Effect of Mechanical Anchorages on Development Length

Mephin Mathew Jose
Department of Civil Engineering
Saintgits College of Engineering
Kottayam, India

Afia S. Hameed
Department of Civil Engineering
Saintgits College of Engineering
Kottayam, India

***Abstract*— Bonding of steel in concrete is very necessary, such that these can act jointly without slip in the loaded structure. Hence the members should be suitably anchored by giving extra length, which is well-known as development length. Magnitude of this bond is calculated by bond stress. Bond stress acts on the boundary between the bars and the concrete, along direction parallel to bars. Overall bond-failure can be avoided by providing development length. This study investigates on bond strength corresponding to various welded plate mechanical anchorages on 8mm diameter HYSD bars of different characteristics strengths, which are bonded inside concrete.**

Keywords*— *Welded plate mechanical anchorages, bond stress, development length, HYSD bars

I. INTRODUCTION

Reinforced concrete materials are composites in which the low ductility and low tensile-strength properties of the normal concrete are counteracted by adding reinforcement of higher ductility and tensile strength. The amount of reinforcement in concrete depends on compatibility of the materials in the concrete, to work together to resist the external load acting on the concrete member. Reinforcing elements such as reinforcing bars has to go through the equivalent strain and deformation as that of the surrounding concrete, in order to avoid discontinuity or separation of the materials under load.

To improve a group of properties of the reinforced concrete section, in addition to the above parameters, the yield-strength and young's modulus of reinforcements should also be considerably superior to that of the concrete. As a result materials like aluminum, brass, rubber, bamboo etc are not appropriate to develop the essential bond that is vital involving them. But steel, fiber glass, etc have the major parameters such as ductility, yield strength and bond value.

Bond strength arises from mixture of numerous factors like the mutual adhesion among concrete and steel interface, and pressure of hardened concrete adjacent to bar. Additionally, friction of surfaces of the bar and the concrete causes micro movements, which results in improved confrontation to slippage. The above effect can be called as bond.

In short, bond strength is affected by the subsequent factors:

- Amount of adhesion among the concrete and the bar,
- Gripping effect - resulting from the drying shrinkage of concrete and shear interlock of bar projections and the nearby concrete,
- Frictional resistances to sliding and interlocks as reinforcing elements are subjected to the tensile stresses,
- Concrete quality,
- Mechanical anchorage effect, of end of bars through splicing, crossbars and hooks,
- Shape, Diameter and spacing of the reinforcement.

The individual effect of the above points are difficult to split or quantify. Shear interlocking and quality of concrete can be noted as key factors.

In a study which investigated Rebar – concrete interfacial properties by single rebar pullout tests, found that bond failure was the dominant failure mode, however either split failure and rebar yielding could also occur [1].

Another study found that the various parameters like strength of concretes, bar diameters, lateral confinements and embedment lengths has effect on bond [2]. Bond lengths considered for this study were 150mm and 50mm, with varying bar diameters. Bar diameters considered were 20mm and 16mm. Also the bars were set in the concrete with confinement and with-out confinement, using the spirals and the ties. It was found that, as concrete strength increases, slip at failure decreases.

In a study with mechanical anchorages [3], the anchorages were detailed according to ACI-318 (90 Standard bent anchorages), ACI-352 (Mechanical anchorage) and IS-456 (Full anchorage), along with the confinement according to IS-13920. Huge improvement in seismic performance, strength and ductility was found, when proposed hair-clip bar along with the X-cross bar, all together with the mechanical anchorage detailing for the high seismic prone areas.

Possibility of using steel plates for the anchorages are also studied [4]. It investigated on the practicability of reducing the development length, of the beam reinforcements by placing steel plates as anchorages (various sizes). Mechanical anchorages are also proposed as alternatives for IS code ductile detailing with about 20% increase in the ductile capacity [5].

Studies have also proposed that the development length could be expressed in terms of steel stress, concrete strength, bar diameter, minimum side or bottom cover, and transverse reinforcement. As a whole proper amount of development length and proper bond between bars and concretes are very important for a structure.

Development length depend on a mixture of parameters: Grade of steel Grade of concrete, Diameter of steel bar, Type of steel bar and so on. Rebar pull out test can be used to investigate the rebar-concrete interface properties. Use of welded plate anchorages can help in reducing the anchorage length required.

II. EXPERIMENTAL INVESTIGATION

A. Experimental Sample

Experimental study was done to study the bond strength corresponding to various welded plate mechanical anchorages (31.75mm x 31.75mm x 6mm, 50.8mm x 50.8mm x 6mm) on 8mm diameter HYSD bars of different grades (Fe 415, Fe500D) , which are bonded inside concrete (M25). Fig.1 shown the mechanical anchorages considered in the study.

For this study the mechanical anchorages are made by welding the metal plates of various sizes to the 8mm diameter bars. Plates are welded to the bars such that he plates are placed at the bottom of the cube as casted.

Fig 1. Mechanical Anchorages

The cube specimens are casted by placing the anchorages vertically in the cube moulds, as shown in Fig.2.

Fig 2. Casting of Specimens

Top surface of cube specimens are capped with a small cover of cement paste and the capped specimen for the testing is shown in the Fig.3.

