SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS WITH MINIMUM PERCENTAGE OF SHEAR REINFORCEMENT

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ABSTRACT

Eurocode 2 adopts the truss model to derive the shear capacity of the reinforced concrete beam. The main drawback of the truss model is the estimation of the crack angle of the diagonal struts. In traditional truss model the failure shear strength of the beam is determined by assuming the θ angle. Otherwise it can be assumed a compressive stress and then find V and θ. However, assuming the diagonal crushing of concrete, the crack angle can be estimated for the ultimate shear force and then the same crack angle will be used to calculate required amount of shear reinforcement for the design shear force assuming the yielding of stirrups. The crack angle may be different for the two failure criterion. As a consequence of that, this study conducts series of experimental testing reinforced concrete beams to understand the better correlation in estimation of crack angle as function of amount of longitudinal reinforcement and shear reinforcement. This paper present the test results of two reinforced concrete beams called Beam 01 and Beam 02 having zero and 0.15% (minimum % of shear reinforcement), respectively.

Keywords: Reinforced concrete beam, shear strength, Eurocode 2, crack angle

1. INTRODUCTION

Recently, Eurocodes are introduced for design of structures in Sri Lanka replacing the British codes. Therefore, design engineers may not be well aware of the different design methodologies adapted in the Eurocodes. Design of shear reinforcement in reinforced concrete beams could be one of them. Actually, Eurocode 2 adopts the truss model to derive the shear capacity of the reinforced concrete beam. The main drawback of the truss model is the estimation of the crack angle of the diagonal struts. In traditional truss model the failure shear strength of the beam is determined by assuming the θ angle. Otherwise it can be assumed a compressive stress and then find V and θ. However, assuming the diagonal crushing of concrete, the crack angle can be estimated for the ultimate shear force and then the same crack angle will be used to calculate required amount of shear reinforcement for the design shear force assuming the yielding of stirrups. As a consequence of that, this study conducts series of experimental testing reinforced concrete beams to understand the better correlation in estimation of crack angle as function of amount of longitudinal reinforcement and shear reinforcement. This paper present the test results of two reinforced concrete beams called Beam 01 and Beam 02 having zero and 0.15% (minimum % of shear reinforcement), respectively.

2. LITERATURE REVIEW

The truss model adopted in current design codes is a good mechanical model to express the behavior of reinforced concrete members after cracking. However, it cannot present the ultimate strength of reinforced concrete beams, but must be accompanied by various other equations for concrete contribution, which are usually derived from test results. i.e state that the normal shear resistance V_n as:

$$V_n = V_c + V_s \qquad (01)$$

Where V_c and V_s are the shear components carried by concrete and shear reinforcement, respectively. V_s can be calculated using truss analogy and the prediction of Vc depends only on the empirical equation which lumps the contribution of aggregate interlock, dowel action and uncracked concrete together.

There are 3 types of failure mechanism in the truss model. They are failure due to stirrups yielding, failure due to crushing of concrete and failure due to longitudinal reinforcement yielding.

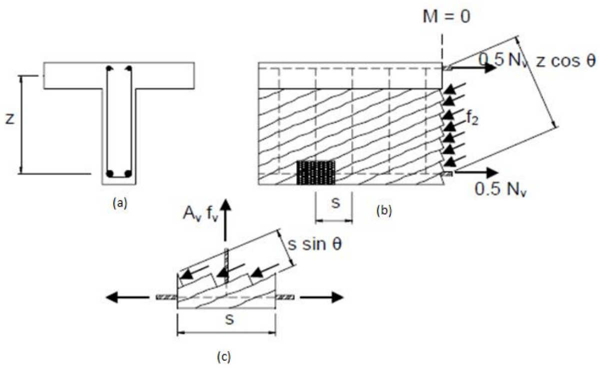

Figure 1: Free body diagram of Truss Model

The required magnitude for the principal compressive stress f_2, can be derive from Figure 1. This compressive stress existing in the web of the beam may lead to crushing of the web as given in eq.(02)

$$f2 = \frac{V}{bwz}(tan\theta + cot\theta) \qquad (02)$$

In predicting the shear strength of beams using variable-angle truss models, it is necessary to use an effective concrete compressive strength smaller in value than the cylinder crushing stress.

