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Analyzing the Shear Behaviour of Reinforced Concrete Beams Containing Shear Reinforcements at Different Angles

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Abstract: Shear behavior has been investigated by many researchers for many years on normal concrete specimens. Some researchers are also studying the shear behavior of reinforced concrete beams by using sand, crushed stones, and steel as coarse aggregate to counter the effect of shear. The aim of this study to investigate the shear behavior of reinforced concrete beams by providing shear reinforcement at different angles. Shear behavior of reinforced concrete (RC) elements can be improved with an adequate amount of steel. The RC element is reinforced by providing stirrups at different angles. In order to study shear behavior on reinforced concrete beams shear strips has been provided as shear reinforcement at the angles of 900,300,450 and 600. Experimental investigation showed that the beams having shear strips at an angle of 450 are more reliable than reinforced concrete beam having stirrups at other angles.

Keywords: Shear Behaviour; Reinforced Concrete Beams; Shear Reinforcements; Different Angles of Stirrups.

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1. Introduction

Concrete is a highly recommended construction material in infrastructure and engineering projects because of its resistance to water and ease of formation in any shape and size. Concrete is among the cheapest and easily available material (Aslam, Shafigh, & Jumaat, 2016; Mehta, P.K., Monteiro, 2006). Structural development across the globe increased the demands for construction material and its characteristics (Jumaat et al., 2009). United States has been producing two billion tons of aggregate yearly and this rate of production is likely to increase in future. The consumption of the primary aggregate was 110MT in UK in 1960 and increased by 275MT by 2006 (Adebar et al., 1997; Aoude et al., 2012). Various researchers are investigating the properties of reinforced concrete structural members. Where, the shear behavior of reinforced concrete members is influenced by many factors and shear forces applies in combination with other loads i-e flexural, axial and torsion. The shear capacity can be measured by experimental and theoretical methods. However, shear failure is unpredictable and can be catastrophic because of its nature of sudden failure (Konig and Fischer, 1995; Lee and Hwang, 2010).

2. Literature Review

Shear in reinforced concrete beams without stirrups is resisted by concrete up to the cracking load. After the cracking load, it is resisted by aggregate interlock, main reinforcing bars and the uncracked concrete cross section (ACI Committee 318, 2008; IS:456, 2000, CSA-A23.3, 2004). Shear Behaviour of concrete beam was investigated by casting eighteen concrete beam applying combined loading of shear and flexure.

The main focus was on longitudinal reinforcement placed in the beam and the response of the beam under the combined loading of shear and flexure (Walraven, 1978; Yoon et al., 1996; JSCE, 2002). Shear behaviour of RC beam have been investigated by using different types of aggregates to study the effect of aggregate types on shear such as recycled aggregates.

Ten Full scale beams were casted having 0%, 50% and 100% recycled aggregate without shear reinforcement and it was observed that beam having lesser recycled aggregate exhibits good shear resistance than the other beams (Sigrist, 2011; Spinella et al., 2012). The experimental investigation was done on treated and untreated aggregate through load deflection curve and ultimate load and it was concluded that treated recycled aggregate have good shear resistance compared to untreated recycled aggregate. It was also observed that the crack pattern was different in different all the mixes and somehow the failure mechanism was similar (Taylor, 1972).

3. Research Methodology

3.1 Steel Fixing & Molding

For analysing the Shear behavior of Reinforced concrete beams, four beams were casted, where each beam consisted of stirrups which are fixed at an angle of 300,450, 600 and 900, in beam, 1, 2, 3 and 4 respectively. The bar used for the stirrups is #3 bars and the bar used for main reinforcement is the #4 bar. The molds are made up of iron having dimensions of 1200*125*250 mm. These molds are fabricated in an iron workshop located near northern bypass Multan. Steel fixer was hired from local market for the preparing steel cage and bar fixation. The spacing from the bottom of mold is 25mm and the spacing from side to side of the mold is 25mm. Shear reinforcement is provided to hold the longitudinal reinforcement and take the shear to resist the diagonal tension cracking to which the structure is subjected.

