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STUDIES IN BOND STRENGTH IN RC FLEXURAL MEMBERS

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ABSTRACT

This paper presents results of an experimental investigation of actual performance of the reinforced concrete beam in bond under flexure, when reinforced with tension steel (TMT Rebar) is going to consider. The major variables studied include lap length and percentage of steel. Five different lap lengths and three different type longitudinal steel were used. Bond strength comprises two basic components identified as adhesive bond and friction bond. It is observed that adhesive force increases with the increase in compressive strengths of concrete (34 MPa and 37 MPa concrete). The frictions bond component is observed to increase with the increase in bar diameter. Frictional bond strength exhibits increasing characteristics with increase in lap length up to about 400 mm. beyond which it remains constant. For the same lap length, it is observed that bond strength increases by as much as 35 percent with increasing bar diameter. The value of development length obtained using ACI 318: 1999, BS 8110: 1985 and IS 456: 2000 is compared, it is observed that the value of development length obtained in tension using IS Code is 8% more as compared to BS Code and 11% more as compared to ACI Code, while the development length obtained in compression using IS Code is 3.5 % more as compared to BS Code and 17 % more as compared to ACI Code.

Keywords: flexure, bond strength; lap length; percentage of steel, adhesion, friction

1. INTRODUCTION

The main parameters that influence the bond strength between steel reinforcing bars and concrete are well documented in the technical literature. Important among these parameters include development/splice length, diameter of the reinforcing bar, and concrete compressive strength [1, 2, 3, 4].

The fundamental assumption of flexure, viz. plain section remains plain even after bending becomes valid in reinforced concrete only if the mechanism of bond is fully effective. The joint behavior of steel and concrete in reinforced concrete member is base on the fact that a bond is maintained between the two materials after the concrete hardens. If a straight bar of round section is embedded in concrete, a considerable force is required to pull

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the bar out of the concrete. If the embedded length of the bar is long enough, the steel bar may yield, leaving some length of the bar in the concrete. The bonding force is friction between steel and concrete. The bond is caused by adhesion and by the grip of the concrete on the steel resulting from the shrinkage of the concrete in setting. For reinforced concrete beams, the load directly acts on concrete whereas the reinforcement subjected to transmitted loads. The tension in the steel is transmitted by the concrete to the steel by surface resistance between concrete and steel. This surface resistance is known as bond stress. It is the force per unit of nominal surface area of reinforcing bar acting on the interface between the bar and the surrounding concrete [5-8].

2. EXPERIMENTAL PROGRAMME

As part of experimental work, a total of thirty beams were tested. The main object of these tests was to study the behaviour and strength in bond of concrete. The major variables studied included lap length and percentage of steel. The mix was with Ordinary Portland cement (OPC) 43-grade, crushed stone of 20mm maximum size, and river sand from Ranipur (Haridwar district). The physical properties of cement and aggregates are tabulated in Table 1 and 2. The water cement ratio was 0.47 by weight, cement content 400 kg/m^3, and 28 days average cube strength was 37.3 N/mm^2 and cylinder strength 32.4 N/mm^2.

Table 1. Physical properties of cement

Standard consistency (%)	27
Specific gravity (gm/cm^3)	3.15
Specific surface (cm^3/gm)	2755
Initial setting time (min.)	110
Final setting time (min.)	175
Compressive strength (MPa)	
3-day	24.86
7-day	34.40
28-day	45.98

Table 2. Physical properties of aggregate

Type of aggregate	Specific gravity	Fineness modulus
Fine (River sand)	2.61	2.45
Coarse (crushed stone)	2.63	7.70

Beams of 1.2 m lengths and 100 mm x 150 mm cross-section have been provided with one reinforcing bar each. The bar diameter has been kept at 8 mm, 10 mm and 12 mm with lap length of 250 mm and 450 mm. The beams have been subjected to bending moment developing under four-point loading system (two active and two passive loading). The appropriate dimensions of the loading device are shown in Figure 1 .Due to less magnitude of shear span 'a', limited amount of bending moment (Pa/2) can only be induced into the beams.

