International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2014 Vol. 4 (1) January-March, pp.72-81/Appa Rao
Research Article

PARAMETERS INFLUENCING BOND STRENGTH OF REBARS IN REINFORCED CONCRETE

***G. Appa Rao**
Department of Civil Engineering, Indian Institute of Technology Madras, Chennai-600 036, India
**Author for Correspondence*

ABSTRACT
This paper discusses experimental investigations on bond stress–slip response in concrete in end anchorages of steel reinforcement. The influence of embedment length, bar diameter and lateral confinement on the end anchorage bond strength, and bond stress-slip response has been studied. Twenty four anchorage pull-out specimens provided with two embedment lengths 50mm and 150mm and two different bar diameters 16mm and 20mm with three types of lateral confinements. The compressive strength of concrete used in this study was 50 MPa. The bond strength of reinforcing bars in concrete decreases with increasing the embedment length. Relatively brittle failures have been observed in members with large embedment length. Further, the bond strength of larger diameter bars decreases as compared with smaller diameter bars. The plain concrete pullout specimens exhibited concrete splitting failures, while the presence of lateral confinement altered the failure from concrete splitting to pullout of rebars. The lateral confinement increases the bond strength and the length of post-peak stress-slip response, thus showing the improvement of ductility.

Keywords: *Concrete, Bond Strength*

INTRODUCTION
The behaviour of reinforced concrete (RC) structures depends up on the type of bond developed between the steel reinforcement and the surrounding concrete. Bond stress is the tangential shear or friction developed between the reinforcement and the surrounding concrete that transfers the force onto the reinforcement. To ensure the integrity of various constituent or composite action of concrete and steel reinforcement, sufficient bond should be developed by the surrounding concrete with the reinforcement. Proper bond between the steel reinforcement and the surrounding concrete is also crucial for the overall strength and serviceability of RC members. The failure of RC structures may be due primarily to the deterioration of the bond. Hence, while modeling an RC member for inelastic dynamic analysis, the slip of the rebars in the interior beam-column joints needs to be considered (ACI 352, 1985).

Review of Literature
Bond in RC members depends on type of bar, state of stress in both bar and concrete, strength of concrete, concrete cover, confinement, space between adjacent bars, number of layers of reinforcement bars, position of reinforcing bars, and casting direction. The type of cracking leading to failure has been investigated using deformed bars in tension by injecting ink around the bars (Rehm, 1961; Goto, 1971). The bond strength of rebars in concrete decreases as the embedment length increases, and decreases with increasing the bar diameter (Mathey and Watstein, 1961). The previous investigations proved that the bond strength of rebars in concrete is influenced by the development length rather than the bar diameter (Ferguson et al., 1962). The ultimate bond strength seems to be a function of $\sqrt{f_c'}$ when other parameters are constant, since the bond strength is related to the tensile strength of concrete. Studies on understanding the nature of bond, modes of failure and factors influencing the failure, bar spacing and beam width, end anchorage, flexural bond and anchorage bond with high strength ribbed bars have been reported (Ferguson et al., 1966*)*. The slip of deformed bars is due to (i) splitting of concrete by wedge action, and (ii) crushing of concrete in front of the ribs (Rehm, 1961; Lutz and Gergely, 1967).
Nilson (1972) used slope of steel strain curve to evaluate the bond stress at a given load in reinforcing bar, and a new test method was adopted to study the local slip, secondary cracking and strain distribution in

