ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

An Analytical study on Impact Loading between Concrete and Reinforcing Bars Bond

Telagamsetty Ramesh
M.Tech (Structural Engineering),
Department of Civil Engineering,
Gokul Institute of Technology and Sciences,
Bobbili, Vizianagaram-Dt., A.P., India.

Amanana Venkatesh
Associate Professor & HOD,
Department of Civil Engineering,
Gokul Institute of Technology and Sciences,
Bobbili, Vizianagaram-Dt., A.P., India.

Abstract:
The bond between reinforcing bars and concrete under impact loading was studied for plain, polypropylene fibre reinforced, and steel fibre reinforced concretes. The experimental program included setting up an impact test system, in which an impact load with considerable energy could be generated, and in which the applied loads, accelerations and the strains along the reinforcing bar could be recorded at a rate of 200 micro seconds per data point. The experiments consisted of both pull-out tests and push-in tests. For both types of tests the experimental work was carried out for three different types of loading: static, dynamic and impact loading, which covered a stress (bond stress) rate ranging from 0.5 - 10' to 0.5 – 10^{-2} M Pa/s.

The other important variables considered in the experimental study were: two different types of reinforcing bars (smooth and deformed), two different concrete compressive strengths (normal and high), two different fibres (polypropylene and steel), different fibre contents (0.1 %, 0.5% and 1.0% by volume) and surface conditions (epoxy coated and uncoated). All of the test data were processed by computer, and the output included the stress distributions in both the steel and the concrete, the bond stresses and slips, the bond stress-slip relationships, and the fracture energy in bond failure. The energy balance at different stages in the bond process was examined. The internal crack development was also investigated.

It was found that for smooth rebars, there existed a linear bond stress-slip relationship under both static and high rate loading. Different loading rates, compressive strengths, types of fibres, and fibre contents were found to have no great influence on this relationship and the stresses in both the steel bar and the concrete.

I. Objectives and Scope:

The initial purpose of the embedment of steel bars in concrete, in the middle of the 19th century, was to produce a supporting steel network [1]. In 1886, G.I. Wayss was successful. from experimental considerations, in elucidating the principles involved in the action of reinforcement. His contributions have subsequently served as a basis for the more general utilization of reinforcement as a component in reinforced concrete whose primary function is to resist tensile forces.

For a reinforced concrete structure, it is the bond between the steel and the concrete which enables the two materials to act together. In the case of plain bars, the bond forces are due to chemical adhesion and friction. In the case of deformed bars, the bond forces are derived mainly by the bearing capacity of the ribs on the concrete. In the case of strands, the bond forces are due largely to a lack of fit. The behaviour of a structure is strongly dependent upon the bond between the concrete and the reinforcing bars.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The accurate prediction of the linear or nonlinear response of reinforced concrete structures subjected to static or dynamic loads, using all the sophisticated methods of analysis, is based upon our knowledge about the local bond stress vs. slip relationship governing the behaviour at the steel-concrete interface. With the introduction of high tensile strength steel as reinforcing material, the importance of bond was further increased. The development of cracks at a given working stress and the width of these cracks depend primarily on the degree of bond between the steel and the concrete. Over the past decade, high performance concretes and fibre-reinforced concretes have become more widely used in concrete structures. High performance concrete is generally stronger than normal concrete, but it may be more brittle than the latter. Concretes with fibre addition make it more difficult for cracks to propagate and more ductile, i.e. they can absorb more fracture energy. All of these may improve the bond strength significantly. However, design engineers of reinforced concrete structures under different loading conditions will benefit from these developments only when the fundamental mechanisms of bond.

II. Literature Review:

The bond between steel and concrete has long been under investigation. These studies have elaborated on the influence of many variables on bond and bond strength, and can be placed into two categories: The stresses produced as a result of the bonding between steel and concrete; and The influence of various parameters on bond strength and bond stress distribution. However, only these studies, to be described below, have been found which deal explicitly with the bond between steel reinforcing bars and concrete under impact loading. These were all experimental studies; no analytical paper have been found. Hence, this literature survey will deal primarily with quasi-static investigations, which are a necessary prelude to the study of the impact problems.

