Experimental Study on Shear Behaviours of Timber-Lightweight Concrete Composite Shear Connectors

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ABSTRACT

Most of the Malaysian timbers have excellent mechanical strength properties which are suitably used as the main building structure components. Some of the Malaysian timbers achieve greater strength to weight ratio than both steel and concrete. Conventionally, structural use of Malaysian timbers is limited to roof construction only. To popularize the structural use of Malaysian timbers, timber-lightweight concrete composite (TLCC) system could be used as the industrialized building system (IBS) in local building construction. Shear connector is used in the timber concrete composite structure to resist the horizontal shear force and prevent slipping between interface of timber and concrete. This research focuses on the experimental study on structural behaviour of TLCC shear connectors. A total of twelve Kempas timber-foamed concrete composite specimens consist of six types of shear connectors were tested for push-out test. S1 and S4 without nail were used as the control specimens. S2 and S5, and S3 and S6 are provided with single and double nails respectively. The push-out test results indicate that connectors with double nails achieved the highest shear capacity followed by the single nail connector while plain connectors achieved lowest shear capacity. The connectors with nails showed good ductility and achieved the higher shear capacity and stiffness compared with the control specimens.

Keywords: Timber-lightweight composite, shear connectors, push out test, ductility.

1.0 INTRODUCTION

Lateral torsional buckling is likely to occur for the unrestrained beam which will prevent the achievement of the full material strength (Way 2003). Many types of construction effectively prevent lateral torsional bucking, thereby enabling the member to be designed by considering its performance in the vertical plane only. One of the most widely used method to restraint the beam is using composite beam and slab construction. Timber-concrete composite (TCC) systems are engineered to benefit from composite action in much the same manner as steel concrete composite floor systems or reinforced concrete members (Peggi 2005). TCC offer results in a substantial improvement to stiffness and strength of the overall structure in comparison to when the materials act independently. In a TCC system, the concrete slab is designed to resist primarily compressive stresses, while the timber beam is used mainly to resist the tensile stresses.

1.1 TIMBER-CONCRETE COMPOSITE ACTION

Literally, timber-concrete beam member is an effort to combine the compressive strength behaviour of concrete with the tensile strength behaviour of timber to provide an improved composite beam (Cole 2004). A high degree of composite action is desired in layered timber-concrete beams because it leads to both reduced deflections and increased load-carrying capacity. Referring to Figure 1(a), when complete composite action is realized, the layered beam acts as a one-layer beam with mixed material properties. In this case the beam is stressed such that all or most of the concrete is in compression and all or most of the timber is in tension, depending on the depth of each material. Also there is complete transfer of stresses between the two layers on the layer interface, and no interlayer slip (relative horizontal movement) occurs. Complete composite action is the most efficient combination of the two materials in a layered beam configuration. Conversely, when the beam has no composite action (Figure 1(c)), the behaviour of the timber-concrete beam is that of an individual concrete beam deflecting on top of an individual timber beam. In this case, the concrete beam and the timber beam are both stressed in a combination of tension and compression. Furthermore in beams with no composite action, there is no transfer of stresses between the two layers but there is large relative movement of the concrete layer with respect to the timber layer, i.e. inter-layer slip occurs.

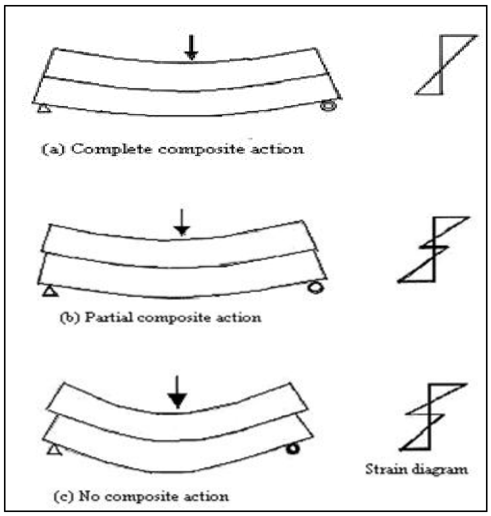

Figure 1. Composite action (Cole 2004)

