CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 General

In this chapter, push-out test results of the three configurations are analysed further. These results are compared with the current code of practice equations, and modified theoretical models, that have been discussed in the literature review in Chapter 2.

Analysis for configurations 1, 2 and 3 was based on concrete top cover and concrete cube strength. According to test results in configuration 2, the failure load was influenced by neither concrete top cover nor concrete cube strength. Then existing formula was modified to predict shear carrying capacity of above three configurations. Configuration 3 test results were also compared with Eurocode 4 prediction equations.

5.2 Prediction Method for Configurations 1, 2 and 3

All over the world many prediction methods have been developed to predict the shear carrying capacity of headed shear studs. No literatures (including prediction technique) have been reported for configurations 1 and 2 types of shear connectors.

Hawkins and Mitchell (1984) found relationship between shear strength, concrete strength, and concrete failure surface area for shear studs (Equation 2.8). Later, Mitchell's equation was modified by Lloyd and Wright (1990) (Equation 2.17, 2.18) to provide a more precise prediction.

The equation 2.18 was with constants for shear friction, and type of concrete (see Equation 2.18, 5.1). The factor $\lambda = 1$ for normal concrete and the factor K = 0.45 used for 38mm and 76mm deep decks with headed shear studs.

$$Q_k = K \lambda \sqrt{f_{cu}} A_c \qquad (5.1)$$

Where, Q_k – characteristic connection resistance
K – Shear friction factor
λ - Constant for concrete type
f_{cu} - Concrete cube strength
A_c – Concrete failure surface area

5.3 Analysis for Configurations 1 and 2

The failure load was analysed with concrete top cover and concrete cube strength to identify the relationship between each other.

5.3.1 The Effect of Concrete Cube Strength and Concrete Top Cover on Shear Carrying Capacity

To find clear correlation of test data, configuration 1 and 2 all test results were used (based on equation 2.18, Hawkins and Mitchell 1984) as given in Figure 5.1. Several prediction models were tried to get closer prediction including variable as concrete top cover, constant (K) with regression types "Linear", "Logarithmic", "Polynomial", "Power", and "Exponential". The best prediction model is given below.