When the stirrups are yielded the beam can't satisfy its equilibrium. Consider a segment length s (include a stirrup at the mid-point) to check whether how the model satisfy its equilibrium (Figure 1.c). f_2 is the shear component along the crack lines. This force tends to cause the top and bottom flanges to separate. Considering the equilibrium of the free body diagram (Figure 1.c) at the initiation of stirrups yielding, shear capacity of the beam can be estimated by using the eq.(03);

$$\frac{Avfv}{s} = \frac{V}{z}\, tan\theta \qquad (03)$$

In traditional truss model the failure shear strength of a beam is determined by assuming the θangle. Otherwise it can ve assumed a compressive stress and then find *V* and θ. However stirrups are unable to resist shear unless they are crossed by an inclined crack. The maximum stirrups spacing should be *d* or less according to the truss model.

The longitudinal component of the diagonal compressive force must be counteracted by an equal tensile force in the longitudinal reinforcement. If the tension of the longitidunal reinforcement increase, the beam may cause the longitudinal reinforcement to yield and produce the failure of the beam. This can be determined from the equation derived by considering the horizontal equilibrium of beam (*Figure 1.b*).

$$N_v = cot\theta \qquad (04)$$

3. METHODOLOGY

3.1. MAKING THE MIX DESIGN

From a report about concrete mix design, the mix design for *30 grade* concrete was prepared. The ratios for the prepared mix design were *1:0.54:1.477:2743* where for *1kg* of cement, *0.54 kg* water, *1.477 kg* fine aggregates and *2.743 kg* coarse aggregates were used. The average size of coarse aggregates supposed to be in the ratio of*16-20 mm*. For this mix design, coarse aggregates of crushed type and fine aggregates of uncrushed type were used. The slump value of this mix design was approximated between *60-180 mm*.

3.2. PREPARATION OF THE SPECIMAN

For this experiment it was proposed to cast 9 beams having a cross section of 600*250 mm and a span of 2440 mm. The *9* beam specimens were designed to be casted under *3* main categories. The 3 conditions are:

Condition 1: Grade of the concrete in the beam is varied as *30MPa*, *50MPa*, and *60MPa* while amount of longitudinal and shear reinforcement is kept constant at *1%* and *0.5%* respectively.

Condition 2: Amount of shear reinforcement in the beam is varied as *0%*, *0.5%*, and *1%* while amount of longitudinal reinforcement and concrete grade is kept constant at *1%* and *50MPa* respectively.

Condition 3: Amount of longitudinal reinforcement in the beam is varied as *0.5%*, *1%* and *1.5%* while amount of shear reinforcement and concrete grade is kept constant at *0.5%* and *50MPa* respectively. Among the 9 beams specified, 2 beams were castes as the first step. Beam 01 is having 0% shear reinforcement. Beam 02 is having 0.15% shear reinforcement. Both the beams having constant longitudinal reinforcement at 1% defined under condition 2 in Table 1.

When casting the beams grade 30 concrete was used and prepared in batches of 100 kg of cement, 150 kg fine aggregates, 280 kg coarse aggregates and 54 kg of water. 3½ of such batches were used in the casting of the 2 beams experimented.

Table 1 explains the above details in context.

Condition	Longitudinal reinf.	Shear reinf.	Con. grading
1	Constant at 1%	Constant at 0.5%	Varied as, 30MPa 50MPa 60MPa
2	Constant at 1%	Varied as, 0% 0.15% 0.50% 1.50%	Constant at50MPa
3	Varied as, 0.5% 1% 1.5%	Constant 0.5%	Constant at 50MPa

3.3 TESTING PROCEDURE

A concentrated load is applied on a simply supported beam whose depth is d at a distance satisfying the *a/d* ratio to be a constant. The loading should be then gradually increased up to a maximum value of *500KN* until the beam approaches failure.