concrete (Jiang et al., 1984). A bond stress-slip model has been proposed to predict the load end slip and anchorage length of bars extended from adjoining beams in to exterior columns under large nonlinear actions (Ueda and Hawkins, 1986). Effect of bar diameter, confinement and strength of concrete on the bond behaviour of bar hooks in exterior beam-column joints has been reported (Soroushian, 1988). The bond strength decreases as the bar diameter increases. The post-peak bond-slip response was not influenced by the bar diameter (Soroushian and Choi, 1989), while confinement has direct influence on the local bond stress (Soroushian et al., 1991). A new bond stress-slip response has been simulated recently by Abrishami and Mitchel (1992). However, consistent bond stress-slip response was obtained on short embedment length (Malvar, 1992). A mathematical model for bond stress-slip response of a reinforcing bar due to cyclic load has been reported (Yankelevsky et al., 1992). Other models to predict the tensile strength of concrete from the pullout load has been reported (Bortolotti, 2003). Confinement by ordinary steel reinforcement has improved the bond strength with significant ductility (Harajli et al., 2004). Several studies on bond in normal strength concrete (NSC) have been reported (Jian et al.,1984: Somayaji and shah, 1981). In high strength concrete (HSC), increasing the development length does not seem to increase the bond strength of deformed bars when the concrete cover is relatively small. A minimum confinement reinforcement needs to be provided over the splice length in RC members when HSC is used (Azizinamini et al., 1993, Azizinamini et al., 1999a). An expression has been proposed to estimate the extra confinement reinforcement (Azizinamini et al., 1999b). The bond strength decreases slightly with increase in the bar diameter, while the frictional resistance does not depend on the bar diameter, lug spacing or relative rib area (Eligehausen et al., 1983). More general information on the local bond can be seen (CEB-FIP Report, 2000).

Research Significance

Significant research efforts have been made on anchorage bond in normal strength concrete (NSC). However, a bond strength and its model need to be developed for HSC members since HSC RC members tend to fail in brittle manner. Further, there is a need to re-evaluate the design requirements in the codes of practice vis-à-vis crack widths and spacing, deflection, rotation capacity, anchorage and splice length, to propose new test procedures and assessment criteria for bond strength of bars incorporating various influencing parameters and with modified surface characteristics. This study attempts to investigate the influence of embedment length on bond strength and bond stress-slip response in RC members with high strength deformed bars for varying bar diameter and confinement.

Development Length in Codes of Practice

For design purpose, the codes of practice recommend provisions for development length of rebars in concrete in terms of the mean bond stress. The design equations provide development length necessary to achieve the full yield strength of reinforcement bar. The minimum embedded length required to develop the yield strength of the rebar is known as the development length. However, the bond stress is an important factor for the development of stresses in the reinforcing bars. ACI code (ACI 318-2005) provisions for development length stipulate an upper limit of concrete compressive strength of 69 MPa. The reason for this upper limit is due to lack of confirmed test data on HSC. The development length of rebar at a critical section can be estimated by,

$$l_d = \frac{9}{10}\frac{f_y}{\sqrt{f_c^{'}}}\frac{\psi_t \psi_e \psi_s \lambda}{\left(\frac{c_b + K_{tr}}{d_b}\right)} d_b \qquad (1)$$

Where,
d_b = Diameter of bar
λ = light weight aggregate factor
ψ_t = top bar effect factor
ψ_e = coating effect factor
ψ_s = rebar size factor
C_b = Cover to reinforcement bar

K_{tr} = Transverse reinforcement index
f'_c = Strength of concrete
f_y = Yield strength of steel
Euro Code 2 (1992) provides a simple expression for estimating the development length of reinforcing bars in concrete in the following form.

$$L_d = \frac{f_{yd}\ \varphi}{4\ f_{bu}} \quad (2)$$

The Indian standard (IS 456–2000) considered the basic development length as a function of yield strength of reinforcement, diameter of rebar. The design bond strength is a function of the compressive strength of concrete as given below

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}} \quad (3)$$

The development length requirements specified by the codes of practice indicate that the bond strength of rebar in concrete is a variable. However, the provisions by various codes of practice are applicable to conventional strength concretes.

Local Bond Stress vs. Slip Response

The local bond stress-slip response is characterized by the variation of local bond stress, 'τ' with the corresponding slip,'s'. The bond stress can be described as a power function of slip i.e. $\tau = a \cdot \Delta^b$. The constants 'a' and 'b' depend on the type of bar and compressive strength of concrete. The constant 'a' depends on the compressive strength of concrete, f_c and can be expressed as, a = kf_c. Few models describe the bond stress as a function of slip alone (Nilson 1972, Mirza and Houde 1979), which are applicable to unconfined concrete with a very small value of slip (s < 0.1mm). The bond strength is a function of compressive strength of concrete. The diameter of the bar is not incorporated in these models. However, the information on bond stress- slip have been limited to conventional concrete. The models proposed by Ciampi *et al.*, (1981, 1982) and Eligehausen *et al.*, (1983) considered the other influencing parameters. As shown in Fig. 1, the bond stress-slip model has three parts. The ascending part of the model is defined by

$$\tau = \tau_1 \cdot \left(\frac{s}{s_1}\right)^{\alpha} \text{ for } 0 \le s \le s_1 \quad (4)$$

The second part is a horizontal plateau at $\tau_{max} = \tau_1 = \tau_2$ between $s_1 \le s \le s_2$, and third part is a linear descending branch starting from bond stress "τ_2" with slip "s_2" and ending at a residual bond stress "τ_3" at a slip of "s_3". The value of "α" is obtained as 0.4 from the regression analysis, for high strength concretes. The ultimate bond strength is $\tau_1 = 2.5\ f_c^{1/2}$, which overestimates the bond strength of rebar in HSC.