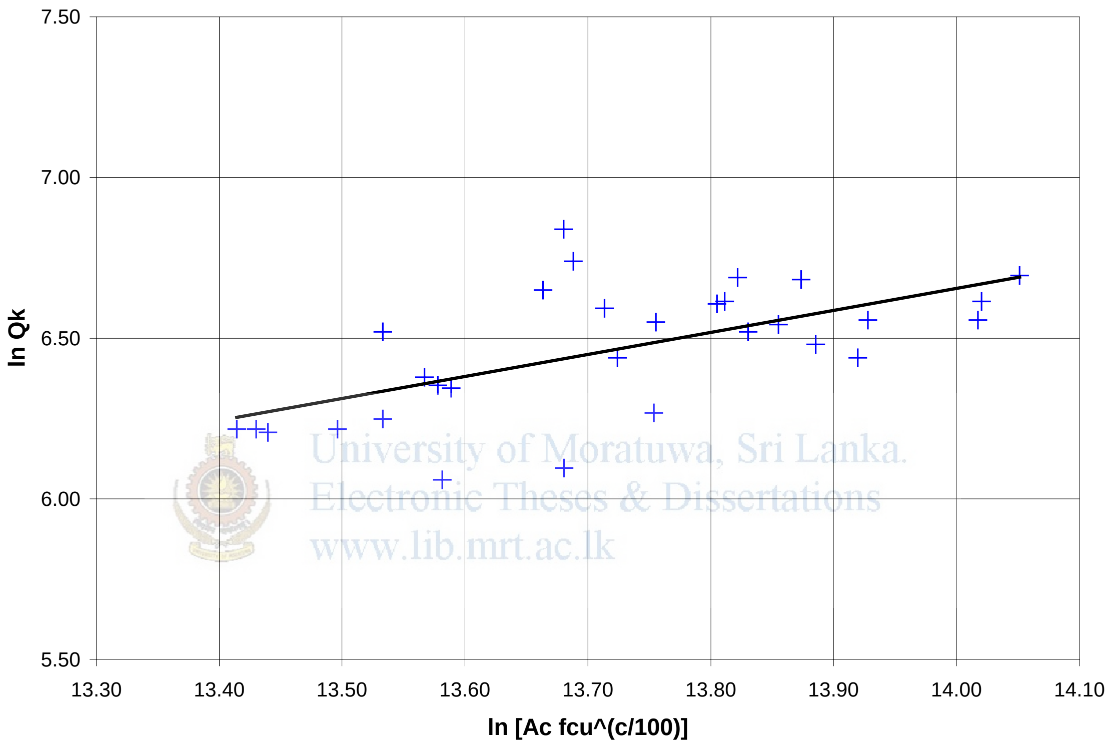

Figure 5.1: Ln Q_k versus Ln [A_c $f_{cu}^{(c/100)}$], Ln Q_k = 0.685 Ln (A_c f_{cu}) – 2.9345, R^2 = 0.372

Above equation can be simplified further as given in Equation 5.2.

$$Q_K = k\,[A_c\, f_{cu}^{(c/100)}]^{0.685} \tag{5.2}$$

Where, k = constant = 0.053

c = concrete top cover (20, 25, 30mm)

5.3.2 Analysis for Configurations 1

The experimental failure loads were analysed with predicted failure loads, to identify the relationship between concrete top cover and concrete cube strength. Then error was calculated with reference to experimental failure load.

Table 5.1: Results of configuration 1

Configuration	Cube strength (Nmm-2)	Failure load (Fu, kN)	First crack load (Ff, kN)	Ff / Fu	Fprd	Error %
s2-c30-20-1-iii	38.2	496	392	0.8	528	-6
s3-c30-20-1-i	36.4	501	350	0.7	524	-4
s4-c30-20-1-ii	33.6	501	470	0.9	519	-3
s5-c30-25-1-iii	26.8	517	438	0.8	563	-8
s6-c30-25-1-ii	30.7	589	459	0.8	576	2
s7-c30-25-1-i	33.5	569	522	0.9	585	-3
s8-c45-25-1-iii	48.2	678	366	0.5	622	9
s9-c45-25-1-i	45.1	772	511	0.7	615	25
s10-c30-25-1-ii	48.3	933	933	1.0	622	50
s11-c20-25-1-ii	32.5	428	418	1.0	582	-26
s12-c20-25-1-iii	32.0	574	496	0.9	580	-1
s13-c20-25-1-i	23.1	501	392	0.8	549	-9
s14-c30-30-1-iii	41.7	678	527	0.8	690	-2
s15-c30-30-1-ii	32.3	527	522	1.0	654	-19
s16-c30-30-1-i	25.3	444	418	0.9	622	-29

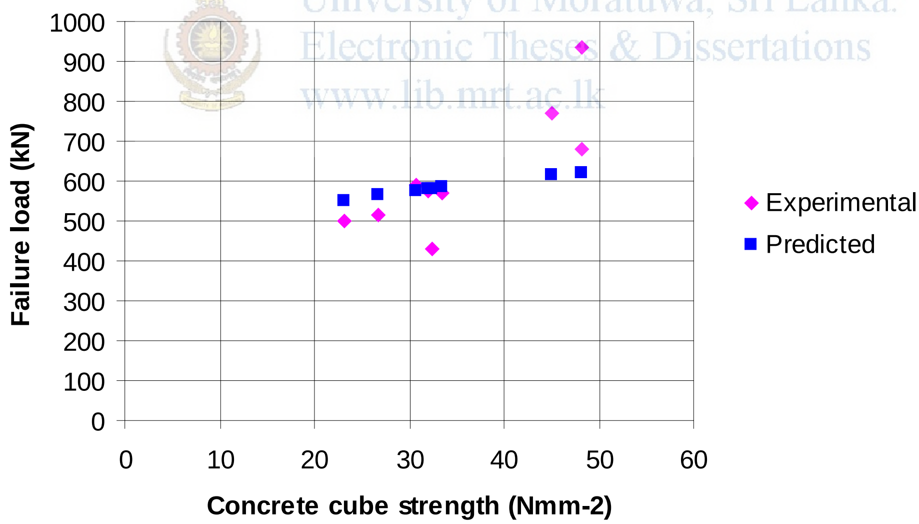

Figure 5.2: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-1(for concrete grade 30 and concrete top covers 20, 25, 30mm)