Shear connectors between the layer of timber and concrete are usually provided in the TCC system to prevent slipping and enable complete or partial composite action to achieve. According to Ahmad (2005), the used of nails as shear connectors in TCC enables composite action between timber joists and cast-in-place concrete slabs, and at least a 50% saving in the cost of the timber joists compared to non composite floors. Figure 2 shows the normal stress distribution in each component of the TCC with shear connector. The concrete layer undergoes compression and bending, meanwhile the timber member undergoes tension and bending, and the connector experiences shear.

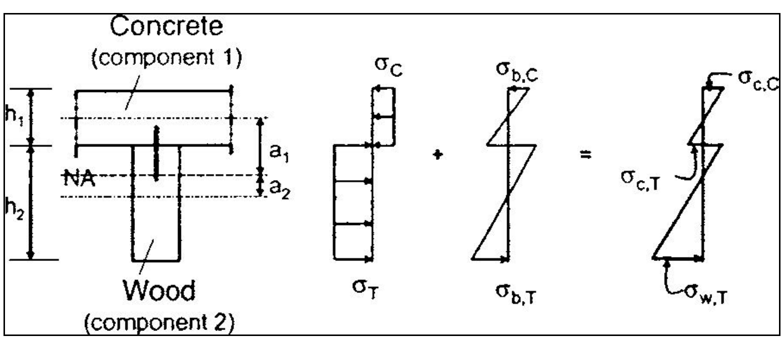

Figure 2. Stress distribution within timber-concrete composite beam (Peggi 2005)

2.0 EXPERIMENTAL PROGRAM

2.1 MATERIALS

The materials used for the timber-lightweight concrete composite (TLCC) push-out specimens are Kempas timber *(Koompassia malaccensis)*, pre-formed foamed concrete, 6 mm mild steel nails with 125 mm length, and 6 mm mild steel reinforcement. The average hardened density of foamed concrete is about 1400 kg/m^3 with the mix proportion of cement to fine sand ratio of 1:2 by weight, water/ cement ratio of 0.55 and foam/ cement ratio of 0.8 achieved an average 28 days compressive strength and tensile strength of 8 MPa and 0.73 MPa respectively. The properties of Kempas timber based on MS 544 (2001) are tabulated in Table 1.

Table 1. Wet grade stresses of Kempas timber moisture content ≤ 19%

Parameter	Properties N/mm^2
Bending Parallel To Grain	18.3
Tension Parallel To Grain	11.0
Compression Parallel To Grain	19.6
Compression Perpendicular To Grain	3.33
Shear Parallel To Grain	1.97
Modulus of Elasticity (Mean)	17,700

2.1 TLCC SPECIMENS AND PUSH-OUT TEST SETUP

A total of twelve Kempas timber-foamed concrete composite specimens consist of six types of shear connectors (Table 2) were made and tested for push-out test. S1 and S4 without nail were used as the control specimens. S2 and S5, and S3 and S6 were provided with single and double nails respectively. Figure 3 shows the TLCC push-out test specimen, and all the dimensions of the specimens are shown in appendix.

Table 2. Connectors of TLCC specimens

Specimen	Dimension of Connector	Description
S1A & S1B	50mm X 50mm	Without nail (Control)
S2A & S2B		Single nail per connector
S3A & S3B		Double nails per connector
S4A & S4B	50mm X 75mm	Without nail (Control)
S5A & S5B		Single nail per connector
S6A & S6B		Double nails per connector

Figure 3: TLCC Push-out test specimen

The push-out test is used to determine the shear capacity and structural behaviour of the shear connectors. All specimens were tested using 50 tones universal testing machine located at Timber Engineering Laboratory of University Tun Hussein Onn Malaysia at 28 days. The setting up of the push-up test is shown in Figure 3. Dial gauge was installed on the timber to measure the vertical displacement during the test.