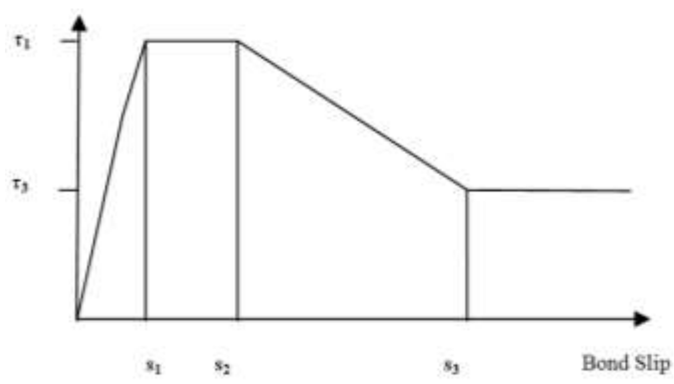

Figure 1: Typical bond stress-slip model

International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2014 Vol. 4 (1) January-March, pp.72-81/Appa Rao
Research Article

MATERIALS AND METHODS

Materials

Portland Pozzolanic Cement (PPC) was used for preparation of end anchorage pullout specimens. The natural river sand, and normal weight granite coarse aggregate of 20mm maximum size were used in the concrete. The main steel reinforcement is of high yield strength deformed (HYSD) bar of diameters 16 mm or 20 mm was adopted as anchorage reinforcement. 6mm diameter plain mild steel (MS) bars were used as spiral confinement reinforcement and closed stirrups or rings. The arrangement of longitudinal and lateral reinforcement in pullout specimen is shown in Fig. 1. The concrete mix proportions were 1: 1.64: 3.02: 0.35 with cement content = 400 kg/m^3 and water-cement ratio = 0.35 for producing 50 MPa compressive strength. Three standard cubes of size 150mm x 150mm x 150mm were also cast along with the anchorage pullout specimen to determine the compressive strength of concrete.

Test Geometry

The test specimen was basically a concrete cube 150mmx150mmx150mm with a reinforcement bar embedded coaxially with nominal spiral reinforcement surrounding the bar (IS: 2770-1997). Well seasoned wooden moulds were used to cast the pullout specimens. The main longitudinal reinforcement bars were placed in the horizontal direction. One end of the bar was projected about 15mm to measure the slip of the bar at the free end, while the loaded end was extended up to 750mm in order to grip it in the machine and transfer the force. Typical pullout specimen is shown in Figure 1. The pullout studies were done for two different bar diameters, 16mm and 20mm, to understand the influence of bar diameter on the bond strength with different embedment lengths. To achieve 50mm embedment length at the centre of the pullout specimen, PVC sleeves were covered at the ends to unbond the rebars. The slip was recorded at both the loaded and free ends of the reinforcement bar. After twenty four hours of casting of concrete, the pullout specimens were demolded and cured for 28 days. The main longitudinal bar was embedded with different confinements by spirals and stirrups or ties along with the controlled pullout specimens without confinement.

Figure 1: Arrangement of Reinforcement and typical Pullout specimen

Testing Procedure

The pullout tests were conducted under displacement control using 250kN capacity actuator. The pullout specimen was accommodated in a steel frame that could be inverted and hung from the actuator. To reduce the frictional resistance of the bearing steel plates on the free movement of concrete specimen, Teflon sheets were placed between the concrete and steel plate of the frame. A load cell along with two linearly variable differential transducers (LVDTs) were mounted with the test specimen to measure the load applied and slip of the two ends of the rebar. Electrical resistant strain gauges were also mounted on the main longitudinal reinforcing bar to measure the strain. The load cell, LVDTs and the strain gauges were connected with a data logger that recorded the readings at a frequency of 0.5Hz continuously. The test set-up and the arrangement of LVDTs are shown in Figure 2. Monotonic loading was transferred through the actuator to the reinforcing bar, and rate of displacement was 1.51mm/min (i.e. 0.025mm/sec). The test was stopped at a slip of 60mm or up to complete pulling out of rebars whichever occurred first to complete the test.