3.2 Shear Reinforcement

The main reasons for providing shear reinforcement in RC beams was to prevent brittle shear failure after diagonal shear crack and to provide reserve strength even after the diagonal shear crack formation. It is also used for the redistribution of the stresses in the region of shear span and to impart ductility to the beam before shear failure. It can also reduce the diagonal crack width well within the limits and to provide reserve deflection. For analysing the shear behaviour of reinforced concrete beam, four beams named as (Beam 1, 2, 3, 4) whose stirrup angle is 30, 45, 60 & 90 degree are casted and tested.

3.2.1 90 Degree Shear Reinforcement

For the 90-degree steel fixing bar size #4 and bar size #3 are used. Bar size #4 is used as main reinforced bars and bar size #3 is used for stirrups as shown in Figure 1. The no of stirrups used for 900 beams are 9. The total net weight of steel for the 90-degree beam is 17 to 20kg approximately. During testing, the beam was in UTM machine and load is applied. The deflection behavior, loading capacity and the appearance of cracks on the beam are observed during the experimental investigation.

3.2.2 30 Degree Shear Reinforcement

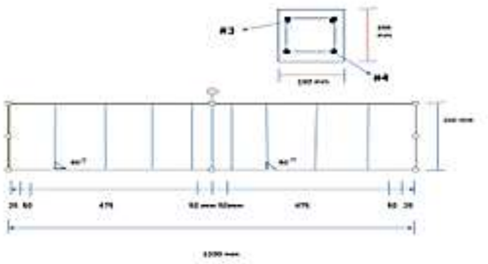
For the 30-degree steel fixing bar size #4 and bar size #3 are used. Bar size #4 is used as main reinforced bars and bar size #3 is used for stirrups as seen in figure 2. The no of stirrups used for 30degree beams are 7. The total net weight of steel for the 30-degree beam is 15 to 18kg approximately.

3.2.3 45 Degree Shear Reinforcement

For the 45-degree steel fixing bar size #4 and bar size #3 are used. Bar size #4 is used as main reinforced bars and bar size #3 is used for stirrups. The no of stirrups used for 45degree beams are 11in Figure 3. The total net weight of steel for the 45-degree beam is 20 to 22kg approximately.

3.2.4 60 Degree Shear Reinforcement

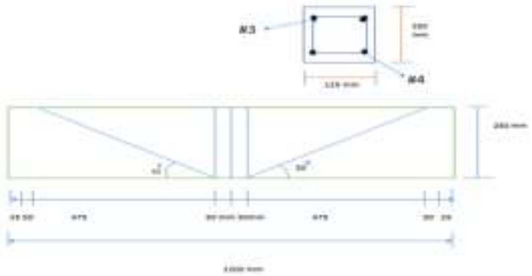
For the 60-degree steel fixing bar size #4 and bar size #3 are used. Bar size #4 is used as main reinforced bars and bar size #3 is used for stirrups. The no of stirrups used for 60degree beams are 17 in Figure 4. The total net weight of steel for the 60-degree beam is 22 to 25kg approximately.



Schematic Diagram of Beam 1 (90° Angle)

Steel reinforcement at the 90° Angle

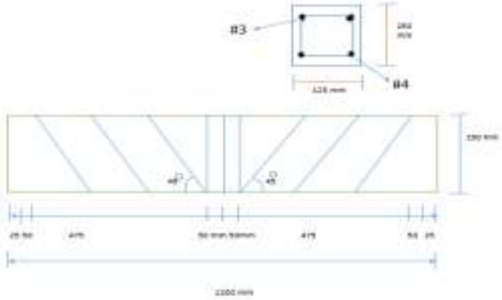
Figure 1 Schematic Diagram of 90 Degree Stirrups



Schematic Diagram of Beam 2 (30° Angle)

Steel reinforcement at 30° Angle

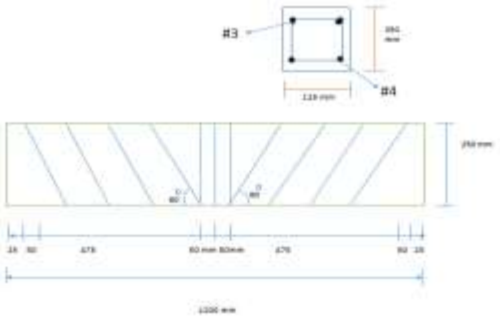
Figure 2 Schematic Diagram of 30 Degree Stirrups



Schematic Diagram of Beam 45° Angle

Steel reinforcement at 45° Angle

Figure 3 Schematic Diagram of 45 Degree Stirrups



Schematic Diagram of Beam 60° Angle)

Steel reinforcement at 60° Angle

Figure 4 Schematic Diagram of 60 Degree Stirrups

4. Concrete Casting

For analyzing the shear behavior of reinforced concrete beam, four beams (Beam 1,2,3,4) were casted initially whose stirrup angle were at 90^0, 30^0, 45^0 and 60^0 in beam #1, 2,3 and 4 respectively. The beam size used for this study was 125mm*250mm*1200mm.