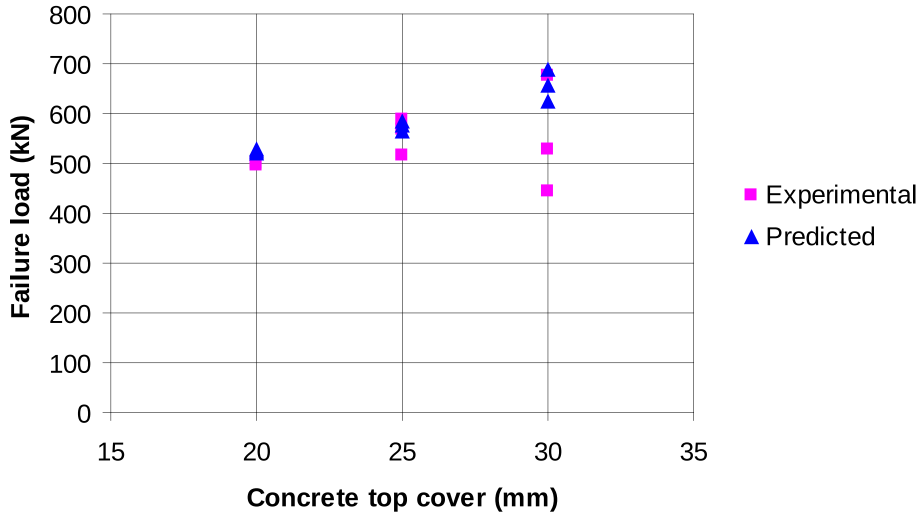

Figure 5.3: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-1(for concrete top cover 25mm and concrete grades 20, 30, 45)

According to Table 5.1 and Figures 5.2 and 5.3 the modified prediction equation was within -29% to 50% accuracy and ten out of fifteen points were within an accuracy of ±9%. All outliers (except one point) are at (Ff / Fu) ratio near to 1, which implies that, the shear connection behaves in a non ductile manner with no warning of failure.

5.3.3 Analysis for Configurations 2

The experimental failure loads were analysed with predicted failure loads, to identify the relationship between concrete top cover and concrete cube strength. Then error was calculated with reference to experimental failure load.

Table 5.2: Results of configuration 2

Configuration	Cube strength (Nmm-2)	Failure load (Fu, kN)	First crack load (Ff, kN)	Ff / Fu	Fprd	Error %
s17-c30-30-2-i	34.2	746	688	0.9	786	-5
s18-c30-30-2-ii	37.9	808	678	0.8	802	1
s19-c30-30-2-iii	33.8	704	589	0.8	784	-10
s20-c30-20-2-i	43.1	730	574	0.8	637	15
s21-c30-20-2-ii	38.0	845	704	0.8	626	35
s31-c30-20-2-iii	45.5	626	522	0.8	641	-2
s22-c30-25-2-i	35.8	694	496	0.7	701	-1
s26-c30-25-2-ii	31.3	803	761	0.9	686	17
s30-c30-25-2-iii	38.5	798	642	0.8	710	12
s23-c45-25-2-i	47.9	704	563	0.8	737	-5
s24-c45-25-2-ii	46.3	626	470	0.8	733	-15
s25-c45-25-2-iii	40.4	652	548	0.8	716	-9
s27-c20-25-2-i	24.0	699	605	0.9	655	7
s28-c20-25-2-ii	31.8	740	647	0.9	688	8
s29-c20-25-2-iii	30.0	746	642	0.9	681	10