Figure 2: Test set-up and arrangement of LVDTs

RESULTS AND DISCUSSION

Tests were conducted on twenty four pull-out specimens to understand the influence of various parameters on the bond strength as well as the bond stress vs. slip response. The unconfined concrete surrounding the end region of the main reinforcing bar in tension provided least resistance due to formation of splitting cracks caused by the high tensile hoop stresses. An ideal pull-out failure was observed in all the specimens designed with confinement reinforcement, while splitting failure was observed in the specimens without confinement reinforcement. Wide longitudinal splitting cracks were noticed on the outer surface of the specimen. In the pullout specimens designed with confinement by ties or spirals, the splitting crack formation and their propagation were effectively contained by lateral reinforcement. The effectiveness of confinement depends up on its form. The descending portion of the bond stress-slip response shows the level of deterioration bond stiffness with decreasing pullout load. The concrete occupied between the rebar ribs was sheared off with the confinement and the stresses in the bars were observed to be much less than their yield strength. However, the unconfined concrete exhibited splitting and there were no traces of crushing of concrete in front of the ribs.

Bond Stress vs. Slip Response

Slip is the relative displacement of reinforcement bar measured with reference to the surrounding concrete. The total slip of the bar includes the relative slip at the interface and shear deformations in concrete also. Therefore, certain displacement was recorded due to the localized strains at the interface even if there was nonoccurrence of bar slip. Figure 3 shows a typical bond stress vs. slip response in pullout specimens provided with 20mm diameter bar with 150mm embedment length. The interaction between concrete and the reinforcing bar in tension can be characterized through four stages in the bond stress-slip response. The first stage of the response corresponds to the low bond-stress, in which chemical adhesion is predominant. At still higher bond stress levels, the longitudinal splitting cracks propagated radially due to the resulting force component developed by the wedging action of the reinforcing bar ribs.

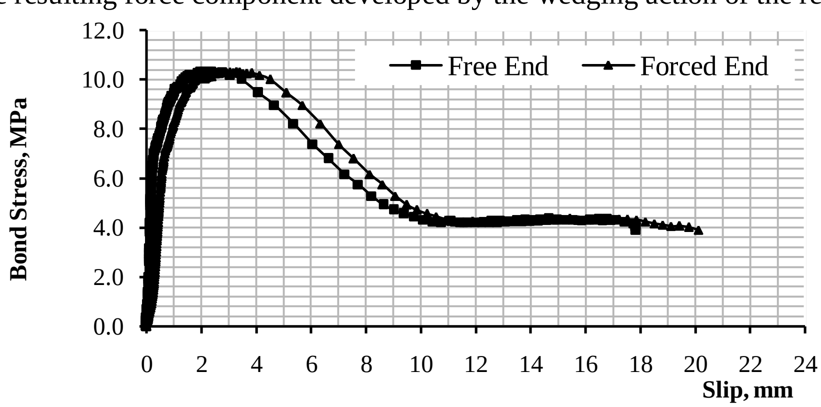

Figure 3: Bond stress vs. Slip (dia. 20mm, l_b = 150mm, f_c = 50 MPa)

By providing the lateral confinement reinforcement, the splitting of concrete was prevented effectively. Subsequently, the force in the reinforcing bar was transferred through friction between the reinforcement and the surrounding concrete. With further increase in the slip of the rebar, the bond stress reached its peak value and then drops. However, the bond stress was not negligible even at the larger slip of the bar. In the descending branch of the bond stress-slip curve, the resistance against the slip was due to dry-friction developed as the concrete keys between the bar ribs were sheared off, and the tips of the ribs offer less wedge action. The lateral reinforcement showed significant influence on the magnitude of slip, relative movement of the concrete between the ribs. The confinement by the lateral reinforcement improved the cracking resistance as well as the load carrying capacity. The cracking distribution was uniform and the failure was gradual. Hence the lateral confinement has improved the shear strength and ductility of anchorage pullout regions.

