CHAPTER 4

EVALUATION OF EXPERIMENTAL TEST RESULTS

4.1 General

In this chapter, push-out test results of the three configurations are presented, and those results are compared with each other.

4.2 Experimental Push-Out Test Results and Connection Behaviour

4.2.1 Experimental Push-Out Test Results

All push-out test results in each configuration are presented in Table 4.1, 4.2, and 4.3 (see Appendix for more details) with average concrete cube strength of four samples. In each configuration concrete cube strength, and concrete top cover were used as variables. In configuration 3, the position of the shear stud was changed and the steel tube tested, is below the slab (not embedded) as in configuration1 and 2.

During the analysis, mean value of each variable was considered and outliers were neglected.

Table 4.1: Configuration 1 Test Results

Specimen	Design concrete strength (Nmm^{-2})	Concrete top cover (mm)	Concrete cube strength (Nmm^{-2})	Failure load (kN)
C30-20-1-i	30	20	36.4	501
C30-20-1-ii			33.6	501
C30-20-1-iii			38.2	496
C30-25-1-i	30	25	34.5	569
C30-25-1-ii			35.3	589
C30-25-1-iii			26.8	517
C30-30-1-i	30	30	25.3	444
C30-30-1-ii			32.3	527
C30-30-1-iii			41.7	678
C20-25-1-i	20	25	32.0	501
C20-25-1-ii			32.2	428
C20-25-1-iii			30.8	574
C45-25-1-i	45	25	45.1	772
C45-25-1-ii			48.3	933
C45-25-1-iii			48.2	678

Table 4.2: Configuration 2 Test Results

Specimen	Design concrete strength (Nmm^{-2})	Concrete top cover (mm)	Concrete cube strength (Nmm^{-2})	Failure load (kN)
C30-20-2-i	30	20	43.1	730
C30-20-2-ii			38.0	845
C30-20-2-iii			45.4	626
C30-25-2-i	30	25	35.7	694
C30-25-2-ii			31.3	803
C30-25-2-iii			38.5	798
C30-30-2-i	30	30	34.2	746
C30-30-2-ii			37.9	808
C30-30-2-iii			33.8	704
C20-25-2-i	20	25	24.0	699
C20-25-2-ii			31.8	740
C20-25-2-iii			30.0	746
C45-25-2-i	45	25	47.9	704
C45-25-2-ii			46.3	626
C45-25-2-iii			40.4	652

Table 4.3: Configuration 3 Test Results

Specimen	Design concrete strength (Nmm^{-2})	Concrete top cover (mm)	Stud position	Steel tube (Filled or Empty)	Concrete cube strength (Nmm^{-2})	Failure load (kN) (one stud per rib)
C30-20-3-I	30	20	Strong	Empty	40.0	121.2
C30-20-3-ii			Weak	Empty	39.8	121.2
C30-20-3-iii			Weak	Filled	36.9	128.3
C30-25-3-i	30	25	Strong	Empty	44.3	151.1
C30-25-3-ii			Weak	Empty	37.8	131.2
C30-25-3-iii			Weak	Filled	39.2	149.6
C30-30-3-i	30	30	Strong	Empty	32.8	135.4
C30-30-3-ii			Weak	Empty	38.6	156.7
C30-30-3-iii			Weak	Filled	36.4	155.3
C20-25-3-i	20	25	Strong	Empty	27.5	149.6
C20-25-3-ii			Weak	Empty	25.0	125.5
C20-25-3-iii			Weak	Filled	31.1	168.1
C45-25-3-i	45	25	Strong	Empty	51.7	192.2
C45-25-3-ii			Weak	Empty	51.1	168.1
C45-25-3-iii			Weak	Filled	49.8	192.2

4.2.2 Behaviour of Shear Connector

Shear connectors can be classified as ductile or non-ductile. Ductile connectors are those with sufficient deformation capacity to justify the simplifying assumption of plastic behaviour of the shear connection in the structure considered. Shear-slip curves are obtained by push-out tests. Figure 2.2 shows examples of both ductile and non-ductile behaviour.