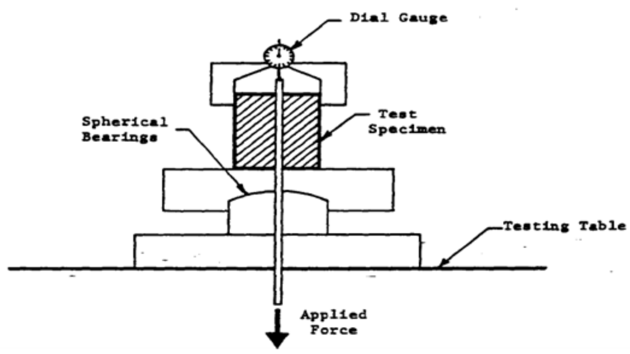

Figure 2.1: Pull-out Test on Bond Strength

2.1. Summary:

A briefly summary of these pull - out investigations is as follows: A reasonable measure of the anchorage length of a bar embedded in concrete could be obtained from the pull-out test.The pull-out tests emphasized the need for a particular length of bar (anchorage length) from the point of maximum tensile stress to avoid pull-out. The pull-out tests provided an approximate indication of what happened adjacent to any crack in the concrete. The drawback of the pull-out test as a standard was that the compressive stress in the concrete complicated the stress conditions and inhibited tension cracking in the concrete.

2.2. Bond Tests with Fiber Reinforced Concrete or Coated Rebars:

The use of short, randomly distributed fibers in concrete is relatively recent. The role of these fibers in improving the crack resistance and the "ductility" of concrete has recently been reviewed. Considerable research has been carried out in the last two decades to evaluate the response of these fiber reinforced composites, including the bond behaviour between the steel bar and fiber reinforced concrete matrix. The first to report improved performance in the anchor-age bond of deformed bars embedded in steel fibre reinforced concrete. Their experimental work consisted of pull-out tests on steel-fiber reinforced specimens. The steel bars are used were of the round straight type and had a length of 25 mm (or 50 mm) and a diameter of 0.40 mm. (or 0.50 mm). Two different fiber contents, 3.5% and 7.0% (by volume) were used.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Based on the bond stress-slip relationship, they found that the anchorage bond strength of fibre reinforced concrete was 40% higher than that for plain concrete. Further, the mode of failure was found to be different in the two cases. The plain concrete specimens showed greater cracking and wider cracks than the fiber reinforced ones. The failure in the latter case was observed to take place more gradually , carried out two series of tests to investigate the effects of polypropylene fiber reinforcement on the bond between concrete and conventional mild steel reinforcement. The first series of tests investigated the differences in the bond stress-slip relationship using the ASTM Standard Test Method (ASTM C234-71), whereas the second series of tests was designed to indicate changes in the transfer length of the several different concrete mixes and mild reinforcement combinations. Two polypropylene fiber lengths (60 and 90 mm), four fiber contents (0, 0.014, 0.050 and 0.086 /b/ft3) 2 , and two water-cement ratio (0.44 and 0.65) were used.

The results showed that the addition of polypropylene fiber reinforcement does not adversely affected the bond strength and that neither increasing the fiber content in the mix nor increasing the fiber length2.2.2 Bond Behaviour Under Impact Loading While there is an extensive literature on static bond tests, there is little experimental work on the bond between concrete and steel reinforcement under dynamic loading, with rather contradictory results. Concrete is a strain rate sensitive material. Generally its strength (compressive, tensile. flexural and shear strength) increases with higher loading rates, especially under impact loading . Since the bond strength depends, to a great extent, upon the strength of the concrete surrounding the rebar, the loading rate should have a considerable effect on the bond behaviour. Also, there is some indication that crack velocities in concrete are proportional to the rate of loading . On the other hand, the presence of reinforcement, either in the form of fibers or of continuous bars tends to reduce the crack velocity , which, in turn, improves the bond strength.