5. Shear Behaviour

The structural behavior is investigated with the respective deflection of the conventional concrete with the shear reinforcement provided at the angle of 90°. Subjecting to loading and resulted cracks the beam # 1 showed the maximum load capacity of about 119kN with the 10 big cracks on the beam. The structural behavior is investigated along with the respective deflection of the conventional concrete in a beam # 2with the shear reinforcement provided at the angle of 30° in the next experiment. The beam 2 showed the maximum load capacity of about 81kN with 9 big cracks on the beam. The structural behavior is observed with the respective deflection in beam # 3 containing conventional concrete with the shear reinforcement at the angle of 45°.

The beam # 3 showed the maximum load capacity of about 162 kN with the 12 big cracks on the beam. The structural behavior of beam # 4 is also investigated along with the respective deflection. Where beam # 4 is made up of the conventional concrete with the shear reinforcements provided at the angle of 60°. The beam # 4 showed the maximum load capacity of about 147kN with the 14 big cracks on the beam. Wight and MacGregor (2009) report that in the design of reinforced concrete (RC) members, the load capacity during flexure is typically the primary consideration.

This determines the member size and the reinforcement needed to achieve the required moment resistance. Restrictions are applied to flexural reinforcement to ensure the structure fails gradually rather than suddenly. However, the shear is the only failure in concrete that is frequently sudden and brittle. Therefore, the shear strength must be higher than flexural strength in the shear design of RC members. For the purpose of calculation & result Beam shows the shear flexure failure at the load of 119KN as mentioned in Table 1. Ten cracks appeared on the beam as shown in Figure- 5.

Figure 6 present the stress strain curve of the beam # 1 when it is subjected to tensile loading in the UTM. It can be clearly seen in the fig-5 that the beam starts to show the phenomenon of shear cracking. The initial crack in the beam, as indicated on the Y-axis of Fig-6, appeared at a load of 53 kN with a strain of less than 0.55% on the X-axis. The second crack emerged under a UTM compressive load of 57 kN, with the strain percentage exceeding 3%. The third crack was observed at an applied load of 62 kN, with the strain surpassing 6%. The beam was giving cracks gradually as the compressive load applied by the UTM was increasing. The process of cracking went up to more than 5minuties. After that beam shows its last crack at the compressive load of 119KN and after the beam shows the flexural shear failure and fails.
Applying the compressive load by UTM, beam shows the shear flexure failure at the load of 81KN. Nine cracks appeared on the beam in Figure 7.

The stress-strain curve of beam # 2 under UTM loading is presented in figure-8. During the test under the UTM, we clearly observed the beam starting to show signs of shear cracking. The first crack appeared at 40 kN with a strain of less than 6.2% on the X-axis. As the compressive load increased to 45 kN, a second crack formed, with the strain exceeding 8%. A third crack was visible at 47 kN, with the strain going beyond 8.2%. The cracks developed gradually as the UTM applied more compressive load. This process continued for over 5-7 minutes. Finally, at a compressive load of 81 kN, the beam showed its last crack and then failed due to flexural shear.

Applying the compressive load by UTM, beam shows the shear flexure failure at the load of 162 kN as shown in Table 1. Twelve cracks have been appeared on the beam in Figure 9. From the Figure 10, it has been observed that the beam whose shear reinforcement is provided at the angle of 45 °C was laid under the UTM for testing purpose. During the test under the UTM it has been clearly observed the beam starts to show the phenomenon of shear cracking. The first crack in the beam became visible on the graph at a load of 113 kN, with the strain measuring less than 10.5%. As the compressive load increased to 127 kN, a second crack formed, showing a strain greater than 11.4%. Finally, a third crack appeared when the load reached 133 kN, with the strain exceeding 12.2%. The beam was giving cracks gradually as the compressive load applied by the UTM was increasing. The process of cracking went up to more than 5-7minuties. After that beam shows its last crack at the compressive load of 162kN and after the beam shows the flexural shear failure and fails.