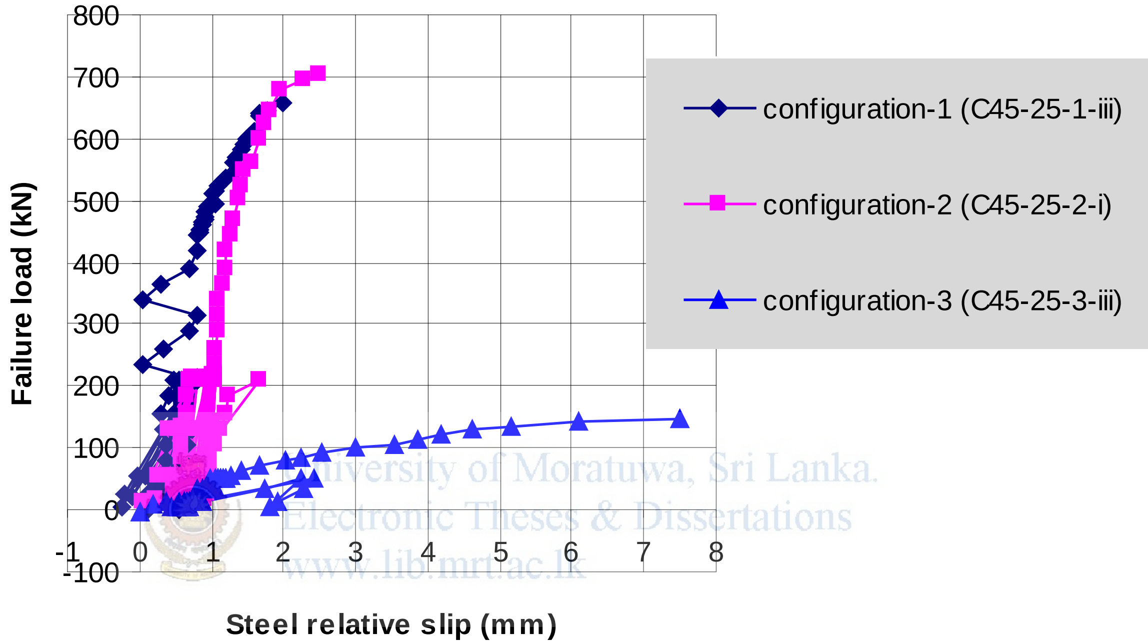


Figure 4.1: Experimental Connection Behaviour

For configuration 3 that is shear connection with headed shear studs the plots against slip, and failure load were showed Figure 2.2 (a) type behaviour. But both configurations 1 and 2 were showed Figure 2.2 (b) type behaviour. As a result of those, it can state that configuration 3 shear connection is ductile and both configurations 1 and 2 have non-ductile shear connection (see Figure 2.2, 4.1).

4.3 Effect of Concrete Strength on Shear Connectors

The effect of concrete strength on the strength of shear connectors was checked in this study and it was checked for configuration 1, 2, and 3.

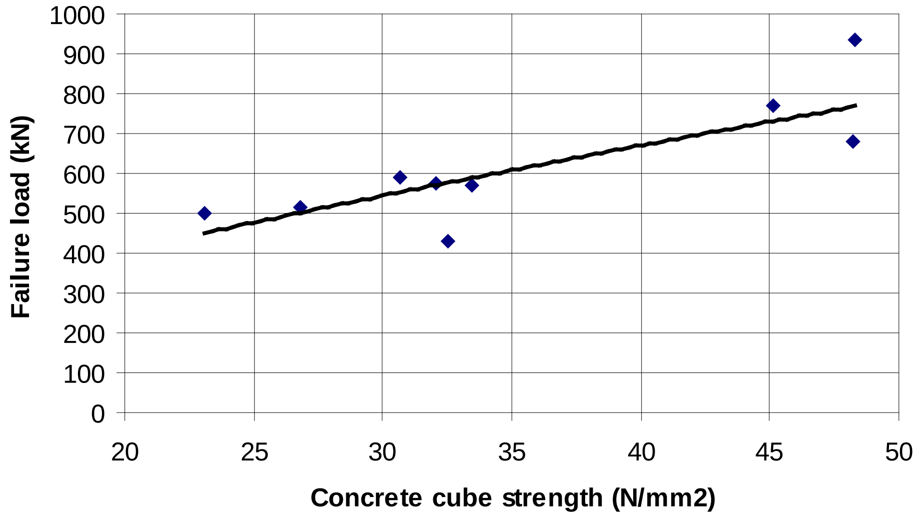


Figure 4.2: Effect of Concrete Strength on Failure Load on Configuration-1 (for concrete top cover 25mm)

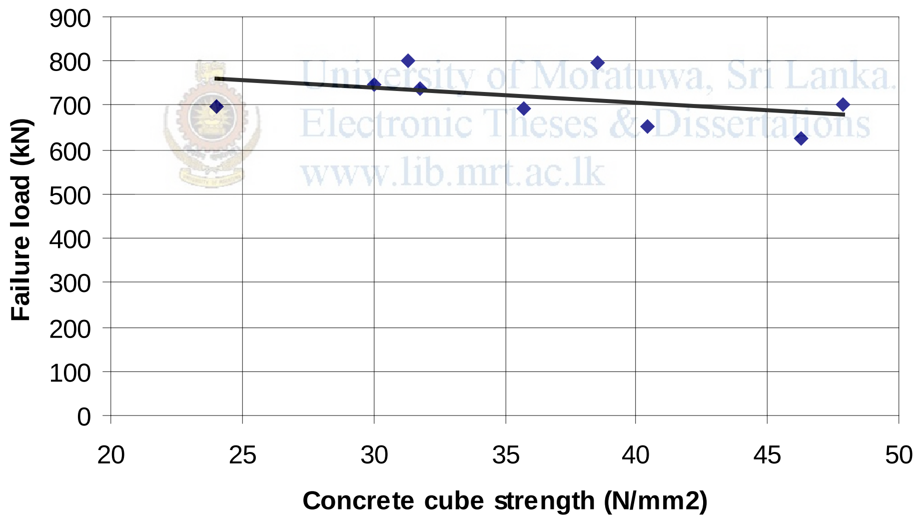


Figure 4.3: Effect of Concrete Strength on Failure Load on Configuration-2 (for concrete top cover 25mm)