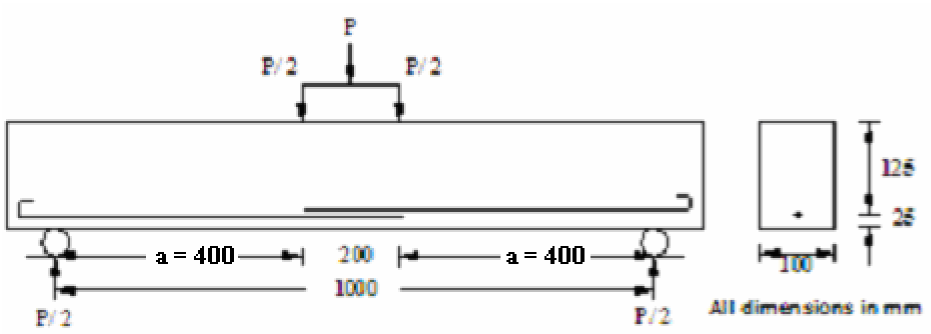

Figure 1. Four-point loading system

With increasing lap length of reinforcing bars, higher amount of bending stress against bonding needs to be developed. For higher amount of moment, the shear span 'a' needs to be increased. Also, to avoid physical bonding of the bar, this will resist slippage, the shear span 'a' needs to be increased. Based on these considerations, beams of 1.8 m lengths have been used in further experiments. The concrete used in these beams is also a little higher in compressive strength (37 MPa against 34 MPa for 1.2 m beams). The lap lengths have been kept at 200, 300, 400, 500 and 600 mm for steel bars of 8, 10 and 12 mm diameter. The failure load has been taken as the first chunk of concrete segment slipping out from the bottom of the beam in the mid-span zone where the magnitude of bending moment is maximum and constant.

3. DISCUSSION OF TEST RESULTS

All specimens developed clear bottom splitting or side splitting cracks were preceded by flexure cracks forming simultaneously at both ends of the splice. Following the formation of the splitting cracks, the load resistance dropped suddenly and diminished gradually with increasing load. As shown in Figure 2, 3 and 4 with increasing lap length from 200 to 600mm, bond strength increases linearly.

Cement content: 400kg/m^3
Lap lengths: 200mm to 600mm

Effective depth: 125mm; a/d: 4.67
Steel: 1-8mm TMT Bar
fy = 448MPa

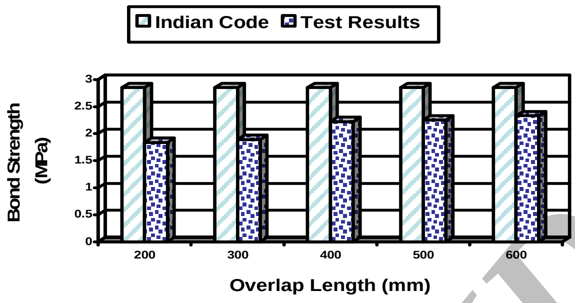

Figure 2. Bond Strength: Indian Code Provisions Vs Test Results (Bar Dia. 8mm)

Cement content: 400kg/m^3
Lap lengths: 200mm to 600mm

Effective depth: 125mm; a/d: 4.67
Steel: 1-10mm TMT Bar
fy = 397MPa

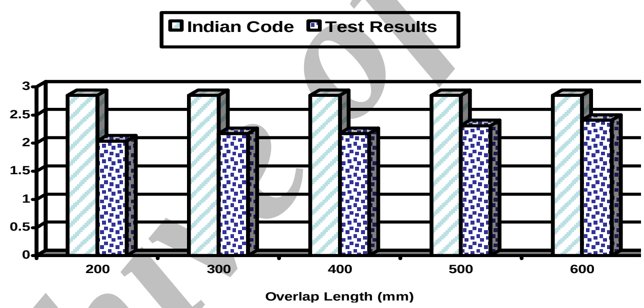

Figure 3. Bond Strength: Indian Code Provisions Vs Test Results (Bar Dia. 10mm)

Cement content: 400kg/m^3
Lap lengths: 200mm to 600mm

Effective depth: 125mm; a/d: 4.67
Steel: 1-12mm TMT Bar
fy = 467MPa

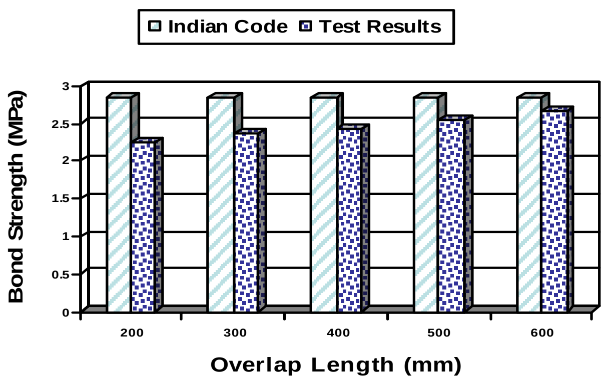

Figure 4. Bond Strength: Indian Code Provisions Vs Test Results (Bar Dia. 12mm)

Cement content: 400kg/m^3
Lap lengths: 200mm to 600mm

Effective depth: 125mm; a/d: 4.67
Steel: 1-8mm TMT Bar
fy = 448MPa

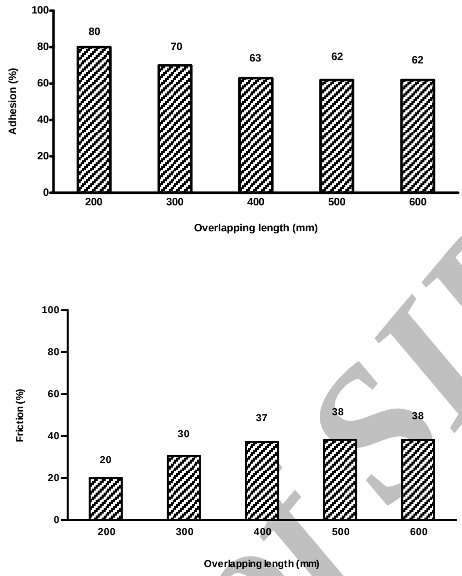

Figure 5. Lap length Vs Adhesion, Friction for 8mm TMT Bar Cement Content

Cement content: 400kg/m^3
Lap length: 200mm
Effective depth: 125mm; a/d: 4.67

Steel: 8mm TMT Bar: fy = 448MPa
10mm TMT Bar: fy = 397MPa
12mm TMT Bar: fy = 461MPa

