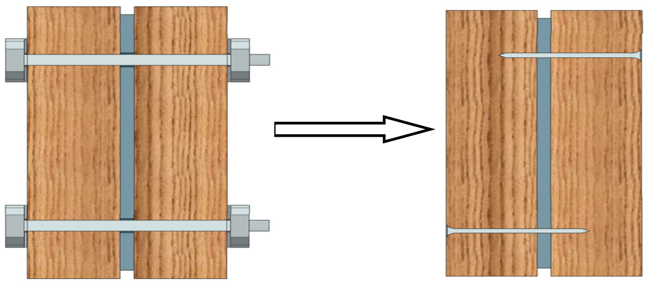
Comparison of readily available beam options

Fabrication of a bolted flitch beam

CTE THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

Method of Connection



a) Traditional bolted connection

b) Shot fired nail connection

a) Nails & cartridge

b) Machined end of nail

c) SPIT P200 Disc Cartridge Tool

Bainitically hardened nails & equipment

Strength of Connection

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} \cdot t_1 \cdot d \\ f_{h,k} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,k} \cdot d \cdot t_1^2}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} \\ 2.3\sqrt{M_{y,Rk} \cdot f_{h,k} \cdot d} + \dfrac{F_{ax,Rk}}{4} \end{cases}$$

Where

$F_{v,Rk}$ is the characteristic load-carrying capacity per shear plane per fastener;

$f_{h,k}$ is the characteristic embedment strength in the timber member;

t_1 is the smaller of the thickness of the timber side member or the penetration depth;

d is the fastener diameter;

$M_{y,Rk}$ is the characteristic fastener yield moment;

$F_{ax,Rk}$ is the characteristic withdrawal capacity of the fastener.

Strength of Connection

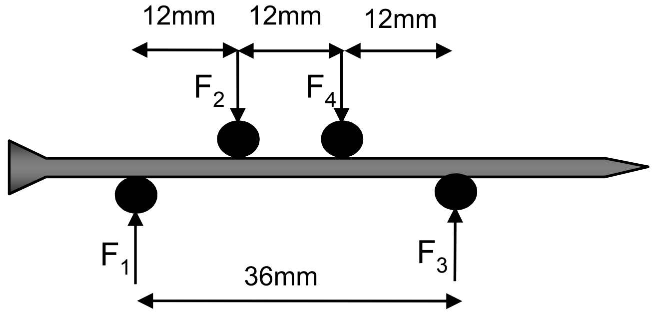
$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} \cdot t_1 \cdot d \\ f_{h,k} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,k} \cdot d \cdot t_1^2}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} \\ 2.3\sqrt{M_{y,Rk} \cdot f_{h,k} \cdot d} + \dfrac{F_{ax,Rk}}{4} \end{cases}$$

$$M_{y,Rk} = 0.3 \cdot f_u \cdot d^{2.6}$$

Where
f_u is the tensile strength
d is the nail diameter in mm

a) Yield moment equation

Or



b) Yield moment test set-up

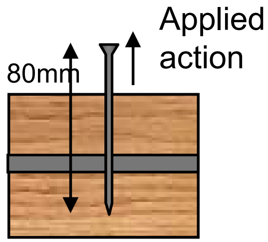
Yield moment

$$F_{ax,Rk} = \min \begin{cases} f_{ax,k} \cdot d \cdot t_{pen} \\ f_{ax,k} \cdot d \cdot t + f_{head,k} + d_h^2 \end{cases}$$

Where
$f_{ax,k}$ is the characteristic pointside withdrawal capacity;
$f_{head,k}$ is the characteristic headside pull through strength;
d is the nail diameter as defined in EN 14592;
t_{pen} is the pointside penetration length;
t is the thickness of the headside member;
d_h is the nail head diameter