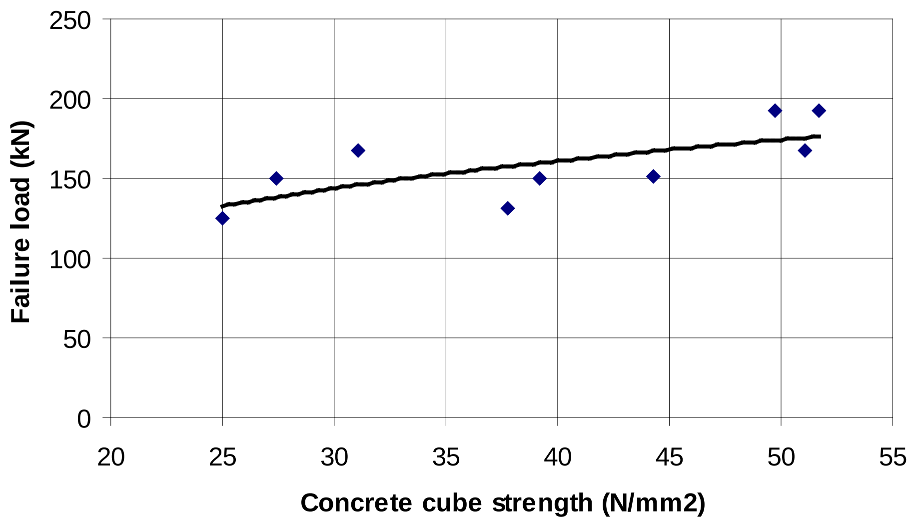


Figure 4.4: Effect of Concrete Strength on Failure Load on Configuration-3 (for concrete top cover 25mm)

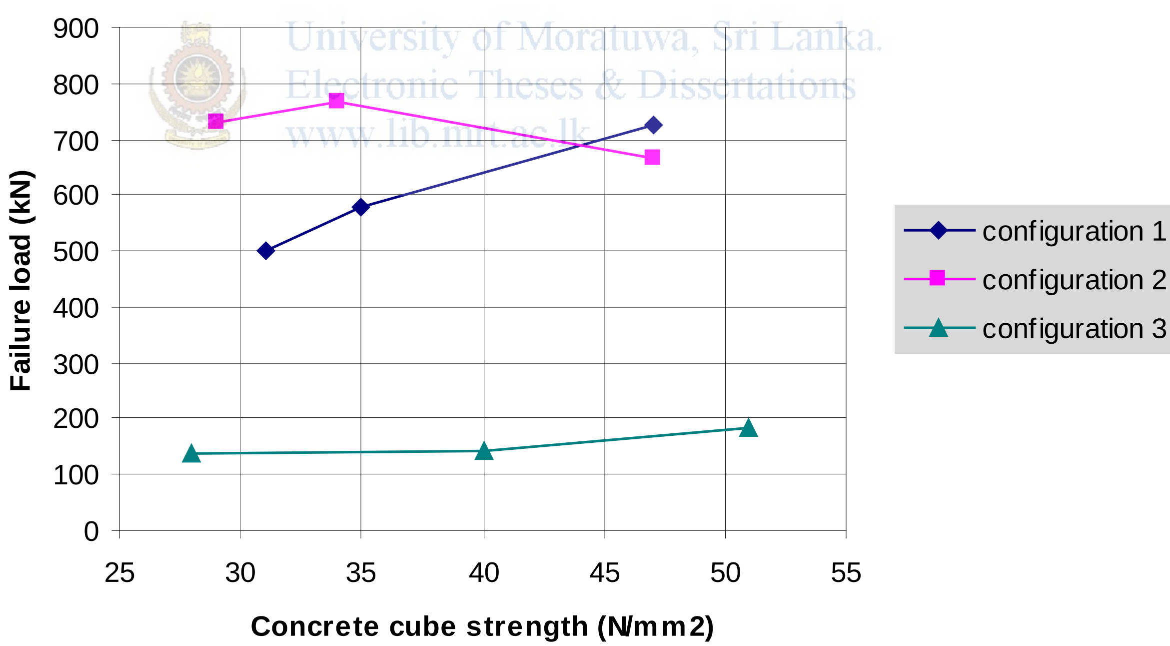


Figure 4.5: Effect of Concrete Strength on Failure Load on Different Configurations (for concrete top cover 25mm)

With configuration 1 and 3 the failure load increased with increase of concrete strength (16%- 21%, 20%- 53% respectively). It appears that there is no influence of concrete strength in configuration 2. That might be due to effective mechanical bond between concrete and shear connector (see Figure 4.2, 4.3, 4.4, 4.5).

4.4 Effect of Concrete Top Cover on Shear Connectors

The effect of concrete top cover on the strength of shear connectors was checked in this study and it was checked for configuration 1, 2, and 3.

