

DEVELOPMENT OF DESIGN PROCEDURES FOR TIMBER CONCRETE COMPOSITE FLOORS IN AUSTRALIA AND NEW ZEALAND PART 2 – CONNECTION CHARACTERISATION

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1 Introduction

The approach adopted for design of timber concrete composite (TCC) floor systems in Australia and New Zealand is based upon extensive testing of the permitted connection types that are specified in the design procedures, identifying strength, serviceability stiffness and so called ultimate stiffness characteristic properties that are required for utilisation of the “Gamma coefficients” method, which manipulates properties of the concrete member in order to predict the cross-section characteristics of the structure. This paper presents an overview of testing undertaken to date and the derivation of characteristic properties (5th percentile for strength and 50th percentile or average for stiffness).

2 Background

An extensive (literature) review of shear connectors used in timber concrete composite structures, covering the period from 1985 to 2004, has been undertaken by Dias (2005). Elsewhere, Ceccotti (2002) also presents an overview of the timber-concrete connectors which are most commonly used to achieve composite action between the concrete and the timber members (Figure 1).

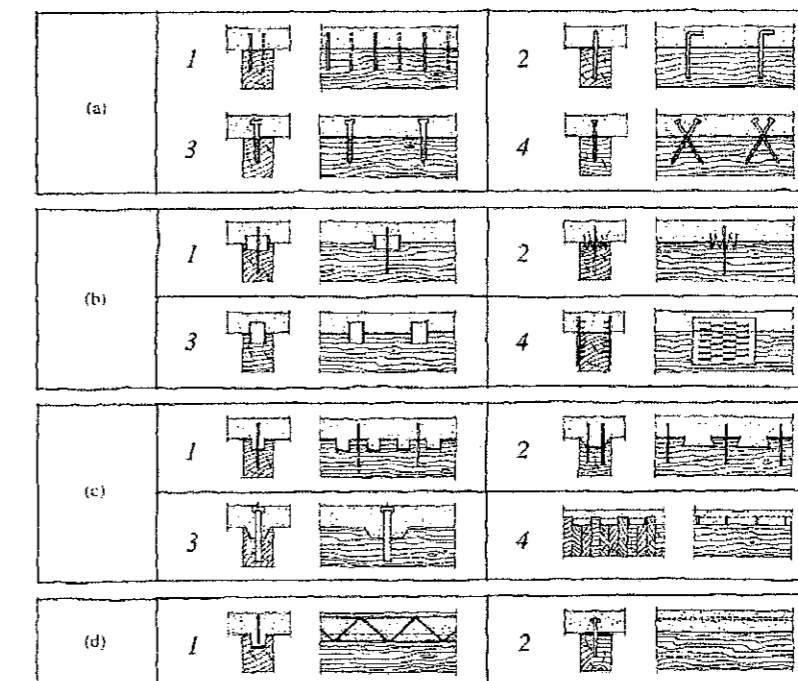


Figure 1 - Examples of TCC connections (Ceccotti 2002)

Notes on Figure 1:

(a1) nails; (a2) glued reinforced concrete steel bars; (a3, a4) screws; (b1, b2) connectors (split rings and toothed plates); (b3) steel tubes; (b4) steel punched metal plates; (c1) round indentations in timber, with fasteners preventing uplift; (c2) square indentations, with fasteners preventing uplift; (c3) cup indentation and prestressed steel bars; (c4) nailed timber planks deck and steel shear plates slotted through the deeper timber planks; (d1) steel lattice glued to timber; (d2) steel plate glued to timber.

The stiffness characteristics of some the shear connectors presented in Figure 1 are plotted in Figure 2. The load-slip plot in Figure 2 indicates that for this group of connector types, the stiffest connections are those in group (d), while the least stiff are in group (a). Connections in groups (a), (b) and (c) allow relative slip between the timber element and the concrete member, that is, the cross-sections do not remain planar under load – and the strain distribution is not continuously linear in the composite cross-section. Only connections in group (d) exhibit a planar behaviour, corresponding thus to fully composite action between timber member and the concrete slab. It can be assumed that TCC structures assembled with connectors from group (a) achieve 50% of the effective bending stiffness of TTC systems constructed with connectors from group (d) Ceccotti (1995).