Fig 3. Test Specimens after final capping

The dimension of each specimen is shown in the Fig.4.

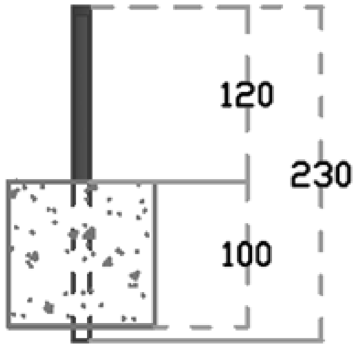

Fig 4. Test Specimens detailing

B. Experimental Setup

To study the bonding properties between the rebar and the concrete pull-out test is done as per IS:2770 (Part 1) - 1967. As per the same code, for testing of the 8 mm diameter bars, 10cm cube is taken as the specimen size with 1 cm projection of the bar at the bottom face.

The test setup is designed and produced as per the test requirements, as per the Indian standards. 20mm thick plates are used to produce top and bottom plate. Four bolts of diameter 20mm connect the two plates. The Test set up, top plate detailing, UTM, used for testing are shown in Fig.5.

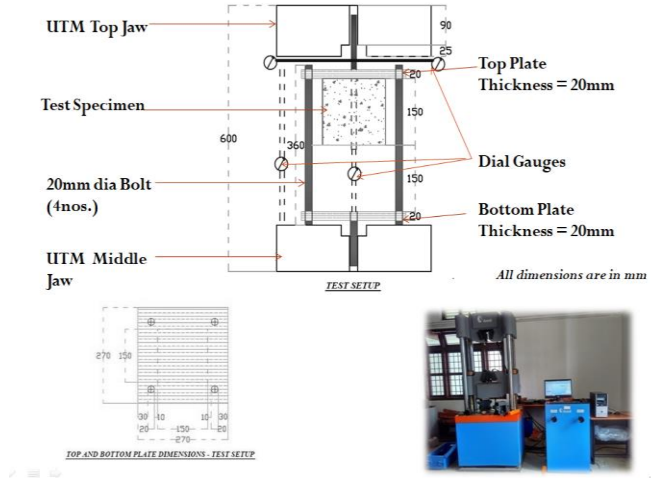

Fig 5. Test set up, top plate detailing, UTM, used for testing

For testing the specimens the specimen is mounted in UTM and is axially pulled out from cube, as shown in Fig.6. The pull is given on the end of bar which projects out from the top of the specimen as casted. Dial gauges are used to record the slip of the rebar from the concrete cube. The loading is continued and the corresponding readings of the dials are recorded.

This procedure is continued until the following takes place:

a) Yield point of the bars is reached,

b) Failure of concrete,

c) minimum slip of 2.5 mm is seen at loaded end of the bar.

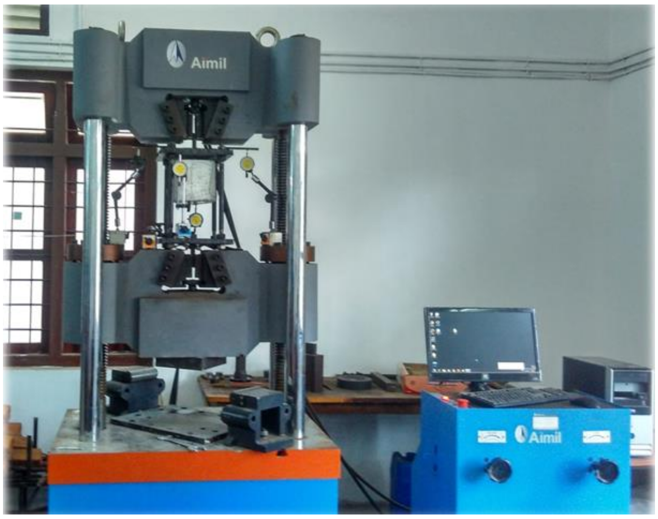

Fig 6. Test set up mounted in UTM

III. RESULTS AND DISCUSSION

The results of the pullout test is tabulated and shown in the table below. Table 1 shows specimen details and average values of the Load at the slip, bond stress and type of failure occurred. All the specimens failed by slip of bar.

TABLE 1

Sample	Bar Diameter (mm)	Concrete Grade	Steel Grade	Plate Size	Load at slip (kN)	Bond Stress (N/mm²)
A1	8	M25	Fe415	No Plate at end	7	2.7
B1	8	M25	Fe415	31.75 x 31.75 x 6mm	12.6	5.0
C1	8	M25	Fe415	50.8 x 50.8 x 6mm	23.5	9.4
D1	8	M25	Fe500D	No Plate at end	10	3.9
E1	8	M25	Fe500D	31.75 x 31.75 x 6mm	17.2	6.8
F1	8	M25	Fe500D	50.8 x 50.8 x 6mm	33	13.1

As per IS 456:2000, Clause26.2.1,

$$\text{Development Length} = (\Phi\ \sigma_s / 4\ \tau_{bd})$$

where,

Φ = bar diameter

σ_s = Stress in bar, at section taken at design load

τ_{bd} = Design bond-stress

Development length required for the samples with respect to its bar diameter, grade of steel and bond stress values are given in Table 2:

TABLE 2

Sample	Bar Diameter (mm)	Steel Grade	Bond Stress (N/mm²)	Development Length (mm)
A1	8	Fe415	2.7	267.44
B1	8	Fe415	5.0	144.42
C1	8	Fe415	9.4	76.82
D1	8	Fe500D	3.9	223.07
E1	8	Fe500D	6.8	127.94
F1	8	Fe500D	13.1	66.41

Load vs Slip at both the loaded and free ends are shown in Fig.7.