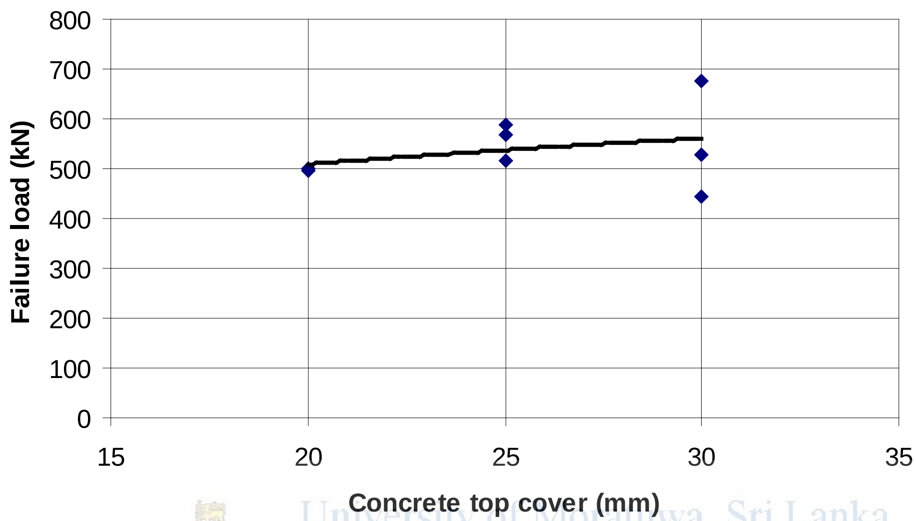


Figure 4.6: Effect of Concrete Top Cover on Failure Load on Configuration-1 (for grade 30 concrete)

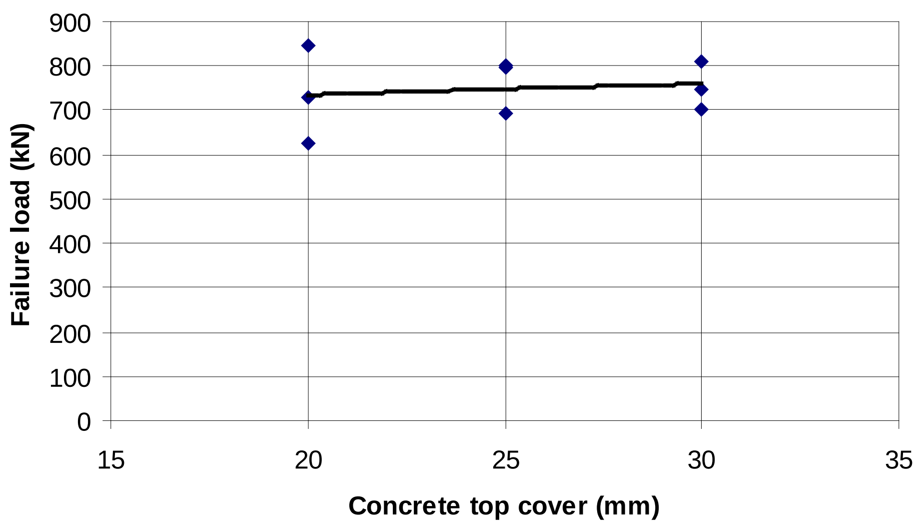


Figure 4.7: Effect of Concrete Top Cover on Failure Load on Configuration-2 (for grade 30 concrete)

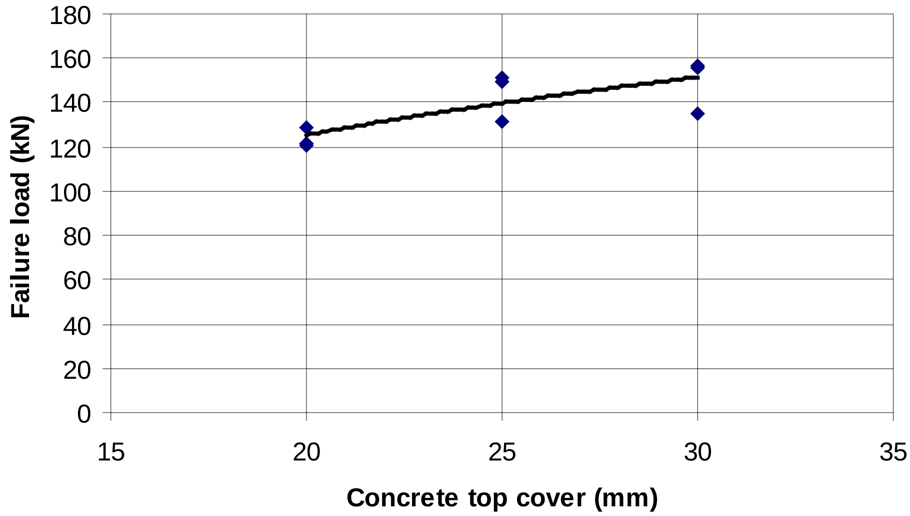


Figure 4.8: Effect of Concrete Top Cover on Failure Load on Configuration-3 (for grade 30 concrete)