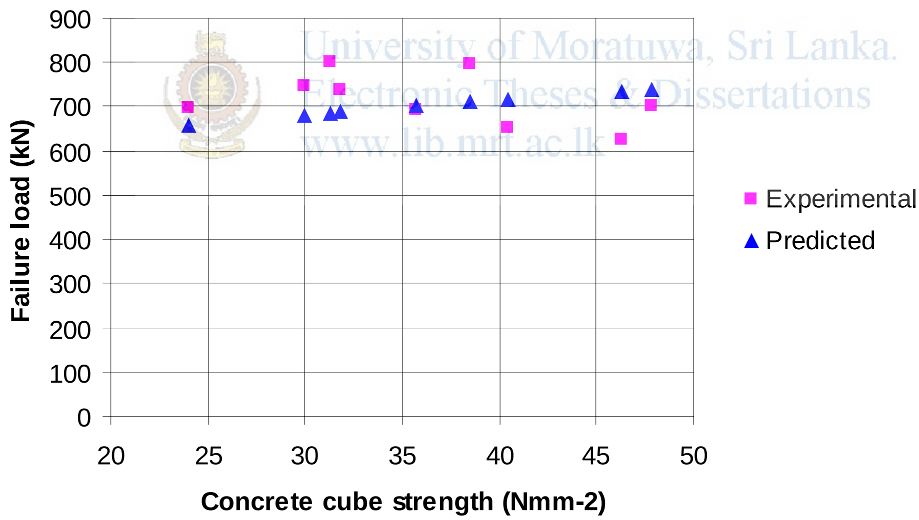

Figure 5.4: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-2(for concrete grade 30 and concrete top covers 20, 25, 30mm)

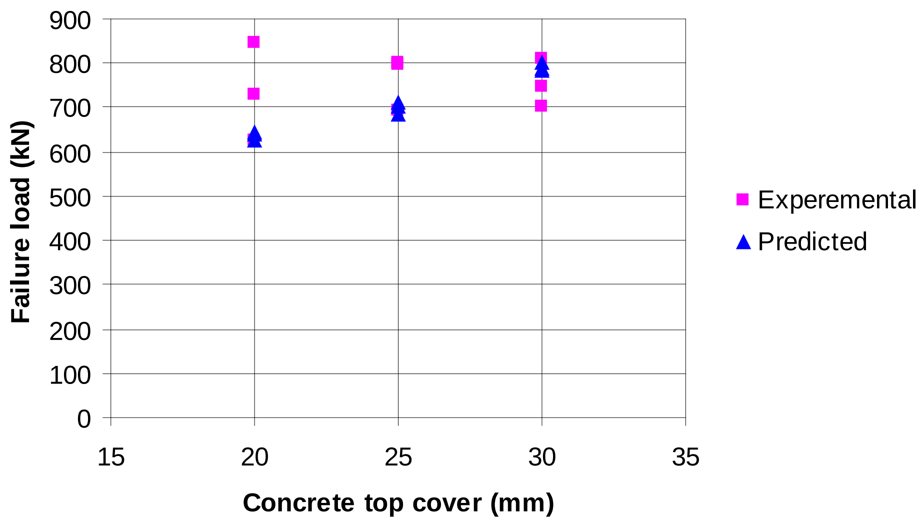

Figure 5.5: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-2(for concrete top cover 25mm and concrete grades 20, 30, 45)

According to Figures 5.4 and 5.5 modified prediction equation was within -15% to 35% accuracy and thirteen out of fifteen points were within an accuracy of ±15%. But curve pattern is not similar.

5.3.4 Analysis for Configurations 3

The experimental failure loads of configuration 3 were compared and analysed with prediction equation obtained for configuration 1 and 2 with additional constant (β, to get closer prediction it was taken as 0.32 because configuration 3 shear connection type is different from others two shear connector types). Then error was calculated with reference to experimental failure load.