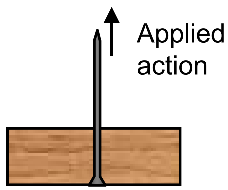
a) Withdrawal equation

Withdrawal

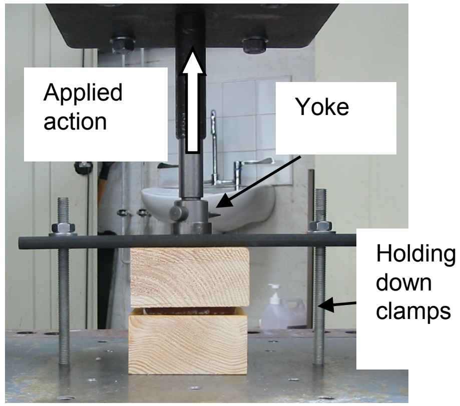


b) Pull out test specimen

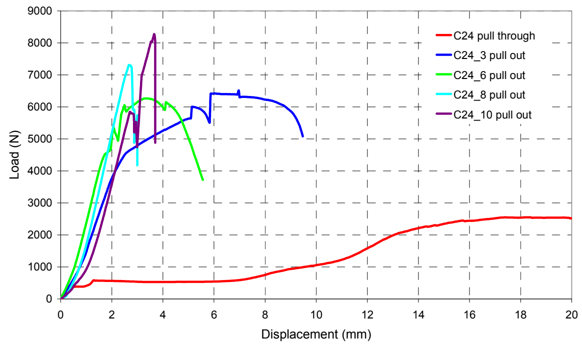
Or

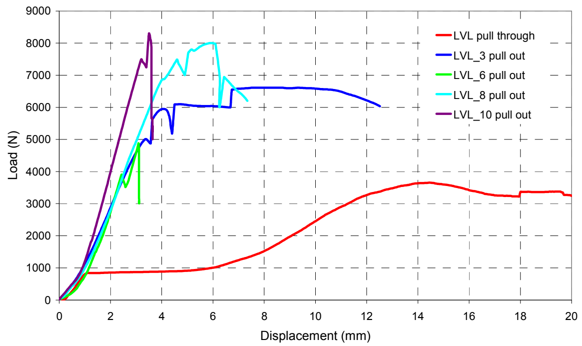


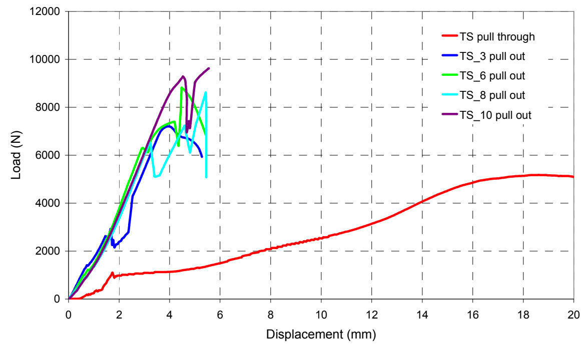
c) Pull through test specimen



d) Pull out test set-up





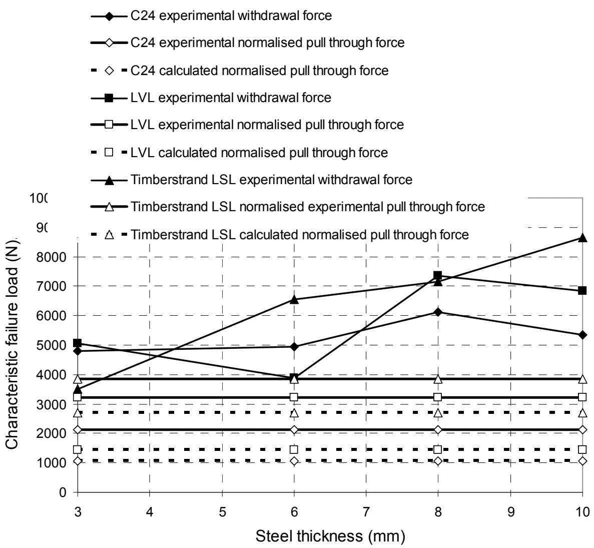


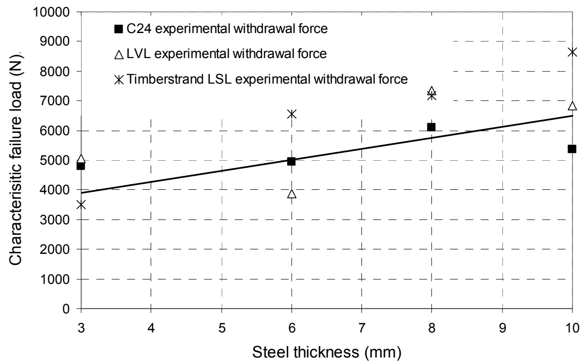
a) C24

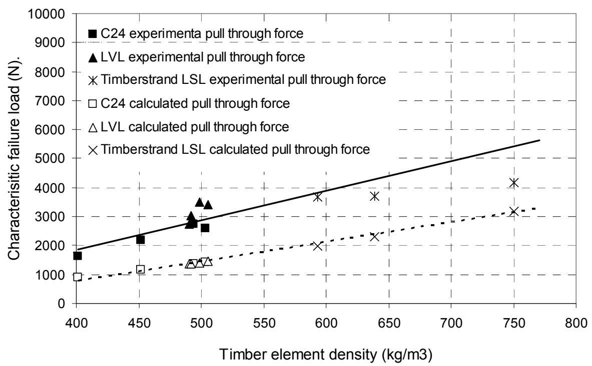
b) LVL

c) Timberstrand LSL

Pull out and pull through load against displacement curves







a) Characteristic withdrawal and headside pull through force relationship with steel thickness

b) Characteristic withdrawal strength relationship with steel thickness

c) Characteristic withdrawal strength relationship with timber density