Figure 3. Setting up of TLCC Push-Out Test

3.0 RESULTS AND DISCUSSION

The ultimate shear capacity average from two TLCC specimens tested using push-out test are summarised in Table 3. The plot of shear capacity versus displacement for 50 mm x 50 mm (S1, S2 and S3) and 50 mm x 75 mm (S4, S5 and S6) connectors is shown in Figure 4 and Figure 5 respectively. The test results indicate that both control specimens S1 and S4 have achieved lowest shear capacity compare with specimens with single or double nails.

The shear capacity of TLCC was increased with the number of nail provided in the shear connectors. S2 and S3 specimens have gained a higher shear capacity of 118.90 % and 178.83% respectively at the first peak, and 339.51% and 354.06% respectively at the ultimate capacity (second peak) compared with S1. Meanwhile, S5 and S6 gained a higher shear capacity of 34.71% and 56.30% respectively at the first peak, and 12.08% and 92.41% respectively at the second peak compared with S4.

Table 3. Shear Capacity of TLCC Specimen

Specimen	Size of Connector (mm X mm)	Number of Nail	Average Shear Capacity (kN)		Capacity Increment (%)	
			First Peak	Second Peak	First Peak	Second Peak
S1	50 X 50	0	10.58	-	-	-
S2		1	23.16	46.50	118.90	339.51
S3		2	29.50	48.04	178.83	354.06
S4	50 X 75	0	21.35	-	-	-
S5		1	28.76	23.93	34.71	12.08
S6		2	33.37	41.08	56.30	92.41

The shear capacity was increased with the size of connector at the first peak load. S2 achieved a significant increment of 101.80% compared with S1. However, the effect of the connector size was reduced when nails are provided. 50 mm x 50 mm shear connectors with nails achieved higher shear capacity than 50 mm x 75 mm shear connectors with nail. This phenomenon is due to the position of nails for 50 mm x 50 mm shear connectors were located nearer to the tensile zone compare with 50 mm x 75 mm shear connectors.

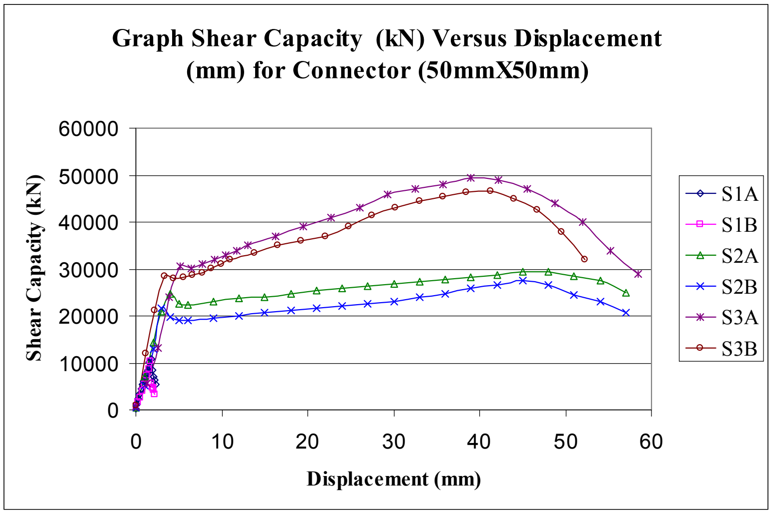

Figure 4. Shear capacity versus displacement plots of TLCC with 50 mm x 50 mm connectors