$$Q_K = k\, \beta\, [A_c\, f_{cu}^{(c/100)}]^{0.685} \qquad (5.2)$$

Where, k = constant = 0.053
β = constant = 0.32

Table 5.3: Results of configuration 3

Configuration	Cube strength (Nmm-2)	Failure load (Fu, kN)	First crack load (Ff, kN)	Ff / Fu	Fprd	Error %
s32-c30-20-3-ssp	40.0	121.2	86	0.7	131	-8
s33-c30-20-3-w	39.8	121	121	1.0	131	-8
s34-c30-20-3-cfst-w	36.9	128.3	57	0.4	130	-1
s35-c30-30-3-ssp	32.8	135.4	57	0.4	162	-17
s36-c30-30-3-cfst-w	36.4	155.3	114	0.7	166	-6
s37-c30-30-3-w	38.6	156.7	93	0.6	168	-7
s38-c30-25-3-ssp	44.3	151.1	64	0.4	152	0
s39-c30-25-3-cfst-w	39.2	149.6	51	0.3	148	1
s40-c30-25-3-w	37.8	131.2	71	0.5	148	-11
s41-c45-25-3-ssp	51.7	192.2	93	0.5	156	23
s42-c45-25-3-cfst-w	49.8	192.2	78	0.4	155	24
s43-c45-25-3-w	51.1	168.1	94	0.6	155	8
s44-c20-25-3-w	25.0	125.5	51	0.4	137	-9
s45-c20-25-3-cfst-w	31.1	168.1	128	0.8	143	18
s46-c20-25-3-ssp	27.5	149.6	128	0.9	140	7

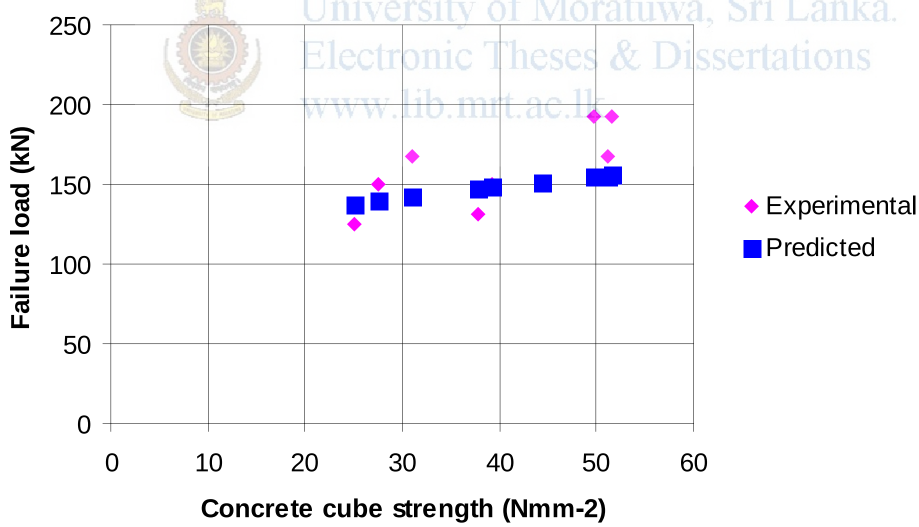

Figure 5.6: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-3(for concrete grade 30 and concrete top covers 20, 25, 30mm)