The effects of loading rate on the bond behaviour involve complex mechanisms. Test techniques for high rates of loading are far more difficult than static testing. To study the behaviour of bond under impact loading. They tested deformed bars under static and impact loading under conditions in which splitting failures were inhibited. They used bars of d = 12.5 mm with an embedment length of 4d. The minimum raise time of the load was about 10 20 ms. The tests showed that the local static bond strengths might be as high as 0.75 L.', but that under single pulse dynamic loading at high strain rates this strength increases to j; (cylinder strength). They concluded that for all practical lengths of embedment of bars, steel failure might be expected under both static and dynamic loading. Bars loaded dynamically would carry a larger load than bars loaded statically. They ascertained that this increase in carrying capacity was due solely to the increase in steel strength under dynamic loading.[1 & 2]. The results of pull-out tests under impact loading. He tested the bond resistance of plain and deformed bars of d = 16 mm, with an embedment length varying from 16 to 160 mm, i.e., 1 10 d.

He used an electro-hydraulic loading system with load control and varied the time to failure from 500 s to 5 ms. The compressive strength of the concrete was 24 ti 29 MPa. Because of the relatively high ratio of the wavelength of the loading pulse , to specimen size (0.1 ,-- 0.2 m) a quasi-static approximation of the result was justified. stirrups of plain round bars. In both types of specimens, attention was given to obtaining accurate measurements of the slip of the bar through the concrete as the loading progressed.[5,6,&8]. Some of the relevant conclusions of this investigation on pull-out tests are as follows: In order to study the load vs. slip relationship over a wide range of values it was necessary to guard against the splitting of the specimen; It was realized that the bond stress was not uniformly distributed along a rebar embedded any considerable length, and having the load applied at one end; Only after slip became general was there an approximately uniform bond stress throughout the embedded length.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

However, in establishing a bond vs. slip curve for different situations, a uniform bond distribution was assumed, and the deformations in concrete and steel were assumed to be proportional to the stress; For a given amount of slip, the bond stress depended upon the stress level in the steel; The tests indicated that a definite relationship existed between the amount of movement of the bar and the bond stress developed. After slipping began, the bond stress increased with further movement of the bar, very rapidly at the first, then more slowly until the maximum bond resistance was reached; the bond stress was reduced with further slip; The load vs. slip relationships for different mixes of concrete were the same; and The bond resistance was greatly increased by lateral pressures.

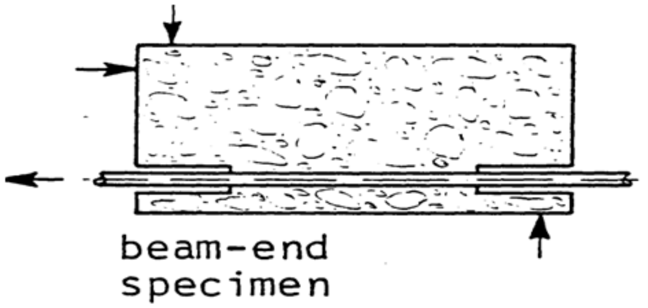

Figure 2.2: Beam Test on Bond Strength

It was found that for smooth bars, the loading rate had no particular effect on the maximum bond resistance or the shape of the bond stress vs. displacement relationships. However, for deformed bars, bond resistance increased markedly with the loading rate.[4]. Extensive experimental and analytical work has been carried out to study the bond behaviour in reinforced concrete members. The experimental investigations have covered, in some detail, the factors influencing bond phenomena and have contributed considerably towards the understanding of bond behaviour. The experimental investigations revealed that bond stress in the desired bond stress-slip relationship was not a function of local slip alone. It was also dependent upon the values of steel stress, the embedment length, the diameter of the reinforcing bar, the reinforcement ratio, and the concrete strength, etc.

It was seen, also, that the development of bond stress depended upon the region inside the member in terms of the type of internal force.

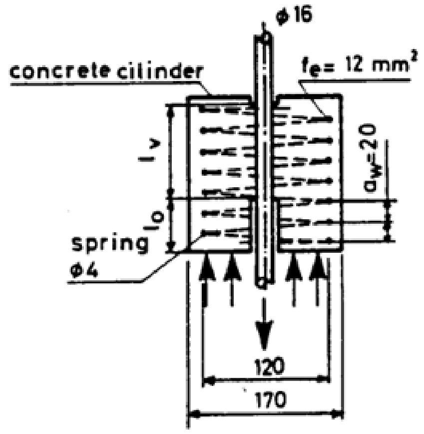

Figure 2.3: Pull-out Specimens for Impact Test.