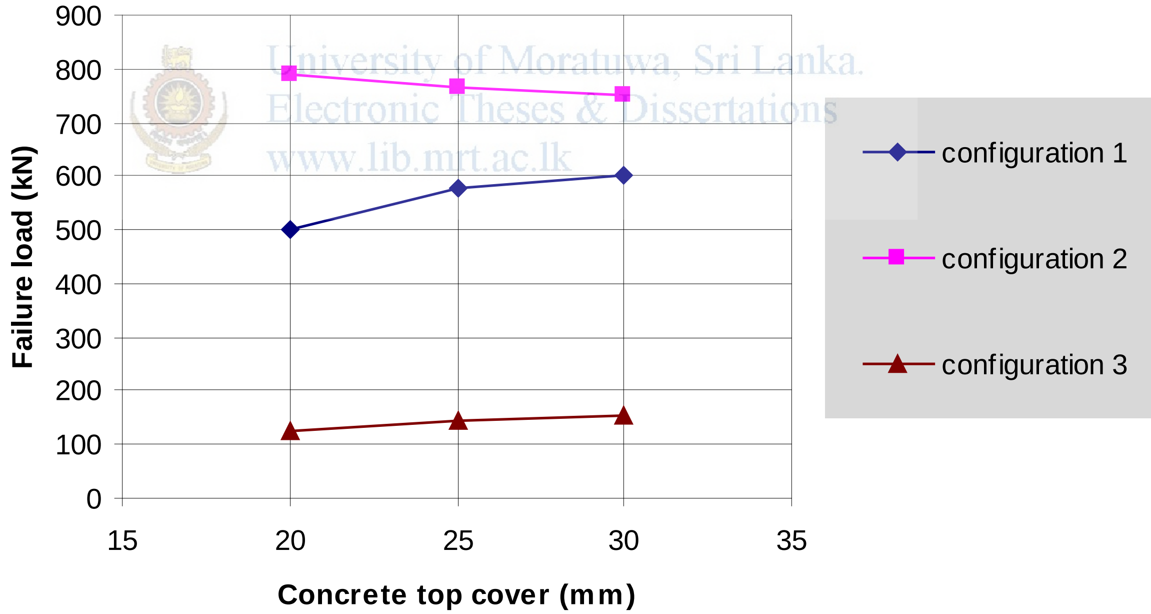


Figure 4.9: Effect of Concrete Top Cover on Failure Load on Different Configurations

With configuration 1 and 3 the failure load increased with increase of concrete top cover (16%- 45%, 23%- 29% respectively). It appears that there is no influence of concrete top cover in configuration 2. That might be due to effective mechanical bond between concrete and shear connector (see Figure 4.6, 4.7, 4.8, 4.9).

4.5 Effect of Concrete Failure Surface Area on Shear Connectors

In both configurations 1 and 2, longitudinal shear failure cracks were propagated due to loss of shear connection at the concrete steel interface. But in configuration 3 wedge cone failure surface were found (see Figure 4.10). According to the past research work (Hawkins and Mitchell (1984)), increase of shear failure surface area considerably increases that shear carrying capacity of composite slabs (Equation 2.8).

(a) Elevation

(b) Plan

Figure 4.10: Wedge Cone Failure Surface (a) Elevation (b) Plan

For configuration 1, failure surface area was taken as steel tube surface area. But it was added to two steel strip areas for configuration 2 failure surface area. For configuration 3, failure surface area was taken as wedge cone area (Hawkins and Mitchell (1984)).