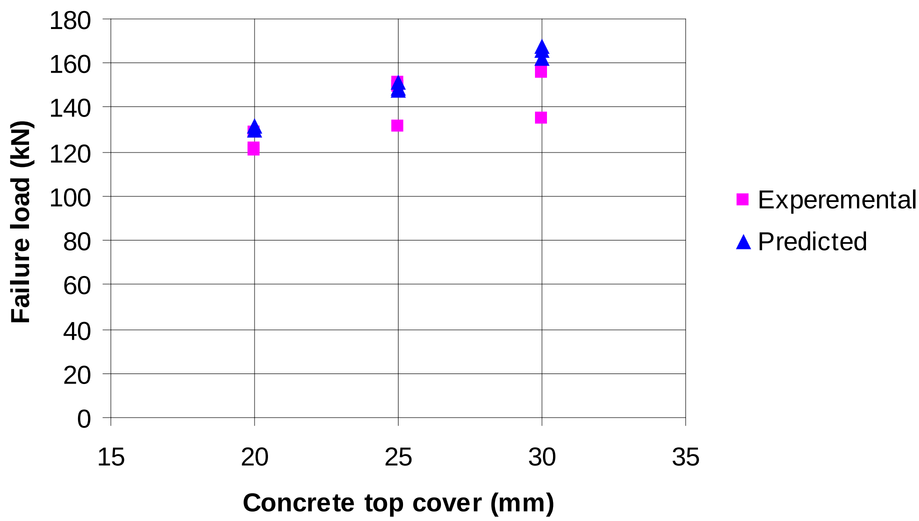

Figure 5.7: Concrete Strength Vs Failure Load (Experimental and Predicted) on Configuration-2(for concrete top cover 25mm and concrete grades 20, 30, 45)

According to Figures 5.6 and 5.7 modified prediction equation was within -17% to 24% accuracy and eleven out of fifteen points were within an accuracy of ±15%.

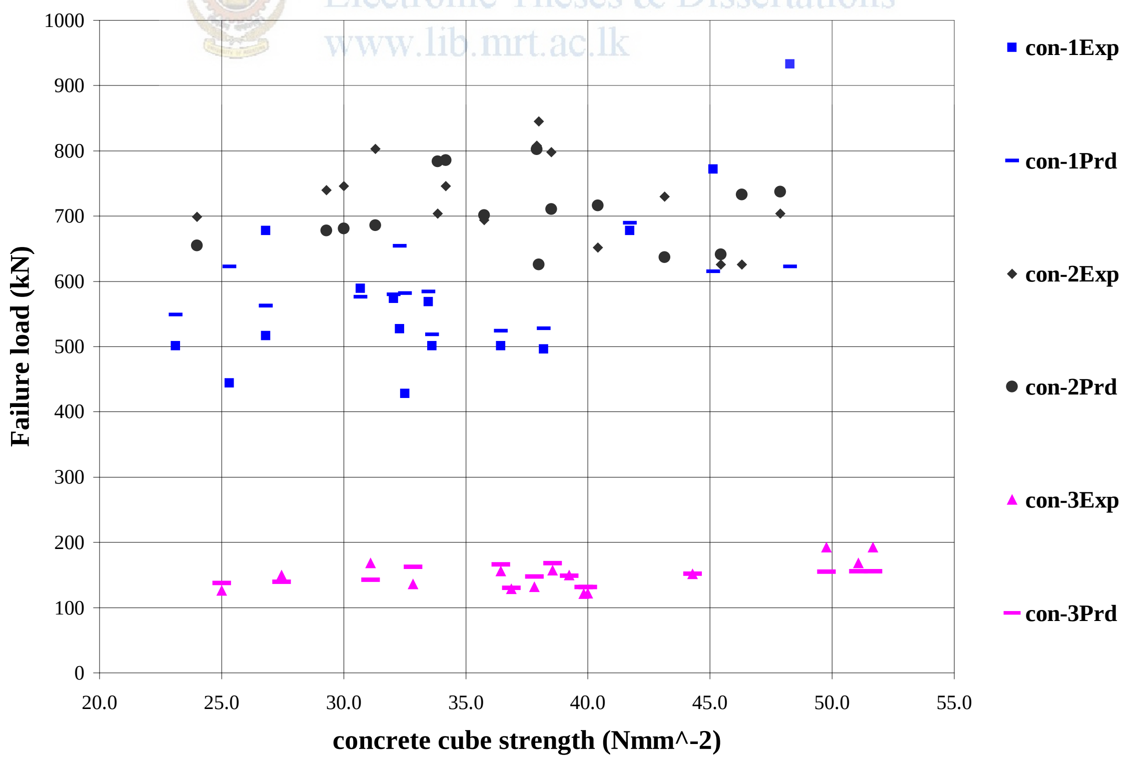

Figure 5.8: Experimental Load Vs Predicted Load

According to Table 5.1 and Figure 5.8 thirty four out of forty five points (76%) were within an accuracy of ±15% and higher shear carrying capacity was obtained in configuration 2. In each configuration shear carrying capacity was changed with concrete cube strength and concrete top cover.