Various types of test specimens have been developed to study bond. Some of them simulate quite closely the behaviour of reinforced concrete members for different loading.[8 & 10].

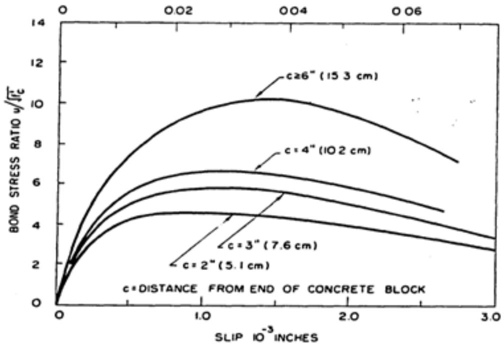

Figure 2.4: Nilson's Bond Stress-Slip Curves.

III. Procedures for Experiments:

3.1 Introduction:

The two prime variables in the present study were local stress and local bond slip. While cracking and energy transfer were also investigated, they were not directly measured in the experiments. The objectives of this investigation were to design experimental models to obtain representative bond-slip relationships for pull-out and push-in tests under dynamic loading; develop instrumentation and techniques for the measurement of stress and slip;obtain bond-slip

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

relationships from the experimental models; investigate the propagation of cracking in concrete during bond-slip process; investigate the transfer and balance of energy.

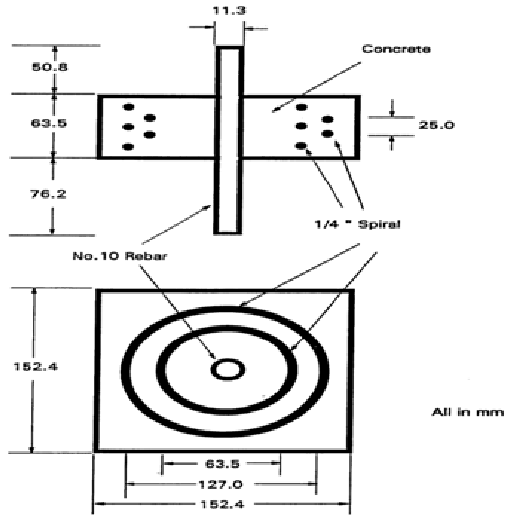

Figure 3.1: The Pull-out and Push-in Specimens

Altogether, 420 different types of specimens were tested under static and medium rate loading . A typical procedure for carrying out a static or medium rate loading test is given below.[9]. Set up the test apparatus needed, including the Instron universal testing machine, the 150 iciV load cell, the dummy strain gauge assembly, and the data. acquisition system, hook up the connections properly; Place the specimen on the support under the load cell in the testing machine, make alignment from both directions; Operate the testing machine, set the crosshead speed to give with the desired stress rate; Run the Scope Driver software in the data acquisition system, set the necessary parameters properly including the trigger control parameters. Set the data acquisition at active mode; Start to move the crosshead of the testing machine; Stop the movement of the crosshead of the testing machine; Check if all the data and the pictures have been recorded, save the data to the disks in ASCII format; Reset the apparatus for next specimen testing; Transfer the data from the disks in the data acquisition system to a mainframe computer for processing.

3.2. Crack Examination:

In order to investigate the crack developments in different specimens, some tested specimens were sliced by diamond and metal saws, then the internal cracks at the interface between the rebar and the concrete were examined and photographed by a stereoscopic microscope.