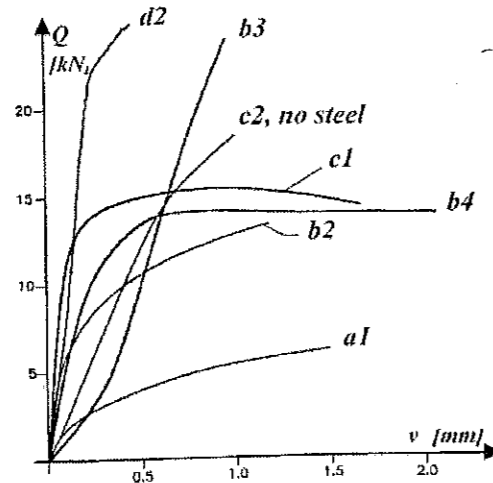


Figure 2 - Schematic of load-slip behaviour of types of connection (Ceccotti 2002)

3 Scope of Testing Program

An extensive experimental investigation has been carried out on shear connections for TCC floors using small scale specimens. The tested connections have been developed over a period of time between 2007 and 2010 and therefore the experimental investigations involved a number series of tests and have been divided more appropriately into different test phases. Experimental study in each phase looked at different connection type which was either an improvement over a preceding test series or investigation on completely new connection type. Details and results for each of the phase are presented elsewhere (Shestha et al 2010).

A number of different types of shear connections were fabricated and tested, including:

1. Nail plates
2. Nail plates with wood screws
3. Nail plates with notch
4. Square notch (with and without coach bolts)
5. Trapezoidal notch (with and without coach bolts)

6. Bird mouth notch (with and without coach bolts)
7. Batten
8. Tri-angled notch (with and without coach bolts)

Typical details for the bird's mouth notched connection are shown in Figure 3.

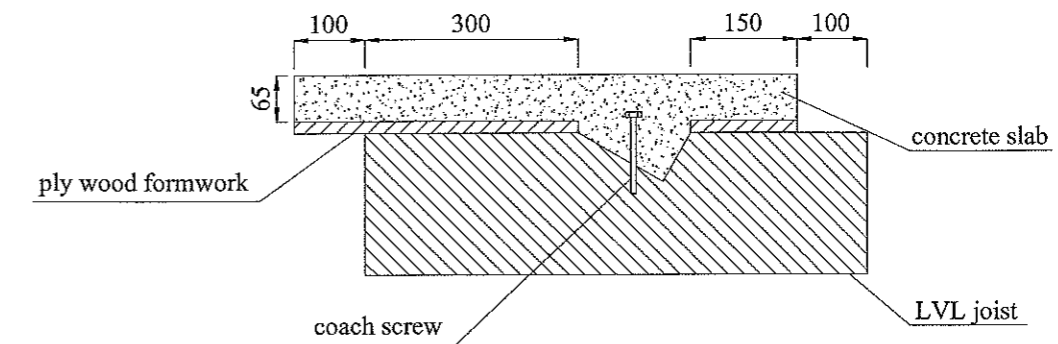


Figure 3- Typical geometry and components of a bird's-mouth shear connection

Analysis of the results from these tests led to the conclusion that the most promising connection types were the trapezoidal and bird's mouth notched connections, with coach bolts. Subsequently, a further study of 100 connections was undertaken in 2010, details of which are summarised graphically in Figure 4.

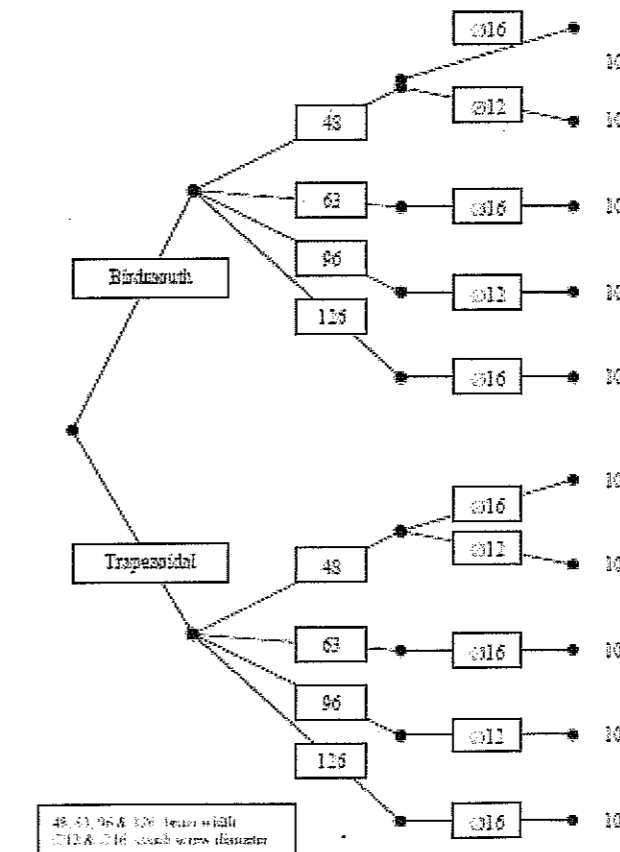


Figure 4- Overview of 2010 research plan for notched connections

Analysis of the test results for this final series of tests has led to the development of the characteristic design properties presented in Part 1 of this paper.