Bond Strength

The bond stress vs. slip (free end and forced end) response in 50 MPa strength concrete is shown in Figures 4 to 6 with various bar diameters and different lateral confinements. The maximum bond stress, τ_{max} has been observed at the rebar slip varying between 0.5 and 1.5 mm in concrete of 50 MPa compressive strength. The bond strength of anchorage pullout plain concrete specimens has been observed to be less than that of the confined concrete, which ranges between 50 and 60% of that of the confined concrete. The bond stress corresponding to the longitudinal splitting was about 11.8 MPa in concrete with compressive strength of 50MPa. After attaining the peak stress, a rapid decrease in the bond stress has been observed. A horizontal plateau has been observed sustaining the maximum bond stress, τ_{max} between the slip ranging between 0.3mm and 3.0mm. After the peak stress, the bond stress vs. slip response has been decreased rapidly between the slip varying from 3.0 to 8.2 mm. At the end of the rapid descending branch, the bond resistance has been decreased to τ_3 or τ_f called frictional bond resistance at a slip of about 10mm. Thereafter, the bond strength has been observed to remain constant until failure.

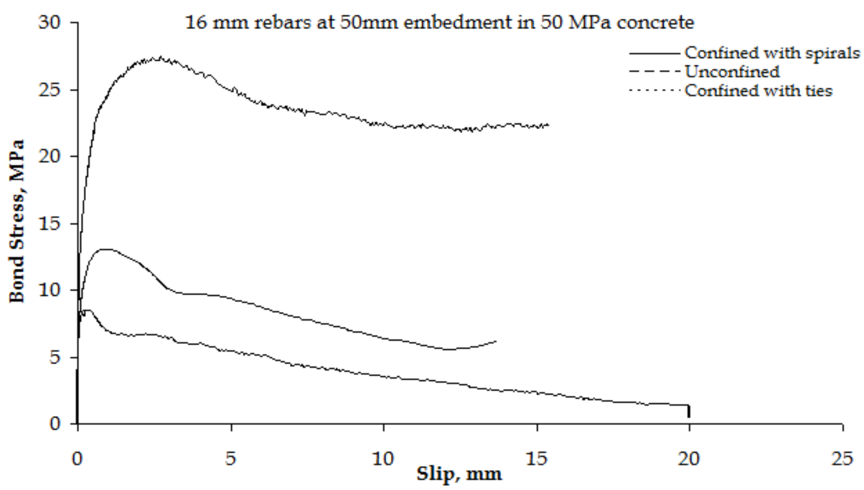

Figure 4: Bond stress vs. slip (φ = 16mm, l_b = 50mm, f_c =50 MPa)

Influence of Embedment Length

The maximum bond stress (τ_{max}) of 25.5 MPa was the highest value achieved with 50 mm embedment length using 16mm diameter bar, at a slip, s_1 ranging between 0.3 mm and 1.5 mm as shown in Figure 4. There was no significant variation in the stiffness of the ascending branch as well as the plateau of the bond stress. However, the post-peak response with 50mm embedment length seems to be more ductile compared with 150 mm length as shown in Figures 4 and 5. With 50 mm embedment length, the slip difference (s_3–s_2) varied between 3.25 mm to 11.5 mm, while with 150 mm embedment length it was varying between 3.5 mm and 24 mm. The fact is that as the surface area of embedment increases, the maximum bond stress decreases. It shows, however, that there exists a size effect on the bond strength. Similar conclusions have been drawn by the earlier researchers that the bond strength decreases as the embedment length increases (Mathey and Watstein, 1961).

Figure 5: Bond stress vs. slip (φ = 16mm, l_b = 150mm, f_c =50 MPa)