IV. Analysis of Test Data:

4.1 General:

The usual output from the impact tests on the bond specimens consisted of the t up (the contact area between the load cell and the specimen) load, the accelerations at two locations and the strains at five locations along the rebar. These three parameters were the fundamental data recorded in this experimental study. These data were all obtained as a. function of time, shows the eight sets of data from the eight channels of the data acquisition system connected to these transducers. The data were acquired at 200 /Ls intervals; an impact event took anywhere from 5 to 30 ins, so there were hundreds to thousands data points for each test. These data were transferred as a data file in ASCII format to a mainframe computer via. FTP (Fast Transform Protocol) service.[11]. One important and difficult aspect of the data processing in impact tests is the noise filtering. The true signal output from the circuits of the load cell, accelerometers or strain gauges (Wheatstone bridges) were at a very low level, ranging from 5.0 to 30.0 V, while the noise from several sources can reach as high as 1.0 mV. The effects of noise on the reliability of the true signal cannot be ignored. The influences of the noise on the true signals depend on the characteristics of the noise, such as frequency, duration etc.

4.1. Data Filtration

4.1.1 Fast Fourier Transform — FFT and Inverse FFT Transient loading conditions, such as impact loading, and material and structural responses to them, are time-dependent variables, which should be studied using a time-domain analysis. However, these variables can be more conveniently studied using a frequency-domain analysis.

Any signal output from the load cell, accelerometers or strain measurement channels can easily be extended from an aperiodic function defined in a finite range [t i , 1 2] to a periodic function defined in an infinite range (—oo, d-oo), the extended function thus satisfies the conditions for Fourier transformation. The signal function is considered as being comprised of many periodic wave forms and a correct evaluation of such wave form characteristics will help study the signal itself.

INPUT DATA FILE

|

(SEARCH USEFUL PORTION OF SIGNALS)

|

BASE LINE SETTING METHOD OF FILTERING

|

APPLY FFT

|

FILTER OUT UNWANTED FREQUENCIES

|

APPLY INVERSE FFT

|

FIND LOAD, PLOT LOAD HISTORY CURVES

|

FIND ACCELERATIONS, VELOCITIES & DISPLACEMENTS

|

PLOT APPLIED LOAD VS. DISPLACEMENT CURVES

|

FIND ELONGATIONS OF REBAR

|

FIND STRAINS & STRESSES IN STEEL & CONCRETE

|

FIND BOND STRESSES & BOND SLIPS

|

PLOT STRESS & STRAIN DISTRIBUTION CURVES

|

PLOT BOND STRESS VS. SLIP CURVES

|

FIND LOAD, STRAIN & STRESS RATES

|

FIND KINETIC, POTENTIAL, STRAIN & FRACTURE ENERGIES

|

OUTPUT RESULTS & GRAPHS

Figure 4.1: Algorithm of Test Data Process

V. Analytical Study

5.1 Introduction

The mechanism of bond between steel rebars and concrete is a highly complex, non-linear process involving progressive cracking, crushing, nonlinearity and in homogeneity of the concrete, especially under high rate (impact) loading. So far no studies have been carried out which use fracture mechanics and finite element methods to establish the bond stress-slip relationship analytically. Previous studies regarding the application of finite element method to the bond problem simply introduced the local bond stress-slip relationships which were obtained from tests. However, in spite of much useful information obtained from extensive experimental studies, there are still many unanswered questions regarding the bond phenomenon. Many variables in bond behaviour are difficult to measure experimentally, and it is hard to design an experimental program to take into account all relevant factors. There is not enough information available in the literature from which the bond stress-slip characteristics can be derived analytically. Theoretically, there is a unique relationship between bond stress and slip at the interface between a steel bar and concrete for which the geometric and mechanical properties are known. The problem can be solved. by reasonably modeling the mechanical properties at the interface between the rebar and the concrete, as well as the constitutive laws for both materials and appropriate cracking and crushing criteria.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

This chapter is devoted to a nonlinear fracture mechanics analysis of pull-out and push-in bond tests under high rate loading conditions, and the finite element method is used in the numerical calculation. The aim of the analysis is to obtain quantitative information to help explain the physical phenomena occurring around the reinforcing bar. The chemical adhesion and frictional resistance between the rebar and the concrete are considered only during early loading in the elastic stage. After that only the rib bearing mechanism is taken into account.