4 Testing Protocol

There are two types of tests that are normally used to study the properties of shear connection and to verify analytical and/or numerical models excluding the consideration of withdrawal test for a dowel-type connection – the shear test and the bending test. The shear test (also called slip test or push out test) can have two types of configurations – either symmetrical or asymmetrical. The asymmetrical configuration has the merits of saving time and cost as concrete is cast on one side of timber beam only. However, there can be an overestimation of strength and stiffness of the connection tested due to the reaction that tends to close any gap that is caused by an eccentric loading force (van der Linden 1999). This can be minimised by appropriate restraint of the specimen to ensure that any eccentric effects are negligible.

The tests on all shear connections in the current study were carried out using an asymmetrical push out test and details of the test rig and setup are presented in Figure 5.

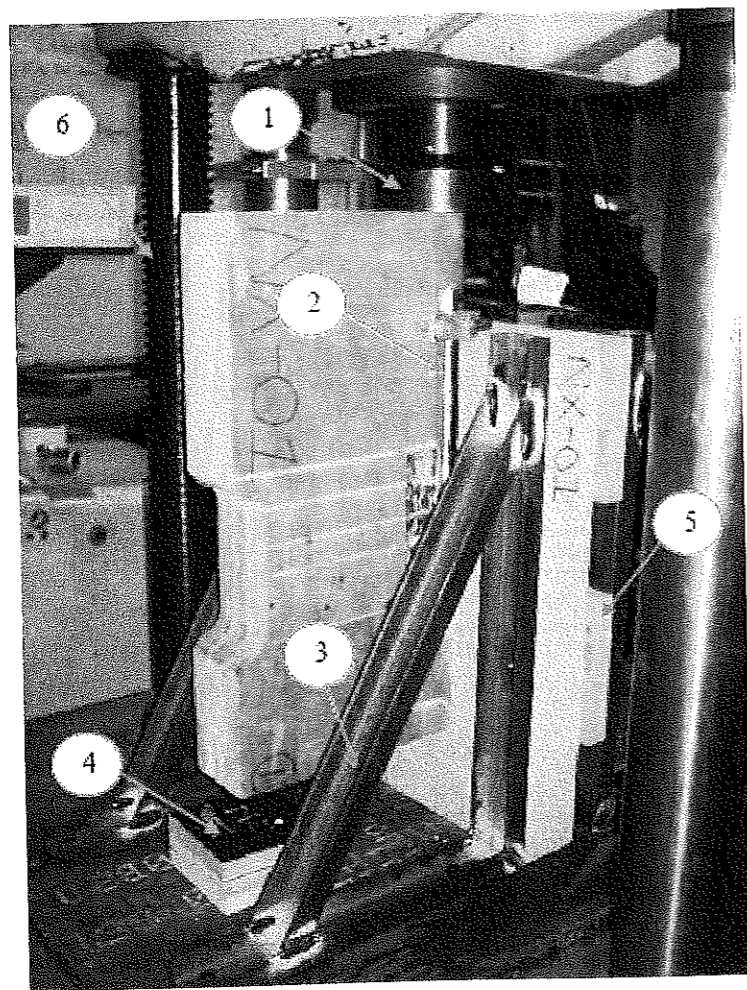


Figure 5 - Setup of a test specimen in the test rig

Notes

1. Spherical seating for loading – top edges were aligned to negate any eccentricity
2. Two LVDTs were screwed onto both sides of the LVL.
3. Steel test rig
4. Several ply boards were placed underneath the LVL to prevent it from causing any damage during the collapse of the specimen.
5. Timber blocks were used to secure the specimen in position during loading.
6. Screw column

4.1 Loading procedure

The loading procedure in European Standard EN26891 described by Dias (2005) and shown in Figure 6 was closely adopted for all tests. The load is applied in following steps.

1. The load is applied until about 40% of the estimated failure load. This stage is normally completed in about two minutes.
2. The load is maintained at this intensity (about 40% of the estimated failure load) for about 30 seconds.
3. The load is released until about 10% of the estimated failure load. This stage aims to last about one and a half minute.
4. The load is maintained at about 10% of the estimated failure load for some 30 seconds.
5. The load is (re-)applied until failure of the specimen. The loading rate should be close to the initial loading rate.