Comparison of experimental and calculated axial load carrying capacity

THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

Results discussion

- The formation of a cold weld increases the withdrawal strength of a shot fired dowel connection..
- Pull out is for the majority of cases greater than pull through (3mm steel and timberstrand LSL the only exception).
- The general trend is an increase in withdrawal strength with plate thickness.
- In all cases the experimental withdrawal strength of the connection is greater than the calculated headside pull through strength.

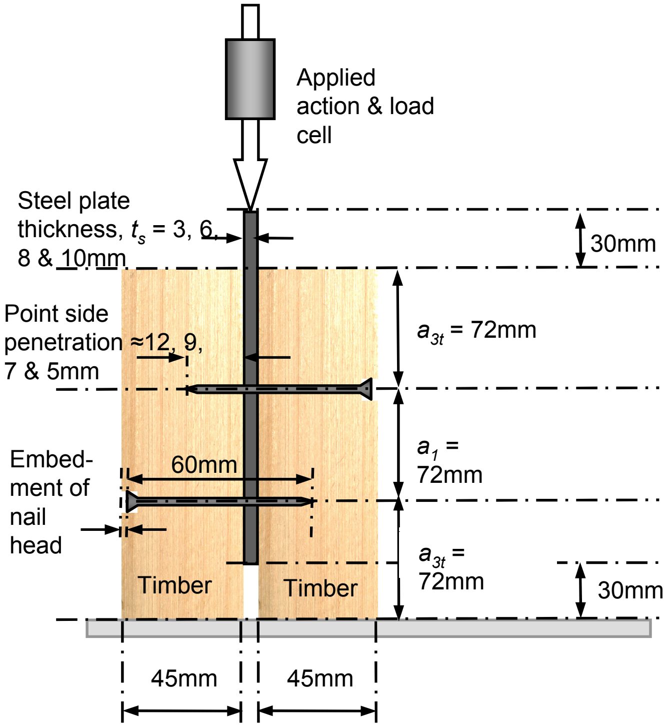
THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

Lateral Load Carrying Capacity

During the lateral load tests the applied load and corresponding displacement was measured using a data logger for each test set which are as designated:

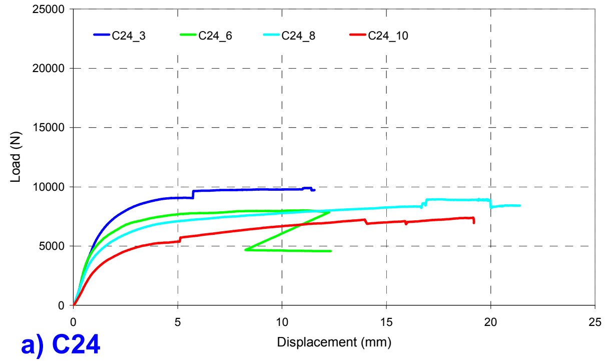
- C24_3, 6, 8 &10 – C24 grade timber with 3, 6, 8 and 10mm steel.
- LVL_3, 6, 8 &10 – LVL timber element with 3, 6, 8 and 10mm steel.
- TS_3, 6, 8 &10– Timberstrand LSL timber element with 3, 6, 8 and 10mm steel



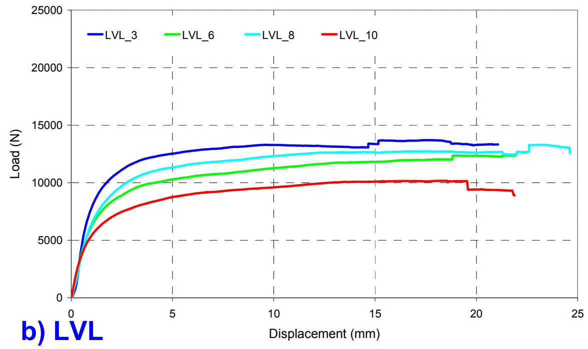
a) Details of lateral shear sample

b) Sample being tested

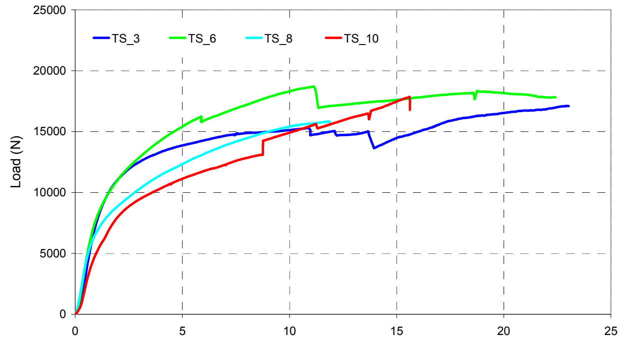
Lateral load test sample and set-up



a) C24



b) LVL



c) Timberstrand LSL

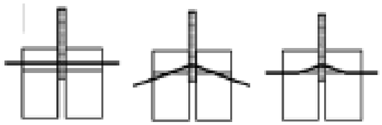
Lateral load - displacement curves

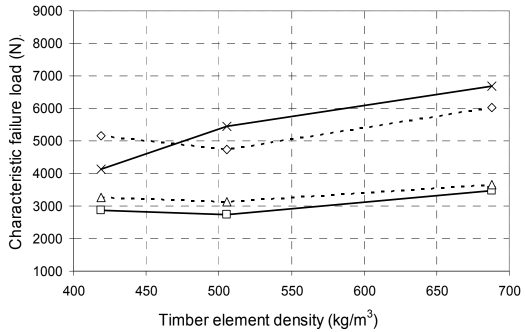
THE CENTRE FOR TIMBER ENGINEERING

NAPIER UNIVERSITY EDINBURGH

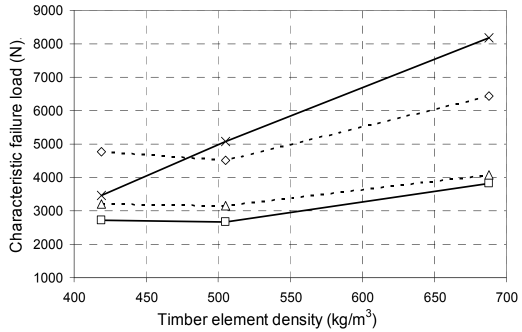
Lateral Load Carrying Capacity

FvRkf — FvRkg — FvRkh — Experimental

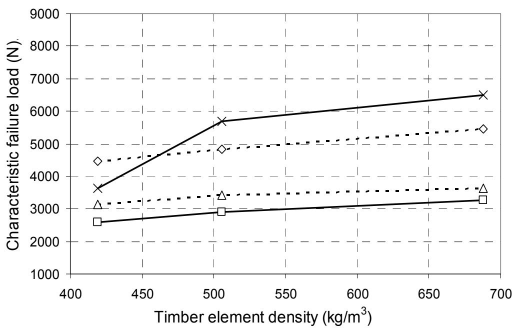




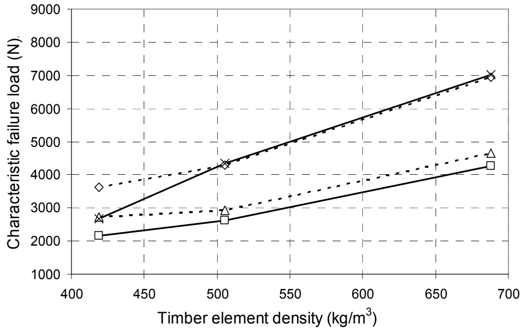
a) 3mm thick steel plate



b) 6mm thick steel plate

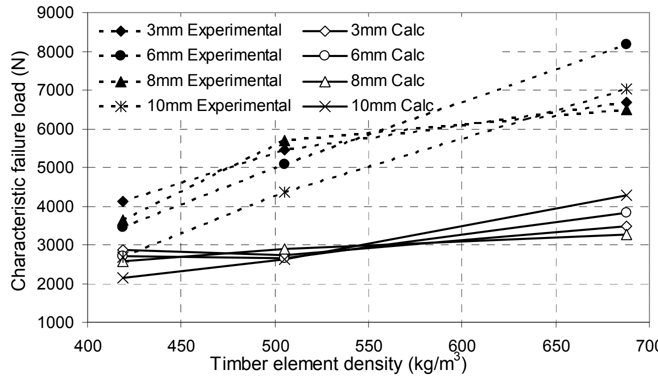


c) 8mm thick steel plate



d) 10mm thick steel plate

Comparison of EC5 calculated results to experimental results for varying timber density (Test yield moment & full fixing embedment have been used for the calculated results)



Variation in characteristic failure load with timber element density

a) Bending failure of fixing in C24 flitch connection

b) Shear failure of fixing in LVL flitch connection

c) Shear failure of fixing in Timberstrand LSL flitch connection

Examples of laterally loaded shot fired dowel connection failures

Remarks

From the experimental work carried out the following is concluded:

- It is recommended that calculated lateral load carrying capacity is determined taking the test determined yield moment of the fixing and taking the full fixing embedment depth.
- In the order of highest to lowest connection strength, shot fired dowel flitch beam connections are listed as follows; Timberstrand LSL, LVL and C24 grade timber.
- The improved strength of Timberstrand LSL connections is as a result of two key factors:
  - the higher density of Timberstrand LSL which relates directly to improved embedment strength
  - the reduced level of splitting due the nature of the material.
- The results from the C24 grade timber section flitch connection show a high level of correlation with the calculated failure mode h which corresponds to the formation of a plastic hinge at the steel timber interface.
- Comparison of the results from the engineered wood composites (LVL and Timberstrand LSL) tests to the calculated failure mechanisms provides further indication of the level of conservatism. According to Equation 6.1 mode g is the critical failure mode. However, in both engineered wood cases the experimental results have a higher degree of correlation with mode f, which is the highest predicted failure mode.