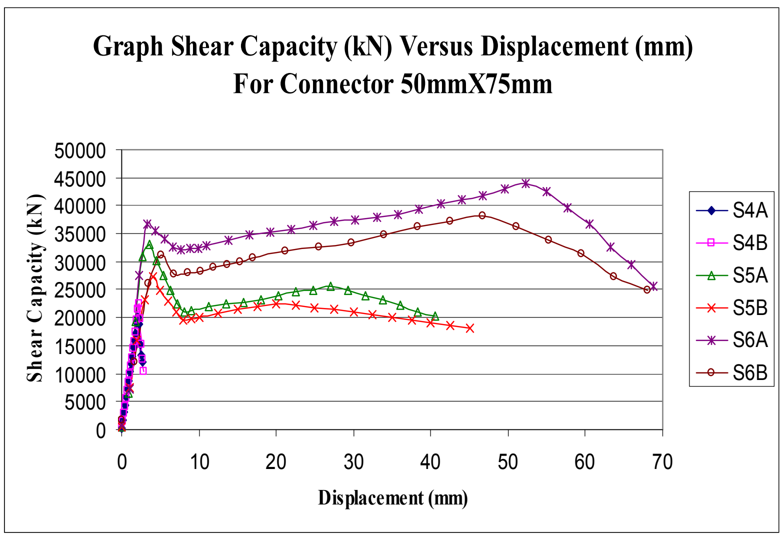

Figure 5. Shear capacity versus displacement plots of TLCC with 50 mm x 75 mm connectors

The ductility of shear connectors with nail is slightly higher than the shear connectors without nail. S1 and S4 specimens were ruptured immediately once the first peak load was achieved with a small displacement. However, S2, S3, S5 and S6 specimens underwent a large deformation after the first peak load and able to achieve another peak load before rupture. The higher ductility of shear connectors with nail is due to the nail embedded in the shear connectors that can resist the tensile load and yield after the foamed concrete achieved the maximum tensile strength. All TLCC specimens were fail at the shear connectors. Separation between foamed concrete and timber were found during the test especially for the shear connectors with nail after achieving the first peak load. Figure 6 and Figure 7 show the connectors of TLCC after testing.

Figure 6. Failure Mode of shear connector without nail

Figure 7. Failure Mode of shear connector with nail

4.0 CONCLUSION

Based on the experimental results, the following conclusions may be drawn:

1. Ductility and capacity of shear connector for TLCC have been increased by embedding the mild steel nail in the connector.

2. Position of nail affects the capacity of the connectors. The most effective location for the nail is at the tension zone.

3. The shear capacity of plain connector increased significantly by increasing the shear area of the connector.

4. Higher grade of lightweight concrete has to be used and studied for TLCC in order to exploit the full capacity of TLCC.