The reason for loading in this way was to eliminate any internal friction in the connections. This is essential to ensure that when the specimen is tested to failure, it does not fail due to initial slip or slack in the connection. A typical test would take approximately 10-15 minutes (600-900 seconds) to complete.

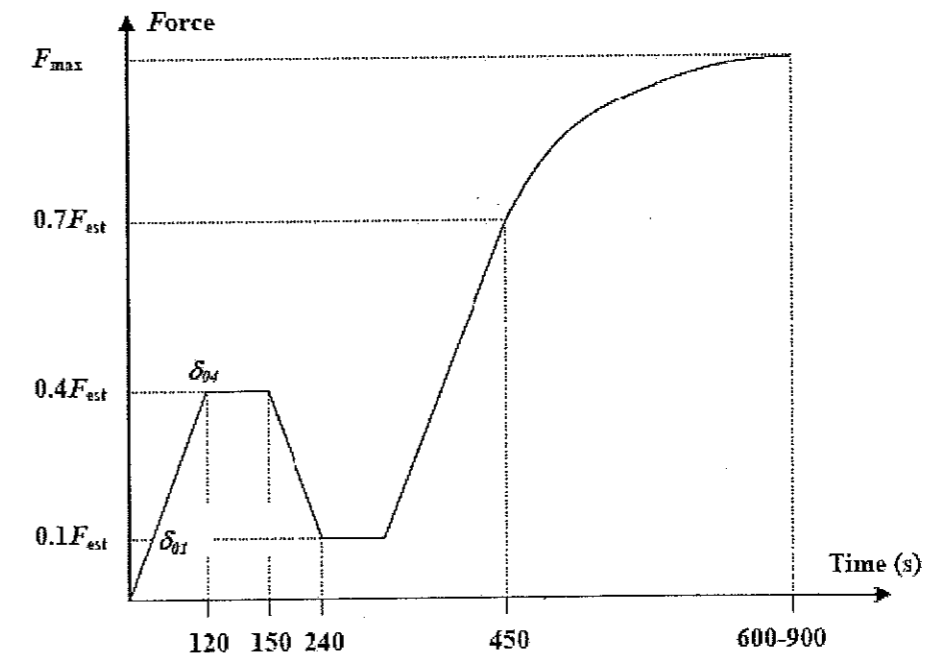


Figure 6 - Loading regime as per EN 26891 (BSI - 1991)

4.2 Test criteria

The behaviour and effectiveness of the tested shear connections were assessed based on their strength (failure load or maximum load), stiffness and failure mode. The strength of the connection specimens was defined as the maximum load that can be applied in the push-out tests before failure. Depending upon the failure mode, the connection specimens may have some load carrying capacity following the maximum load resulting in a ductile behaviour. The failure modes were therefore carefully documented in all tests. The connection stiffness or slip modulus, which represents the resistance to the relative displacement between the timber joist and the concrete slab, is one of the key parameters that define the efficiency of a shear connection. Stiffness for the serviceability limit state (SLS) and ultimate limit state

(ULS) are essential to characterise a shear connection. The stiffness for SLS (K_{ser}) corresponds to the inclination of the load-slip curve between the loading start point (generally taken as 10% of failure load to overcome "settling in") and the 40% of the failure load. The stiffness for ULS (K_u) corresponds to the inclination of the load-slip curve between the loading start point and the 60% of the failure load. As a general rule, it can be assumed that $K_u = (2/3) K_{ser}$.

5 Test Results

The main results for both connection types (which are described schematically in Figure 7), are presented in Table 1.

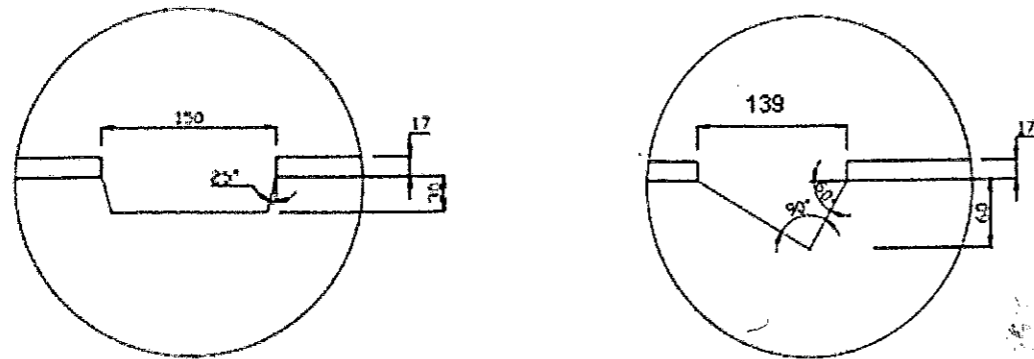


Figure 7 - Connections T3 (left) & B3 (right) - 63mm thick LVL with 16mm coach screw