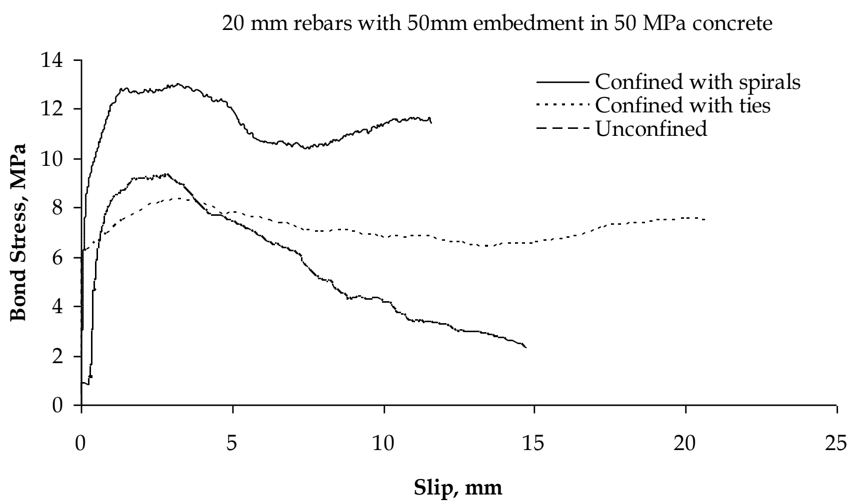

Figure 6: Bond stress vs. slip (φ = 20mm, l_b = 50mm, f_c =50 MPa)

Influence of Lateral Confinement

The influence of lateral confinement on the bond strength of rebars in concrete can be demonstrated in Figures 4 to 6. The splitting failure of concrete was prevented by the lateral confinement. The spiral reinforcement improved the bond strength of concrete. However, there appears a limit on the confinement level beyond which the bond strength does not increase substantially. The length of the descending branch of the bond stress-slip curve has been significantly increased with the confinement by spirals. The confinement by spirals has been very effective than the ties. When the embedment length was 50 mm, the performance of ties was similar to that of the spirals. It has been reported earlier that the confinement of concrete influences the local bond stress in deformed bars (Soroushain et al., 1991). By varying the confining ties, consistent bond stress-slip response was achieved with short embedment length (Malvar 1992). Further, confinement with ordinary steel improved the bond strength marginally, while the ductility was improved significantly (Harajli *et al.*, 2004).

Influence of Bar Diameter

The bond strength of rebars does not seem to be increased as its diameter increases. However, using 16mm diameter bar, the maximum bond stress (τ_{max}) was sustained between the bar slip ranging between 0.3mm and 1.5mm. The maximum bond stress (τ_{max}) was achieved at a bar slip ranging from 0.5 mm to 2.0mm with 20mm diameter bars. This shows that the slip at the peak stress was slightly increased with 20mm diameter bars. There has not been much influence of the bar diameter on the range of the bar slip in the horizontal plateau i.e. between the slips s_1 and s_2. The frictional resistance (τ_f) with 16mm diameter bars varies between 1.0 MPa and 8.0 MPa, while it varies between 2.8 MPa and 10.5MPa using 20mm diameter bars. This indicates that the frictional bond resistance has been slightly high when 20mm diameter bars were used. However, negligible effect of the bar diameter was observed on the maximum bond stress. The studies by Soroushian (1988) and Mathey and Watstein (1961) on surface deformed bars with different diameters in confined concrete showed that the bond strength decreases as the bar diameter increases. However, the post-peak response and the overall bond-slip response were not influenced by the bar diameter (Soroushian and Choi, 1989). The bond strength decreases with the increasing bar diameter and the frictional bond resistance was not influenced by the bar diameter, spacing of rib (Eligehausen *et al.*, 1983).

Modeling of Bond Stress-Slip Response

A generic local bond stress-slip model, as shown in Figure 1, has been reported (Eligehausen et al., 1983). This model has five parameters; bond stresses τ_1 and τ_3, and the slip at different stages s_1, s_2 and s_3. These parameters s_1, s_2, s_3 and τ_3 are independent of the compressive strength of concrete, confinement of the transverse reinforcement, and the bar diameter. However, the bond stress "τ_1" depends on the strength of concrete and bar diameter. In the present study, the bond stress-slip models have been studied by varying the diameter of bar, type of confinement and embedment length. The salient points of the model are; maximum bond strength, τ_{max} and the corresponding slip, s_1, the slip at the end of plateau, s_2 and the frictional bond strength, τ_f and corresponding slip, s_3. The model consists of nonlinear portion in the ascending branch up to s_1 and a plateau from slip s_1 to s_2. The expression for the bond stress of the ascending portion is