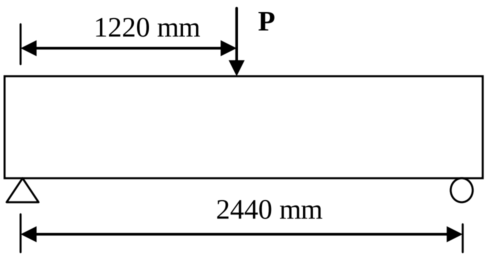

Figure 2: Testing Arrangement

4. Results and Discussion

In the following text, it is discussed the results obtained from the two tests. Figure 3 illustrates the variation of applied load against the mid vertical displacement. The curves show that after initiation of the shear crack at the mid depth, there is a drastic reduction of shear strength as the crack propagates across the depth of the beam. Table 2 indicates the failure load, shear strength obtained from the test , the predicted shear strength by the EC2 and the percentage of the difference.

Table 2: Test results

No.	Failure Load (kN)	Shear Strength (kN)	EC 2 (kN)	% Diff.
Beam 01	295	147.5	170	-15
Beam 02	365	182.5	131	28

Figure 4 illustrates the comparison of experimental shear strength and the predicted shear strength for the two beams.

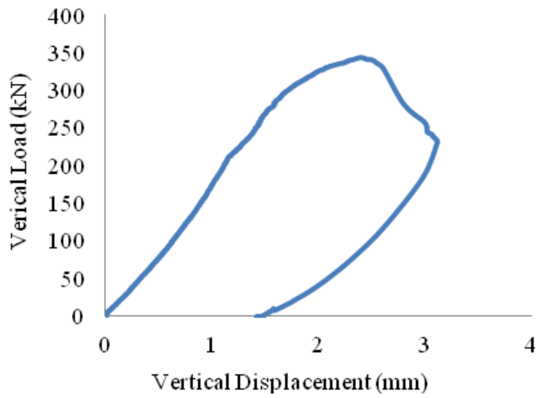

Figure 3: Load - lateral deformation curve for Beam 2

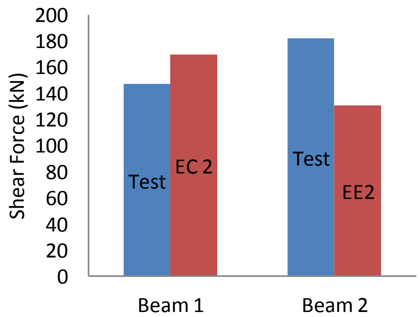

Figure 4: Comparison of the results

The observed crack pattern is approximately tri-linear as shown in Figure 4. The crack angle at mid region is approximately 45 degrees while it is 24.5^0 and 22.5^0 at the upper and lower region of the beam, respectively. The crack angle at the upper and the lower regions of the beam is reduced significantly due to the presence of longitudinal reinforcement. In the middle region of the beam, there are no longitudinal reinforcements. Only shear reinforcements are there. Therefore, shear resistance is less in mid region. That results in the higher crack angle of 45 degrees.

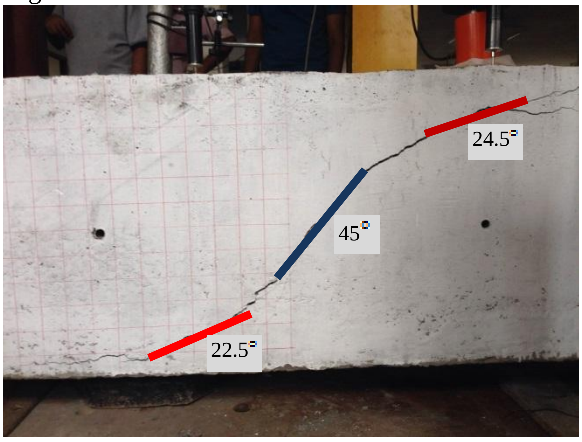

Figure 5: Observed crack

When the stress block is rotated by 45° the principal stresses occurs where the shear forces become zero and the stresses becomes maximum.

5. CONCLUSION

Based on the comparison of the results and the observed crack pattern, it can be concluded that the crack angle of 45^0 is proposed to use for the calculation of shear resistance by the vertical stirrups with code suggested minimum percentage of reinforcement or low. Furthermore, it can be concluded that the prediction of shear resistance of the concrete itself by the equation given in the EC 2 is conservative.

6 REFERENCES

[1] Commission for the European Communities, Eurocode 2: Design of Concrete Structures – Part 1: General Rules and Rules for Buildings, EN 1992-1-1, 2005.