The fiber concrete composite and the high strength concrete are appropriately modeled. In the finite element analysis quadratic solid iso parametric elements with 20 nodes and 60 degree of freedom are employed for the rebar and the concrete before cracking. After cracking, the concrete elements are replaced by quadratic singularity elements, which are quarter-point elements able to model curved crack fronts. The dynamic constitutive laws of both steel and concrete, the criteria for crack formation and propagation in concrete based on the energy release rate theorem for mixed mode fracture, and the criterion for concrete crushing are used in the finite element process (see below).

It is an iterative program with rapid convergence. Not only can the bond stress and crack distribution be found through the analysis, but also a bond stress-slip relationship under high rate loading can be established analytically. The most important part of the finite element analysis is to develop appropriate types of elements suitable to the specific problem, and then to choose reasonably accurate `shape functions' for these elements and to establish the corresponding stiffness matrixes. After that, the assembly of the global stiffness matrix and the external load matrix, and the strategy for equation solving, etc., are similar for all finite element processes.

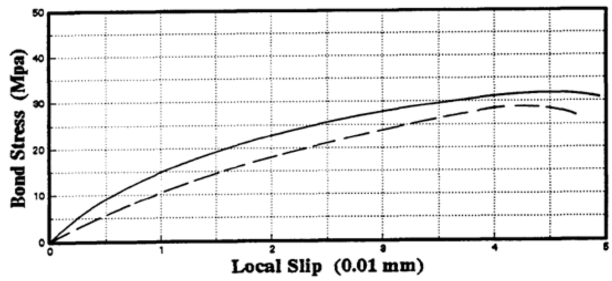

Figure 5.1: The Bond Stress-slip Relationship by the Finite Element Method(Steel Fibre Concrete, Pull-out, Impact III — 0.5 • 10_2 Mpa/s)

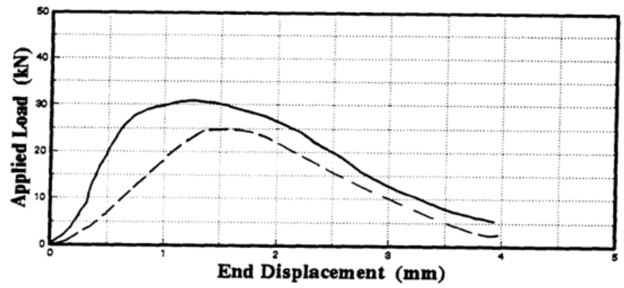

Figure 5.2: The Applied Load vs. Displacement Curve the Finite Element Method (Steel Fibre Concrete, Push-in, Impact III — 0.5 • 10-2 Mpa/s)

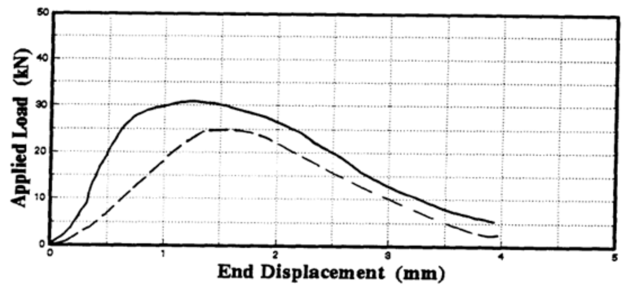

Figure 5.3: The Applied Load vs. Displacement Curve the Finite Element Method (Steel Fibre Concrete, Push-in, Impact III — 0.5 • 10-2 Mpa/s)

VI. Conclusions and Further Scope

6.1 Conclusions

The purpose of this research work has been to provide a more fundamental under-standing of the bond behaviour of rebars in concrete subjected to high rate loading, to develop appropriate techniques to investigate the bond phenomenon using both experimental and analytical approaches, and to study