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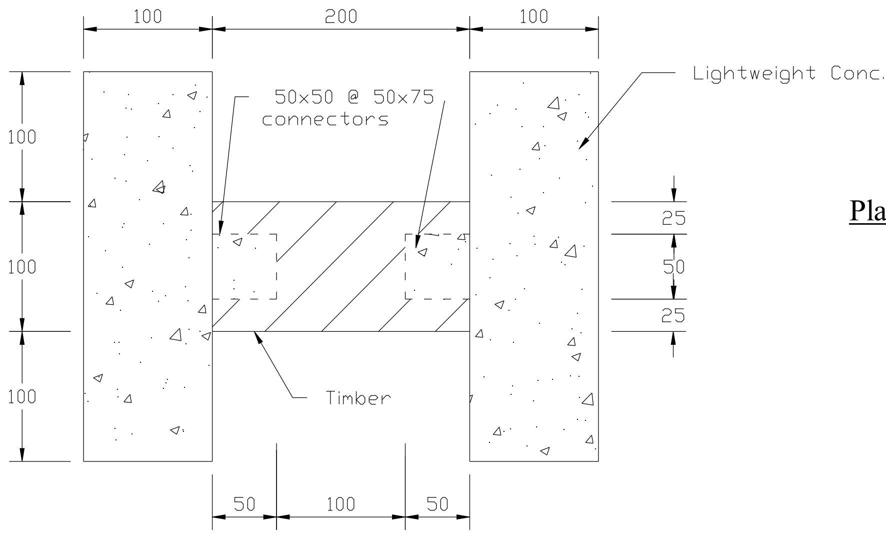
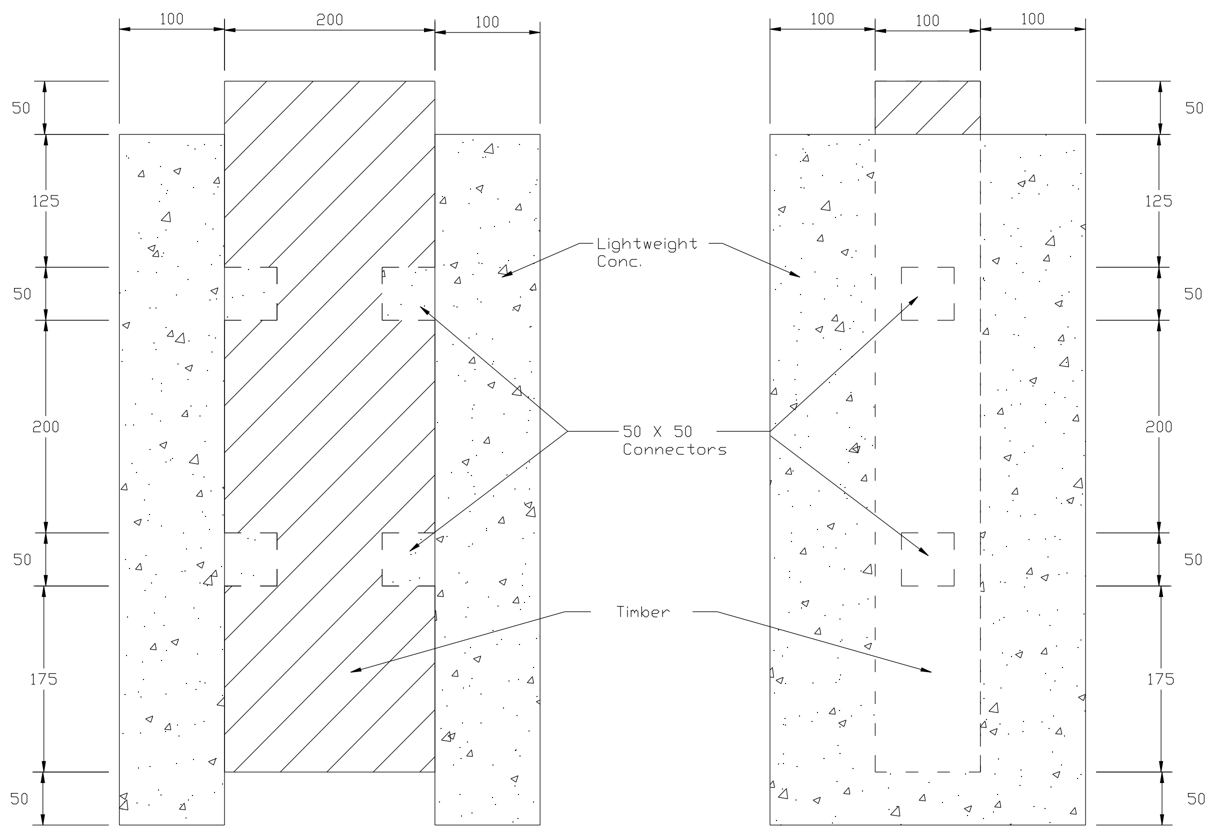
Appendix: Detail of Timber-Lightweight Concrete Composite (TLCC) Specimens