5.4 Comparison of different prediction method related to Configurations 3

The experimental failure loads were compared with Eurocode 4 (EN2001) (see Appendix). The predicted shear carrying capacity is smaller value of concrete failure load (referred as "c" in Table 5.4, column $Q_{Eurocode}$) and stud failure load (referred as "s" in Table 5.4, column $Q_{Eurocode}$). The ratio of experimental values and predicted values were used to evaluate the prediction method (see Table 5.4).

Table 5.4: Failure load comparison

Sample	Failure load/Number of studs (Qe)	$Q_{Eurocode}$	$Qe/Q_{Eurocode}$
c30-20-3-I	61	50-c	1.22
c30-20-3-ii	61	50-c	1.22
c30-20-3-iii	64	47-c	1.35
c30-30-3-I	68	44-c	1.55
c30-30-3-ii	78	49-c	1.61
c30-30-3-iii	78	47-c	1.66
c30-25-3-I	76	53-c	1.41
c30-25-3-ii	66	48-c	1.37
c30-25-3-iii	75	49-c	1.52
c45-25-3-I	96	55-s	1.76
c45-25-3-ii	84	55-s	1.54
c45-25-3-iii	96	55-s	1.76
c20-25-3-I	75	39-c	1.92
c20-25-3-ii	63	37-c	1.71
c20-25-3-iii	84	42-c	2.00

According to past researchers Eurocoe 4 is not conservative but it is giving close prediction values with at least 22% safe margin as shown in Figure 5.9 in this study.

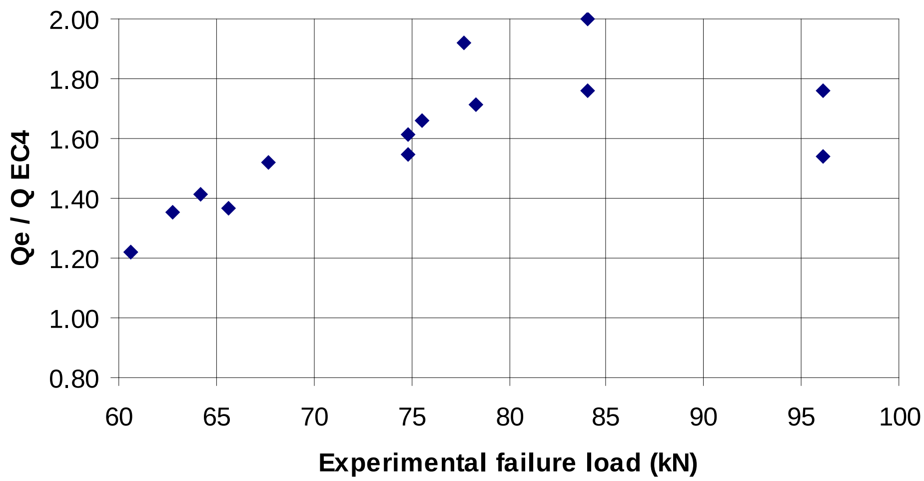

Figure 5.9: Experimental Load Vs Predicted Load (Eurocode 4)

According to Table 5.4 and Figure 5.9 stud shear connection resistance increases (see Q_e / $Q_{Eurocode}$ ratio change) with concrete top cover but Eurocode 4 prediction equation does not facilitate for it. But modified prediction equation (Equation 5.2) facilitates both concrete top cover and concrete grade and accurate prediction also possible.

The equation 5.1, the factor $\lambda = 1$ for normal concrete, and during this research used concrete mixes were normal concrete. Therefore no factor was used for type of concrete to modify the prediction equation. The factor K = 0.45 used for 38mm and 76mm deep decks with headed shear studs, but during this study the used deck was 51mm deep. The shear friction factor (K) used as $\beta = 0.32$ for configuration 3 (with headed shear studs) in this study (see Equation 5.3).

$$Q_K = k\,\beta\,[A_c\, f_{cu}^{(c/100)}]^{0.685} \qquad (5.3)$$

Where, k = constant = 0.053
β = constant = 1 for both configuration 1 and 2, 0.32 for configuration 3
c = cover (20, 25, 30mm)