$$\tau = \tau_{\max}\left[\frac{s}{s_{\max}}\right]^{\alpha} \qquad (5)$$

Where, $1.0 \le s_{max} \le 1.2$mm

The initial portion of the bond stress-slip response is curvilinear. However, the value of α tends to be 0.3 when the concrete compressive strength ranges from 40 MPa to 80 MPa, which needs further investigations. The descending branch of the bond stress-slip response is extended up to the bond stress, τ_f, and the corresponding slip, s_3). After slip, s_3, the bond resistance remains constant at τ_f until failure. In concrete specimens without confinement, the mean ultimate bond strength, τ_{max} is observed to be 8.35 MPa with the corresponding slip, s_1 of 0.95 mm. The mean slip at the end of plateau, s_2 is 1.50 mm in concrete specimens without confinement. The post-peak response has been observed to be relatively steep without confinement. The value of frictional resistance, τ_f (τ_3) is 1.5 MPa. The slip of the bar at the end of descending branch, s_3 is 5.0 mm. The slip at the end of the test is assumed as 7.5 mm without confinement at a bond stress of 1.5 MPa. For concrete specimens with confinement, the ultimate bond strength, τ_{max} has been observed to be 12.30 MPa with the corresponding slip, s_1 of 2.0mm. The post-peak response of the bond stress-slip response is gradual with the lateral confinement. The value of the frictional resistance, τ_f (= τ_3) is 6.5 MPa in concrete with the lateral confinement. The slip at the end of the descending branch, s_3 is 10.0 mm in concrete with lateral confinement. The slip at the end of failure was assumed as 20 mm with the lateral confinement with a bond stress of 6.50 MPa. It appears that the bond strength increases significantly in concrete provided with lateral confinement. At a given bond stress, the slip increases in concrete with lateral confinement. The resisting bond capacity after slip, s_3 is improved by providing the lateral confinement.

Table 1: Bond stress and other parameters for modeling of bond stress-slip response

S. No	Lateral Confinement	Strength of Concrete, MPa	l_b mm	d_b mm	$\tau_{(max)}$ MPa	s_1 mm	s_2 mm	s_3 mm	$\tau_{(f)}$ MPa
1	Ties	50	150	20	14.0	1.0	1.8	10.0	4.4
2	Ties	50	150	16	13.2	0.8	3.8	7.5	7.2
3	Spirals	50	50	20	12.8	1.3	4.3	7.5	10.5
4	Spirals	50	150	16	10.8	0.5	2.0	9.3	5.0
5	Ties	50	50	20	9.2	1.5	3.0	9.0	4.4
6	UC*	50	150	16	8.4	0.5	0.8	4.8	1.0

** unconfined concrete*

Table 2: Typical Anchorage bond model parameters in concrete

Parameter	Unconfined Concrete	Confined Concrete
S_1	**0.95**	**2.0**
S_2	**1.50**	**7.5**
S_3	**5.0**	**10.0**
α	**0.3**	**0.3**
τ_f	$0.18\tau_{max}$	$0.5\tau_{max}$

Conclusions

From the experimental results, the following conclusions can be drawn

1. The maximum bond strength of rebar in concrete without lateral confinement ranges between 50 and 60 % of that of the laterally confined concrete. The splitting of concrete occurs in plain concrete, and the bond strength drops to zero suddenly after the splitting of concrete.
2. The lateral confinement ensures the development of full bond strength, which results in an ideal pull-out rebars. The rebars confined with spiral reinforcement showed increase in the bond strength and improvement in the ductility.
3. The bond strength of rebars decreases as its embedment length increases. The influence of bar diameter on the local bond stress-slip is not clear in the range (d_b = 16 and 20mm) of diameters used.

REFERENCES

Abrishami HH and Mitchel D (1992). Simulation of uniform bond stress. *ACI Materials Journal* **T. No. 89-M18 89**(2) 161-168.

ACI 318 (1995). Building Code Requirements for Structural Concrete and Commentary, 2005. *American Concrete Institute, Farmington Hills, Michigan.*

ACI 352 (1985). Recommendations for Design of Beam-Column Joints in Monolithic Reinforced-Concrete Structures. *ACI Journal* **82**(3) 266-283.

Azizinamini A, Darwin D, Eligehausen R, Pavel R and Ghosh SK (1999b). Proposed modification to ACI 318-95 tension development and lap splice for high strength concrete. *ACI Structural Journal* **96**(6) 922–926.