Table 4.4: Effect of Concrete Failure Surface Area

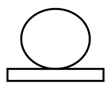
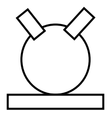
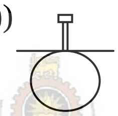
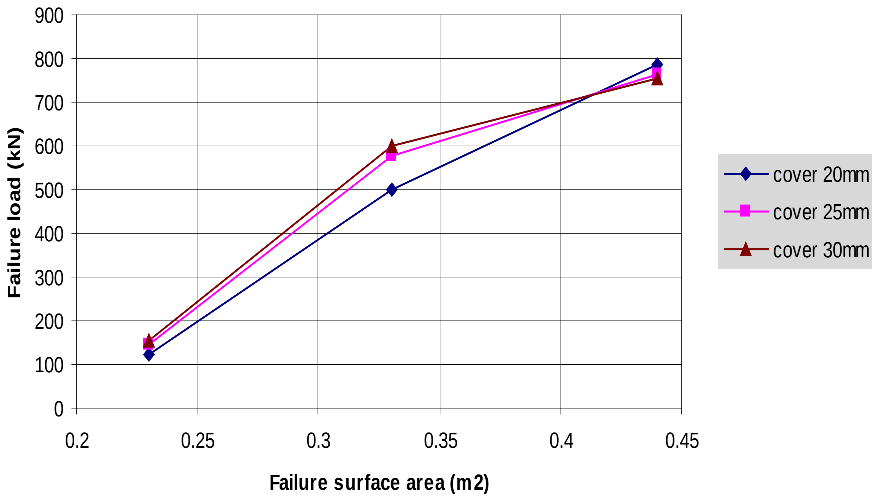
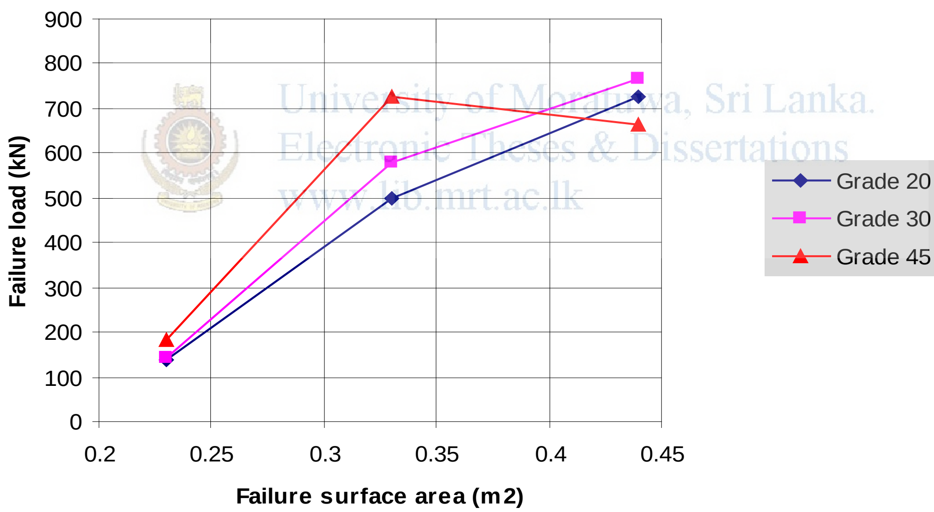
Configuration	Concrete shear failure surface area (mm^2)
Configuration 1 (cylinder area) 	331,414
Configuration 2 (cylinder area, with two steel strips area) 	425,394
Configuration 3, for stud per rib (wedge cone failure surface, Hawkins and Mitchell (1984)) 	227,334

Table 4.5: Effect of Concrete Failure Surface Area on Shear Capacity

Configuration	Concrete Grade	Failure load (kN)		
		Cover 20mm	Cover 25 mm	Cover 30mm
Configuration 1	20	-	501	-
	30	499	579	602
	45	-	725	-
Configuration 2	20	-	728	-
	30	788	765	753
	45	-	665	-
Configuration 3	20	-	138	-
	30	124	144	156
	45	-	184	-



(a) For Concrete Grade 30



(b) For Concrete Cover25mm

Figure 4.11: Effect of Concrete Failure Surface Area on Failure Load on Different Configurations (a) Concrete Grade 30 (b) Concrete Cover 25mm

For both configurations 1 and 2 the failure surface areas are higher than configuration 3. Irrespective of concrete strength and concrete top cover, the configurations 1 and 2 gave higher failure load than with headed shear studs in configuration 3. Between configurations 1, and 2, configuration 2 gave higher shear carrying capacity, as its concrete failure surface area is higher than configuration 1 (see Tables 4.4 and 4.5, Figure 4.11).

4.6 Effect of Position of Shear Stud, and Status of Steel Tube on Shear Capacity in Configuration 3

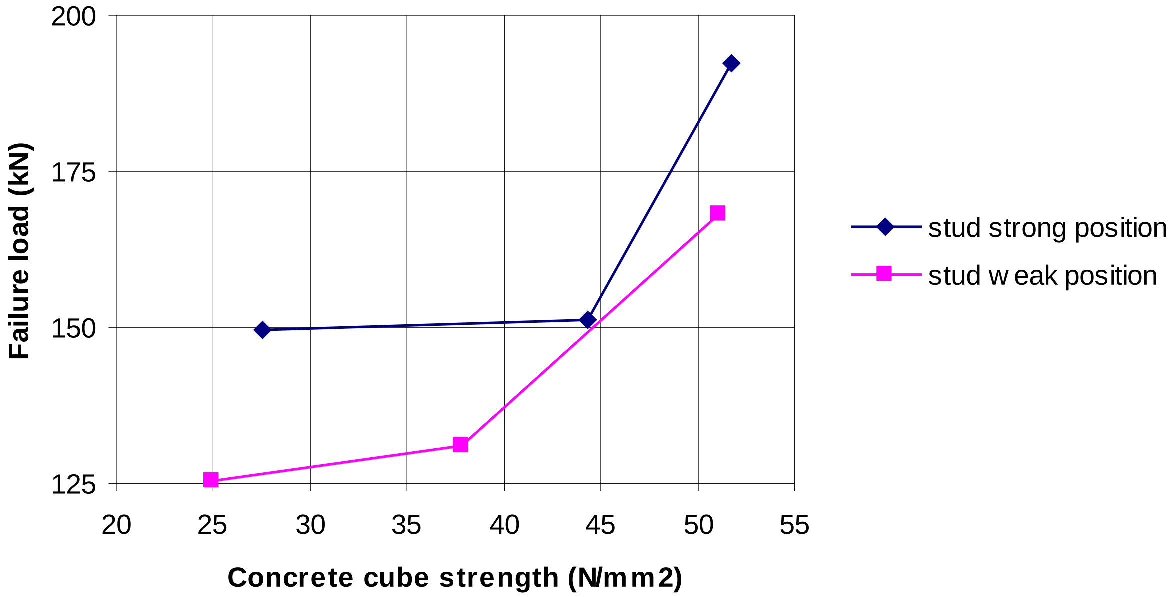
The effect of Position of Shear Stud, and Status of Steel Tube on Shear Capacity in Configuration 3 was as shown in Tables 4.6, 4.7 and Figure 4.12.