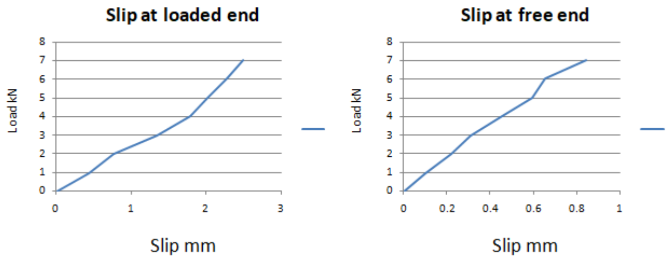

Fig 7a. Specimen A1

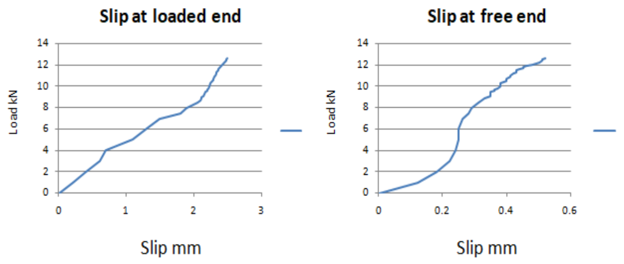

Fig 7b. Specimen B1

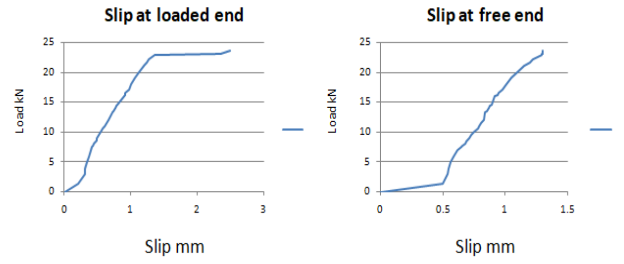

Fig 7c. Specimen C1

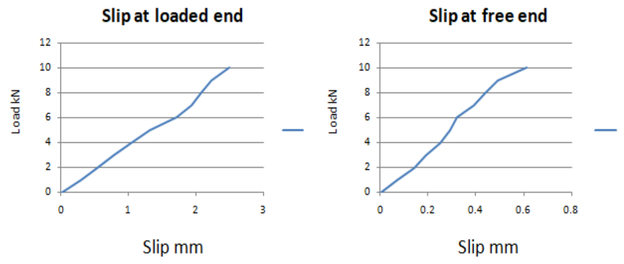

Fig 7d. Specimen D1

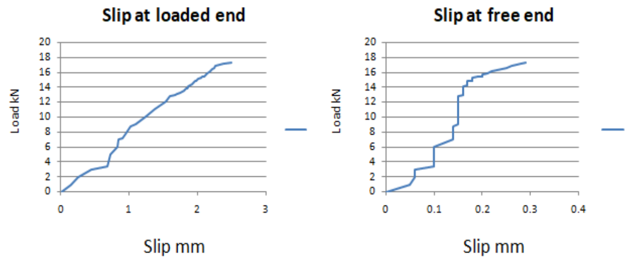

Fig 7e. Specimen E1

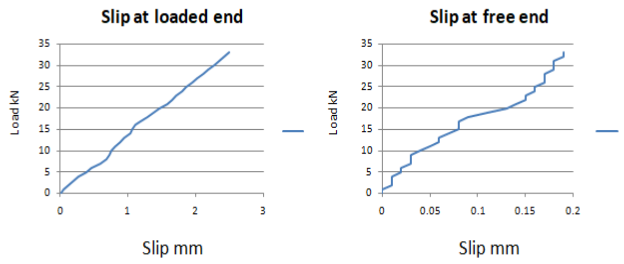

Fig 7f. Specimen F1

IV. CONCLUSION

In this study all the parameters are made constant except the steel grade and the plate used to create the mechanical anchorages. From the obtained data it is clear that the failures are due to the slip of the bar as shown in Fig7. When mechanical anchorages are used the load at slip and correspondingly the bond stress also increased. Again as the areas of the mechanical anchorages are increased, these values again increased as shown in the Table1.

Corresponding to the bond stress values of each specimen, calculated development-length shows an inversely proportional pattern. When mechanical anchorages are used the development length requirement gets reduced to about half and one-fourth for the plate sizes 31.75x31.75x6mm and 5038x50.8x6mm respectively.

As the steel grade of the bar varies, the bond stress values also varies. Fe 500D shows more superior values than Fe415 for the equivalent specimens.

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