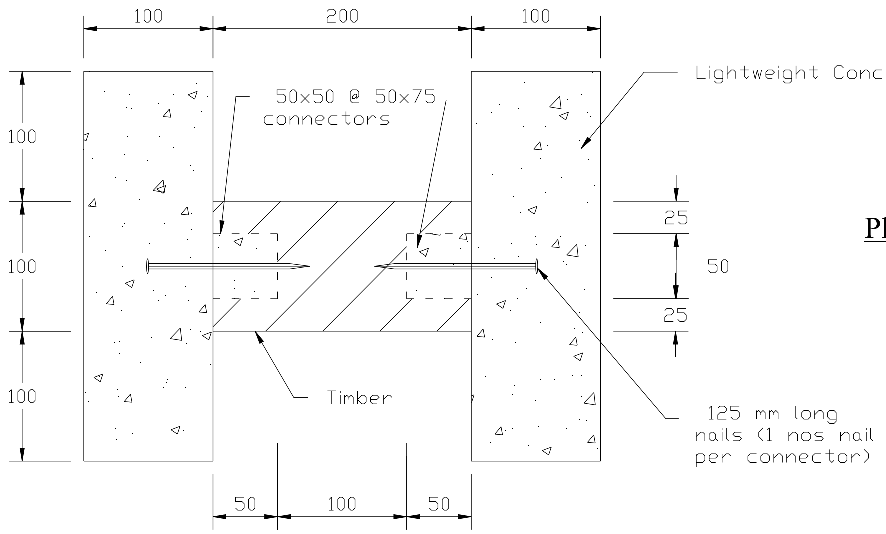
Plan View



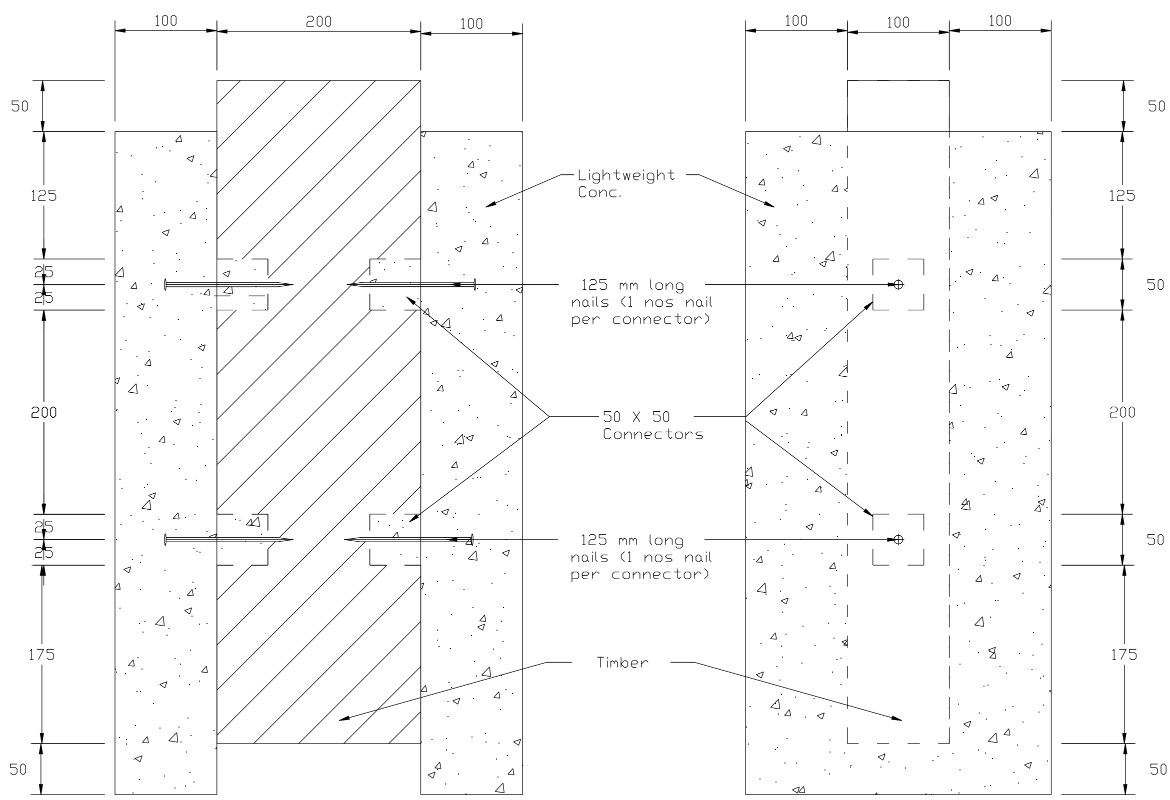
Front View

Side View

S1/S4 TLCC Specimen



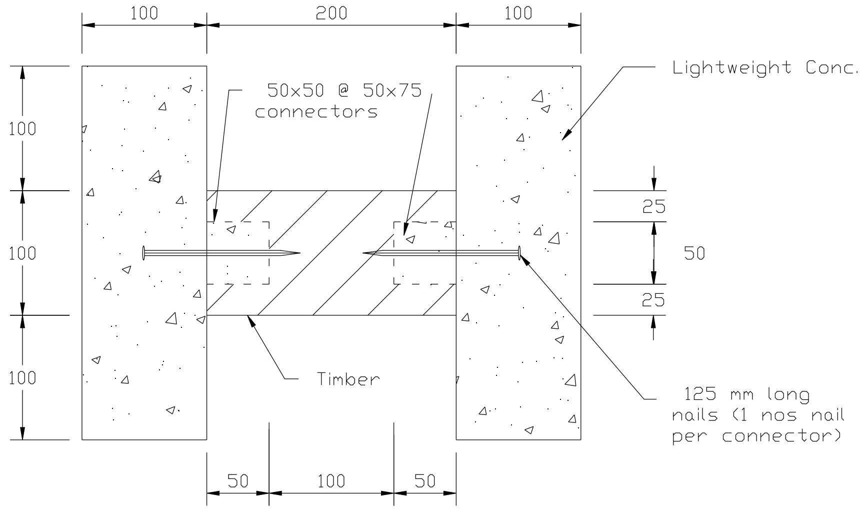
Plan View



Front View