Applying the compressive load by UTM, beam shows the shear flexure failure at the load of 147KN in Table 1. Fourteen cracks appeared on the beam shown in Figure 11. From the Figure 12, it has been observed that the beam whose shear reinforcement is provided at the angle of 600 was laid under the UTM for testing purpose. During the test under the UTM it has been clearly observed the beam starts to show the phenomenon of shear cracking. During the testing, we noticed the first crack in the beam when the load reached 69 kN. At that point, the beam had stretched by less than 7.5%, showing a minor amount of deformation. As we continued to apply more load, reaching 83 kN, a second crack appeared. The beam was now deforming more noticeably, with the strain exceeding 10%. Finally, at 107 kN, a third crack became visible. By this stage, the beam had stretched by more than 12.9%, indicating significant deformation and stress. These cracks on the graph show how the beam responded as we increased the load gradually. Each crack represents a point where the beam couldn't withstand the stress anymore, highlighting its structural limits under compression. The beam was giving cracks gradually as the compressive load applied by the UTM was increasing. The process of cracking went up to more than 7minuties. After that beam shows its last crack at the compressive load of 147kN and after the beam shows the flexural shear failure and fails.

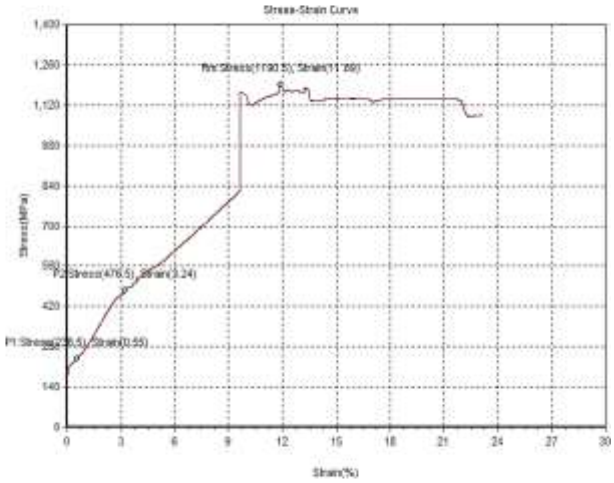
Cracking of Beam at 90° Angle

Flexural Cracks of Beam at 90° Angle

Figure 5 Cracking Behaviour of Beam having 90 Degree Stirrups

Table 1: Testing result of Beams Having Different Stirrups Angle

Sr #	**Sample Type**	**Dimensions (mm)**	**Area (mm^2)**	**Design Mix**	**Stirrup Angle**	**Compressive Load (kN)**	**No of cracks**
1	RC Beam	125*250*1200	150000	1:1.76:2.1	90°	119	10
2	RC Beam	125*250*1200	150000	1:1.76:2.1	30°	81	09
3	RC Beam	125*250*1200	150000	1:1.76:2.1	45°	162	12
4	RC Beam	125*250*1200	150000	1:1.76:2.1	60°	147	14