Azizinamini A, Pavel R, Hatfield E and Ghosh SK (199a). Behavior of spliced reinforcing bars embedded in HSC. *ACI Structural Journal* **96**(5) 826–835.

Azizinamini A, Stark M, Roller JJ and Ghosk SK (1993). Bond performance of reinforcing bars embedded in HSC. *ACI Structural Journal* **90**(5) 554–561.

Bortolotti (2003). Strength of concrete subjected to pull out load. *ASCE Materials Journal* **15**(5) 491-495.

CEB-FIP Report (2000). Bond of reinforcement in concrete: state of the art report. *FIB Bulletin*-10, Switzerland.

Ciampi V, Eligehausen R, Bertero VV and Popov EP (1981). Analytical Model for Deformed-Bar Bond under Generalized Excitations. *Trans. IABSE Colloquium on Advanced Mechanics of Reinforced Concrete, Delft, Netherlands.*

Ciampi V, Eligehausen R, Bertero VV and Popov EP (1982). Analytical Model for Concrete Anchorages of Reinforcing Bars under Generalized Excitations. *Report No. UCB/EERC 82-83*, Univ. of California, Berkeley (USA).
Eligehausen R, Popov EG and Bertero VV (1983). Local bond stress-slip relationships of deformed bars under generalized excitations. R. No. UCB/EERC-83/23, EERC, Berkeley.
EN 1992 (2003). Design of Concrete Structures-Part 1.1: General rules and rules for buildings, European Standards.
Ferguson PM, Breen JE and Thompson JN (1966). Pull out tests on high strength reinforcing bars. *ACI Journal* **T.No.62-55** 933-950.
Ferguson PM, Robert I and Thompson JN (1962). Development length of high strength reinforcing bars in bond. *ACI Journal* **T. No.59-17** 887-922.
Goto Y (1971). Cracks formed in concrete around deformed bars in concrete. *ACI Journal* **68**(2) 244-251.
Harajli MH, Hamad BS and Rteil AA (2004). Effect of confinement on bond strength between steel bars and concrete. *ACI Structural Journal* **101**(5) 595-603.
IS 2770 (1997). Method of testing bond in reinforced concrete part I-pullout test (BIS New Delhi).
IS 456 (2000). Indian Standard Code of Practice for Plain and Reinforced Concrete (BIS, New Delhi).
Jiang DH, Shah SP and Andonian AT (1984). Study of the transfer of tensile forces by bond. *ACI Journal* **T. No.81-24** 251-258.
Lutz LA and Gergely P (1967). Mechanics of bond and slip of deformed bars in concrete. *ACI Materials Journal* **T. No. 64-62** 711-721.
Malvar LJ (1992). Bond of reinforcement under controlled confinement. *ACI Materials Journal* **89**(6) 593-601.
Mathey RG and Watstein D (1961). Investigation of bond in beam and pull out specimens with high yield strength deformed bars. *ACI Journal* **T. No.57-50** 1071-1089.
Mirza SM and Houde J (1976). Study of Bond Stress-Slip Relationships in Reinforced Concrete. *ACI Journl* **76**(1) 19-46.
Nilson AH (1972). Internal measurement of bond slips. *ACI Journal* **69**(7) 439-441
Rehm G (1961). Uber die grundlagen des verbudzwischen stahl undbeton, Heft 138, Deutscher Ausschuss fur Stahlbeton, Berlin.
Somayaji S and Shah SP (1981). Bond stress versus slip relationship and cracking response of tension members. *ACI Journal* **78**(3) 217–225
Soroushian P (1988). Pull out behavior of hooked bars in exterior beam-column connections. *ACI Structural Journal* **85** 269-276.
Soroushian P and Choi KB (1989). Local bond of deformed bars with different diameters in confined concrete. *ACI Structural Journal* **86**(02) 217-222.
Soroushian P, Choi KB, Park GH and Aslani F (1991). Bond of deformed bars to concrete: effects of confinement and strength of concrete. *ACI Materials Journal* **88**(3) 227-232.
Ueda T, Lin I and Hawkins NM (1986). Beam bar anchorage in exterior column-beam connections. *ACI Structural Journal* **T. No. 83-41** 412-422.
Yankelevsky DZ, Adin MA and Farhey DN (1992). Mathematical mode0l for bond slip behavior under cyclic loading. *ACI Structural Journal* **89**(6) 692-698.