Side View

S2/S5 TLCC Specimen



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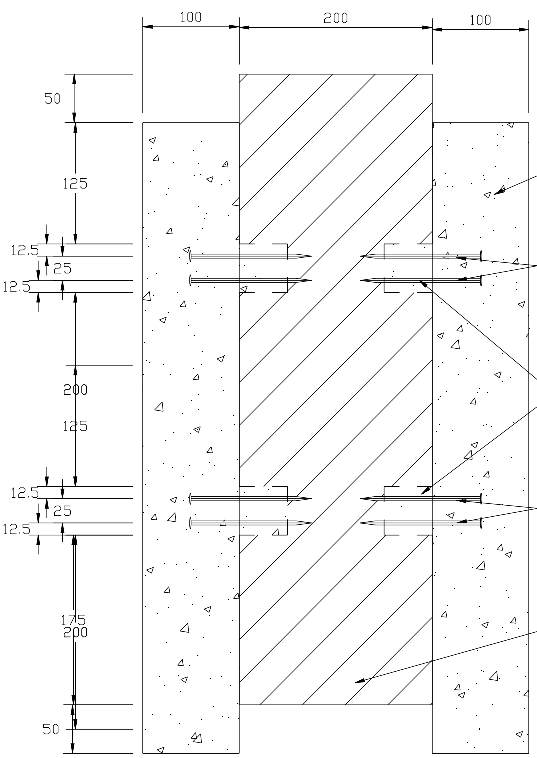
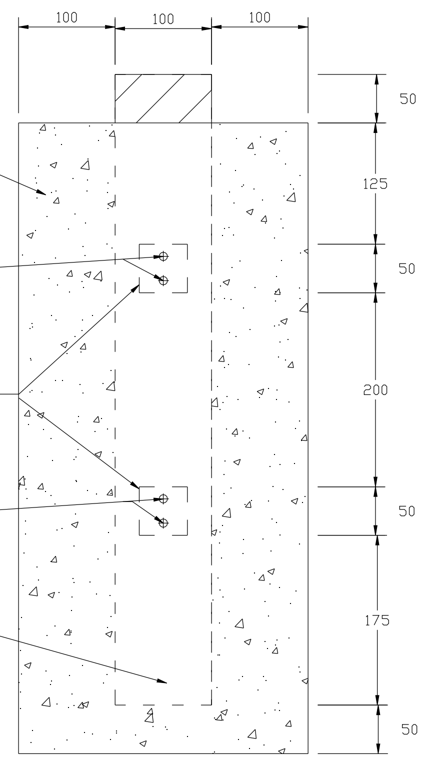


Front View



Side View

S3/S6 TLCC Specimen