Figure# 6: Stress Strain Behaviour of Beam having 90 Degree Stirrups

Cracking of Beam at 30º Angle

Flexure Cracking of Beam at 30º Angle

Figure 7 Cracking Pattern for the beam at 30º angle

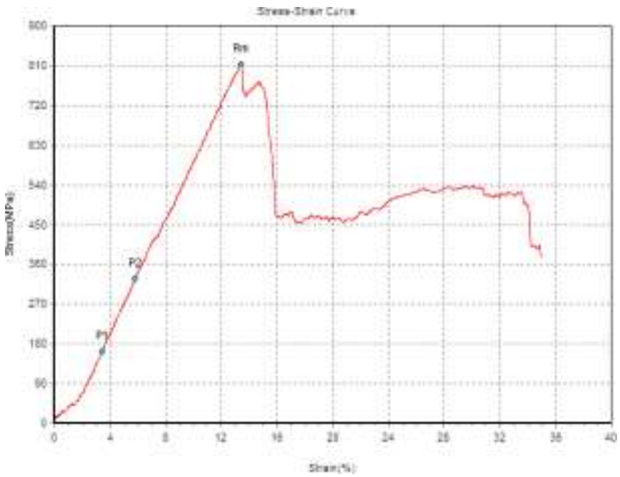


Figure 8 Stress Strain Behaviour of Beam having 30 Degree Stirrups

Cracking of Beam at 60º Angle

Flexural Cracking of Beam at 60º Angle

Figure 11 Cracking Pattern for the beam at 60º angle

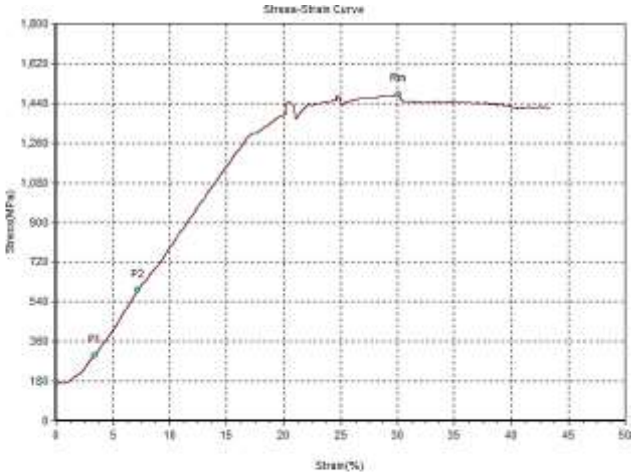


Figure 12 Stress Strain Behavior of Beam having 30 Degree Stirrups

6. Cracking Pattern Behavior

The failure modes of all designed beams with shear reinforcement upon testing under UTM are shown in Figure 5,7,9 and 11. It can be seen in these figures that all beams showed flexural shear failure without showing any anchorage failure. Flexural shear failure occurs in these beams through three main stages: At first, the crack begins to form at the bottom of the beam due to flexural tensile stress. In second stage, the crack bends in a diagonal direction as it travels towards the upper end of the beam along with continuation to propagate in length and widen in breadth. And, finally, when the diagonal tensile stress exceeds the tensile strength of the concrete, the RC element fails by crushing or by shear.

Flexural cracks form where the bending moment was maximum in the beam. For example, in a beam with uniformly distributed load, the flexural cracks are observed at the mid-span. Similarly, web shear cracks form at the locations of the beam where the shear force is maximum. In our study, all the beams exhibited pure shear failure without experiencing any problems related to anchorage failure. Each beam was designed with a consistent ratio of beam depth (d) to effective depth (a), which was set at 2.87.

This design parameter led to the formation of diagonal cracks across all beams during testing. These diagonal cracks are a visible sign of how the beams responded to the forces they were subjected to. They show where the beams were most vulnerable to shear stress, highlighting a critical aspect of their structural behaviour under load. Alengaram and colleagues (2011) conducted research on PKSC and NWC concrete beams to understand how they performed under shear forces, with and without additional shear reinforcement.

They discovered that PKSC beams without this reinforcement often failed due to shear alone. Interestingly, some beams from both types of concrete also experienced anchorage failure, especially near the supports where stress concentrations were most intense. This underscores the critical role of shear reinforcement: its absence can lead to failure primarily caused by shear stress, rather than other factors like anchorage failure. In practical terms, when a beam supports a uniformly distributed load, it's common to see flexural shear cracks forming where both the bending moment (the force causing the beam to bend) and shear stress (the force causing layers of the beam to slide past each other) are most pronounced.

These cracks typically appear some distance away from the supports and mid-span of the beam. To put it simply, flexural shear failure begins when cracks develop due to bending stresses and progresses to a point where the concrete fails under shear stress. This highlights the critical zones where the structural integrity of the beam was most vulnerable to the simultaneous effects of shear and bending forces.

7. Conclusions

Concrete play a vital role in construction industry. The demand of concrete structural members is increasing day by day. The concern is growing in the construction industry upon the failure modes of RC elements, especially in the Shear Behaviour of concrete structural members with reinforcement. After investigating the failure modes of four RC beams with shear reinforcement at different angles by performing test under UTM loading, it is concluded that the beams reinforced in shear at the angle of 45 degrees shows higher shear resistance and capacity as compared to the other shear reinforcements, which makes this strategy as commercially viable method to be applied. Furthermore, in terms of failure modes, all the four types of reinforcements showed similar failure mode of shear-flexure failure.

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