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

the feasibility of using steel fibres, high strength concrete and other measures for better bond performance under impact loading. Based on the experimental investigation and the analytical study, the following important conclusions may be drawn: The entire testing program as designed was suitable for the experimental investigation of the bond behaviour under impact loading. The testing machines was able to provide a wide range of high rate loading with a considerable amount of energy; the transducers and instrumentation used were able to measure and record the basic data, such as the applied load, the accelerations and the strains, at a sufficiently high rate with an acceptable level of error; the mechanical and mathematical models for processing the test data to obtain the most important parameters, such as the external forces, displacements, stresses, slips and the fracture energy, are appropriate and accurate: the specimens used are satisfactory and most of the important variables, which may affect the bond behaviour under high rate loading, have been considered. For smooth bars, the bond resistance is due to the chemical adhesion and the frictional force at the interface between the rebar and the concrete. There exists a linear bond stress-slip relationship under both static and high rate loading. Different compressive strengths, types of fibres, fibre contents, and loading rates were found to have no great influence on this relationship or the stresses in both the steel bar and the concrete. For deformed rebars, the chemical adhesion and the frictional force at the interface between the rebar and the concrete are less important for the bond resistance.

References:

[1].CANS-A23.3-M84, "Design of Concrete Structures for Building," Canadian Standards Association, Toronto, 1984. 281 pp.

[2].ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-89/ACI 318R-89)," American Concrete Institute, Detroit, 1989, 353 pp.

[3].ASTM C 234-91a, "Standard Test Method for Comparing Concretes on the Basis of the Bond Developed with Reinforced Steel," ASTM Annual Book of Standard, Section 4, construction, 1991.

[4].Ba2ant, C.P. and Sener, S., " Size Effect in Pullout Tests," ACI Materials Journal, Vol. 85, No. 5, Sept.-Oct. 1988, pp. 347-351. ACI Committee 408, "State of the Art ^ Bond under Cyclic Loading," ACI Material Journal, V.88, No.6, Nov./Dec. 1991, pp. 669-673.

[5].Mindess, S., "Effects of Dynamic Loading on Bond," ACI Committee 446: State-of-the Art Report, Section 4.2.3., 1989

[6].CEB Task Group VI, "Bond Action Behaviour of Reinforcement — State of the Art Report," Dec. 1981.

[7].Rehm, G., "The Basic Principles of Bond Between Steel and Concrete," Translation No.134, Cement and Concrete Associations, London, pp. 1-31.

[8].Khurana, R.S., Magarotto, R. and Moro, S. (July 2010) have improved the concept of 'Smart Dynamic Concrete: an innovative approach for the construction industry'.

[9].Rashid Jaffrey, Roberta Magarotto& Joana Roncero have researched on Smart Dynamic Concrete using fines lower than 380 kg/m3 is feasible by means of an innovative Viscosity Modifying AdMixture called RheoMATRIXc in 2010.

[10].A.M. Neville, Properties of Concrete, 4th edR, Prentice Hall/Pearson, Harlow, 2000.

[11].M.S.Shetty, "Concrete Technology", S.Chand& Company Ltd. New Delhi.

Websites:

https://repository.tudelft.nl/islandora/object/uuid:7d26e057-a9fa-4e99-a0e8.../view

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

https://repository.tudelft.nl/islandora/object/uuid:7d26e057-a9fa-4e99.../download

https://www.hindawi.com/journals/amse/2015/604280/

https://www.hindawi.com/journals/amse/2015/604280/

https://www.hindawi.com/journals/amse/2012/328570/

https://www.hindawi.com/journals/amse/2012/328570/

www.sciencedirect.com/science/article/pii/S1687404815000164

https://www.researchgate.net/publication/309171624_Experimental_and_analytical_inve...

https://www.researchgate.net/publication/266143966_Bond_stress_behavior_between_c...

Author's Details:

Amanana Venkatesh, M.Tech (Structural Engineering), Associate Professor and H.O.D. of the Department of civil Engineering, Gokul Institute of Technology and Sciences, Bobbili, Vizianagaram-D.t., Andhra Pradesh, INDIA. He has 5 years of Teaching Experience and guided number of projects for M.Tech and B.Tech students. He has many publications in various National and International Journals and Conferences. His Research area is Structural Engineering.

Telagamsetty Ramesh, Student, M.Tech (Structural Engineering), Regd.No.13H91D8714, Department of Civil Engineering , Gokul Institute of Technology and Sciences, Bobbili, Vizianagaram–D.t., Andhra Pradesh, INDIA.
E-mail Id: ramesh.telagamsetty@gmail.com