Table 4.6: Effect of Stud Position on Shear Capacity for Concrete Top Cover 25mm

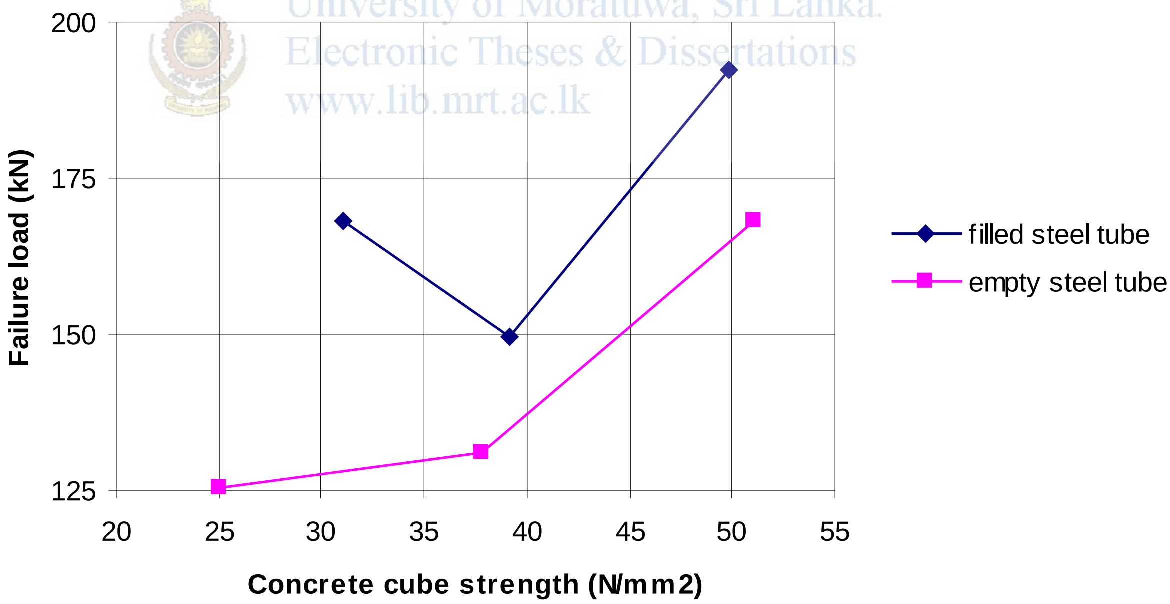
Specimen	Concrete Grade	Stud position	Concrete cube strength (Nmm^{-2})	Failure load (kN)
C20-25-3-i	20	Strong	27.5	149.6
C20-25-3-ii		Weak	25.0	125.5
C30-25-3-i	30	Strong	44.3	151.1
C30-25-3-ii		Weak	37.8	131.2
C45-25-3-i	45	Strong	51.7	192.2
C45-25-3-ii		Weak	51.1	168.1

Table 4.7: Effect of Steel Tube on Shear Capacity for Concrete Top Cover 25mm and Stud Weak Position

Specimen	Concrete Grade	Steel tube (filled or empty)	Concrete cube strength (Nmm^{-2})	Failure load (kN)
C20-25-3-ii	20	Empty	25.0	125.5
C20-25-3-iii		Filled	31.1	168.1
C30-25-3-ii	30	Empty	37.8	131.2
C30-25-3-iii		Filled	39.2	149.6
C45-25-3-ii	45	Empty	51.1	168.1
C45-25-3-iii		Filled	49.8	192.2



(a) For Concrete Top Cover 25mm



(b) For Concrete Top Cover 25mm and Stud Weak Position

Figure 4.12: Effects of Stud Position and Steel Tube on Shear Capacity (a) For Concrete Top Cover 25mm (b) For Concrete Top Cover 25mm and Stud Weak Position

The effect of position of shear stud was described with concrete top cover 25mm since it has more test results. The effect of position of shear stud was not considerable with reference to Table 4.6 and Figure 4.12(a). But shear carrying capacity of stud strong position was slightly higher than stud weak position. According to past research (Mottram and Johnson 1990); it was also found that the effect of position of shear stud in steel deck is not considerable when it is shallow deck, in this study that used steel decks were shallow (Figure 3.1).

To check easy of construction the effect of status of steel tube also checked. The effect of steel tube was described with concrete top cover 25mm and stud weak position since it has more test results. The effect of status (filled/empty) of steel tube was also less according to Table 4.7 and Figure 4.12(b), but specimens with filled steel tube has higher shear capacity than specimens with empty steel tube.