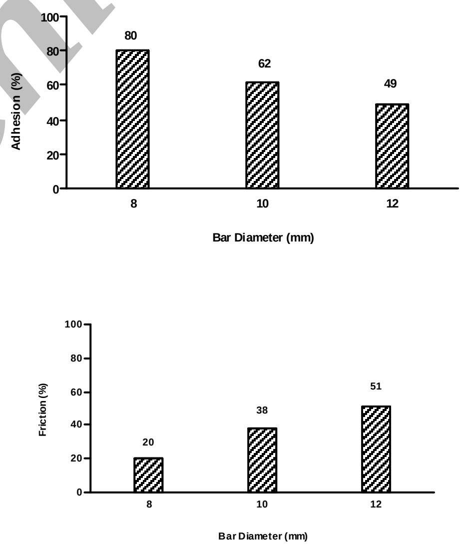

Figure 6. Diameter of Bar Vs Adhesion, Friction for 200mm Lap Length

Bond strength has two components, namely an adhesion component and a friction component. Adhesion component is mainly attributable to the properties of concrete such as compressive strength and shrinkage. Friction component, on the other hand, depends on the nature of the lateral surface of steel bars (shape and size of longitudinal and transverse ribs), yield strength of steel (higher the yield strength lower the strains for the same value of stress) and the shape and size of the coarse aggregate (interlocking effect between the ribs and the coarse aggregate particles). It is, therefore, pertinent to asses quantitatively the contributions of the two components so that attempts may be made to further enhance the overall bonding between the two materials. Figure 5 show that with the increase in overlapping length from 200 to 600 mm adhesion between concrete and steel decreases from 80 to 63 percent thereafter, it remains constant and with the increase in overlapping length from 200 to 600 mm friction between concrete and steel increases from 20 to 37 percent thereafter, it remains constant. Figure 6 shows with the increase in diameter of steel bar, the adhesion between the concrete and steel decreases linearly from 80 to 49 percent and with the increase in diameter of steel bar, the friction between the concrete and steel increases linearly from 20 to 51 percent.

Table 3. Development length (mm): (Code: ACI 318: 1999, BS 8110: 1985 and IS 456: 2000/ bar dia: 8mm, 10mm, 12mm)

Nature of force in the bar	**Bar Diameter (mm)**	**Code**		
		IS 456: 2000	**BS 8110: 1985**	**ACI 318: 1999**
Tension	8	273	256	305
	10	341	283	305
	12	410	396	350
Compression	8	219	203	305
	10	242	225	305
	12	338	314	305

The development length for 8 mm, 10 mm, 12 mm bar diameters according to ACI 318: 1999[9], BS 8110: 1985[10] and IS 456: 2000 [11] is tabulated in Table 3. The value of development length obtained using ACI 318: 1999, BS 8110: 1985 and IS 456: 2000 is compared, it is observed that the value of development length obtained in tension using IS Code is 8 percent more as compared to BS Code and 11 percent more as compared to ACI Code, while the development length obtained in compression using IS Code is 3.5 percent more as compared to BS Code and 17 percent more as compared to ACI Code.

3. CONCLUSIONS

Based on the results of this experimental study the following conclusions can be drawn:

- Bond strength comprises two basic components identified as adhesive bond and friction bond. It is observed that adhesive force increases with the increase in compressive strengths of concrete (34 MPa and 37 MPa concrete).
- The friction bond component is observed to increase with the increase in bar diameter. With increasing bar diameter, it becomes possible to improve the shape and size of ribs on the bars. The enhanced shape and size of the transverse ribs are expected to contribute more than the longitudinal ribs.
- Frictional bond strength exhibits increasing characteristics with increase in lap length up to about 400 mm. beyond which it remains constant. It means that the shape and size of ribs plays a limited role in the overall bond strength development.
- For the same lap length, it is observed that bond strength increases by as much as 35 percent with increasing bar diameter.
- The value of development length obtained using ACI 318: 1999, BS 8110: 1985 and IS 456: 2000 is compared, it is observed that the value of development length obtained in tension using IS Code is 8 percent more as compared to BS Code and 11 percent more as compared to ACI Code, while the development length obtained in compression using IS Code is 3.5 percent more as compared to BS Code and 17 percent more as compared to ACI Code.

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