TABLE 1 - Characteristic Properties of Connectors

Connection Description	Strength Q_k (kN)	K_{serv} (kN/mm)	K_u (kN/mm)
T1 - 48mm LVL, 16mm bolt	46 - 8.7%	87 - 20.5%	60 - 13.0%
T2 - 48mm LVL, 12mm bolt	46 - 6.6%	106 - 15.0%	87 - 17.9%
T3 - 63mm LVL, 16mm bolt	78 - 6.4%	109 - 19.3%	81 - 24.7%
T4 - 96mm LVL, 12mm bolt	89 - 10.0%	110 - 34.8%	93 - 39.3%
T5 - 126mm LVL, 16mm bolt	134 - 4.8%	124 - 41.3%	103 - 30.2%
B1 - 48mm LVL, 16mm bolt	55 - 8.1%	37 - 12.4%	36 - 15.2%
B2 - 48mm LVL, 12mm bolt	51 - 8.4%	115 - 48.4%	46 - 54.0%
B3 - 63mm LVL, 16mm bolt	66 - 7.7%	98 - 12.9%	74 - 27.7%
B4 - 96mm LVL, 12mm bolt	91 - 5.5%	156 - 19.8%	119 - 20.8%
B5 - 126mm LVL, 16mm bolt	120 - 11.6%	213 - 34.2%	150 - 22.7%

NOTES:

- integer = capacity; % = CoV
- Strength - 5th percentile based on a log normal distribution
- Stiffness - 50th percentile

6 Conclusions

A number of shear connections have been tested using push-out tests on full scale specimens and load-deflection plots and stiffness for these connections have been determined. Parameters such as the type of connector, shape of notches, use of mechanical anchors and concrete properties have been investigated and analysis of this data has led to number of conclusions.

- Early research showed that use of nail plates alone as shear connectors did not prove to be effective, whilst a combination of nail plates with either screws or concrete notches was more effective - especially incorporation of concrete notches.
- A number of concrete notch type shear connections were then tested such as trapezoidal, bird-mouth type and tri-angled notch and parameters such as slant angle, use of either coach screw or normal wood screw as mechanical fastener, inclination of the mechanical fastener, inclination of the slanting face and use of low shrinkage concrete were studied.
- Use of coach screws has the advantage of deeper penetration depth inside the concrete slab in comparison to normal wood screws due to their longer length. This resulted in a single coach screw providing higher shear capacity than a combination of four wood screws.
- Interesting results were obtained from the bird-mouth type connections as these connections generally exhibited higher strength and stiffness than the trapezoidal notch connections and especially so for bird-mouth connections using 70-20 and 60-30 angle combinations.
- Tri-angled notch connections were also found to be superior to the trapezoidal notch connections, however, the complex angle sequence makes such connections difficult to fabricate.
- On the other hand, bird-mouth type connections are much easier to fabricate with a simple cutting sequence and do not need special tools for fabrication. Use of a slanted coach screw configuration in the bird-mouth notch connections provided higher stiffness; however, the effect on characteristic strength was not significant, while steel plate placed on top of the coach screw did not provide any additional strength or stiffness. It should however be noted that the coach screws in the bird-mouth notch provided only limited post peak plastic behaviour when compared to trapezoidal notch connections.
- The depth of the notch has a significant effect on both the stiffness and strength of the connections. Connections with 60 mm deep notch had superior strength and stiffness compared to the connections with 90 mm deep notch. Test results also showed that widening the slot dimension had a positive effect on strength and stiffness of the connections.
- The effect of the ratio of coach screw diameter to LVL thickness is one of the parameters that needs to be further investigated. Table 1 highlights the effect of the ratio of coach screw diameter to LVL thickness and suggests that there is no advantage to using 16mm diameter screws in 48mm thick LVL beams

Whilst the variability of maximum load (strength) is considered to be acceptable, the variability of the characteristic stiffness properties highlights some of the uncertainty that is inherent in the performance of notched connections for TCC constructions. It is proposed to use the data generated to date, to refine connection performance and attempt to reduce that stiffness variability to lower levels that could lead to more efficient design of these type of floor structures.

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