4.7 Shear Failure Pattern with each Configuration

The shear failure pattern of configuration 1 is shown in Figure 4.13; the longitudinal crack was propagated on top of the embedded steel tube. The failure of the composite slab is mainly due to loss of friction force at steel concrete interface and it is shown in Figure 4.14 (first crack at nearly 83% of failure load).

Figure 4.13: Configuration 1 Shear Failure Pattern

Figure 4.14: Configuration 1 Failure Surface

The shear failure pattern of configuration 2 is shown in Figure 4.15; two longitudinal cracks were propagated on top of the steel strips, which were welded to the embedded steel tube. The failure of the composite slab is mainly due to loss of friction force at steel concrete interface and it is shown in Figure 4.16 (first crack at nearly 83% of failure load).

Figure 4.15: Configuration 2 Shear Failure Pattern

Figure 4.16: **Configuration 2 Failure Surface**

The shear failure pattern of configuration 3 is shown in Figure 4.17, longitudinal crack, and transverse cracks were propagated on top of the headed shear studs. The failure of the composite slab is mainly due to pulling out of stud it is shown in Figure 4.18 (first crack at nearly 58% of failure load), and it is known as shear cone failure. Wedge cone failures were common, but pyramid cone failures also formed (see Figure 4.10, 4.19).

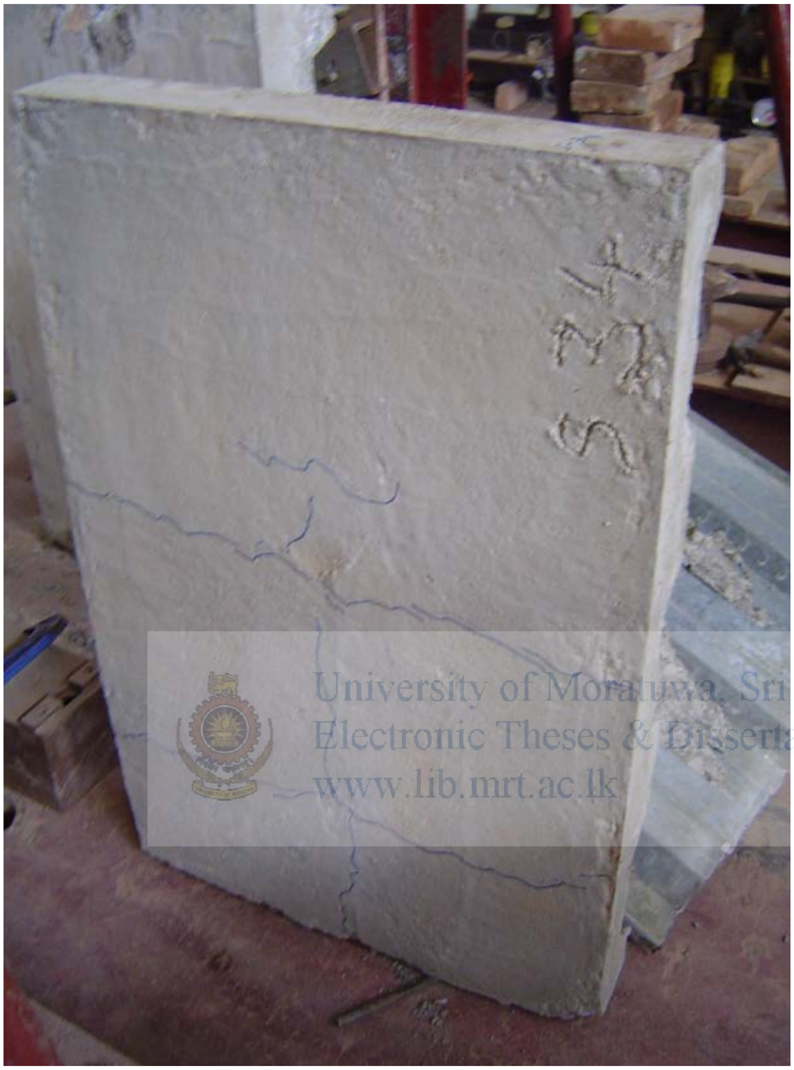


Figure 4.17: Configuration 3 Shear Failure Pattern

Figure 4.18: Configuration 3 Failure Surface

Figure 4.19: Wedge Cone and Pyramid Cone Failure

Basically, with configuration 1 and 3 shear carrying capacity was increased with concrete top cover and concrete grade. But with configuration 2, shear carrying capacity was not influenced by both concrete grade and concrete top cover. The position of the headed stud and the status of steel tube have negligible effect on shear carrying capacity of configuration 3. The shear failure pattern propagated at minimum top cover at configuration 1 and 2. One longitudinal crack was seen at top of the steel tube in configuration 1, two longitudinal cracks were seen at top of the steel strips welded to steel tube in configuration 2, and shear cone failure was seen with configuration 3. With all cases first cracked appeared as given in appendix.