EXPERIMENTAL INVESTIGATION ON SHEAR CAPACITY OF HIGH STRENGTH CONCRETE DEEP BEAM

A Project Report

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report titled **"EXPERIMENTAL INVESTIGATION ON SHEAR CAPACITY OF HIGH STRENGTH CONCRETE DEEP BEAM"**, is the bonafide work of **Mr.V.SENTHIL KUMAR, Reg. No. 71206413015** who carried out the research work under my supervision. Certified further that to the best of my knowledge the work reported herein does not part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

This is to study (investigate) the shear behaviour and shear strength of high strength concrete deep beams with and without shear reinforcement.

The shear capacity of the concrete beams having stirrups is assumed as the sum of individual contribution of both the concrete and shear reinforcement. Different international building codes have suggested empirical relations for both of these contributions.

In this study four beams with same longitudinal reinforcements and same shear span to depth ratios were tested in two sets with and without shear reinforcement to study the contribution of stirrups in resisting shear. The beams were tested under the concentrated load at mid span.

Experimental investigations were carried out on the shear strength of High strength concrete beams, made using concrete with compressive strength 50 Mpa.

The test results obtained were analyzed for the contribution of stirrups to resist shear and compared here with.

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LIST OF SYMBOLS

a	-	Shear span
b	-	Breadth of deep beam
D	-	Depth of deep beam
Ec	-	Modulus of rigidity concrete
Es	-	Youngs modulus of steal
Ece	-	Short term elastic modulus of concrete
Wcr	-	Width of crack
εm	-	Mean strain
εi	-	Strain at the level considered
T_t	-	Tensile strength of concrete
Vn	-	Ultimate shear
Vc	-	Shear taken by concrete
Vs	-	Shear taken by tension steel
Vsh	-	Shear taken by web steel
Vst	-	Shear taken by stirrups
Asv	-	Area of shear reinforcement
Sv	-	Spacing of shear reinforcement

CHAPTER 1

Introduction

1.1 General

Reinforced concrete deep beams are used as load distributing structural elements such as transfer girders, pile caps, foundation walls, offshore structures etc.

The shear strength evaluation of reinforced concrete deep beam has been the subject of several studies devoted to determine the influence of the main parameter, due to small value of span to depth ratio (a/d).

The strength of deep beams is usually controlled by shear rather than flexural strength, if normal amount of longitudinal reinforcements are used.

In addition the deep beam shear strength is sufficiently greater than that of slender beams because of the special capacity of deep beams in redistributing normal forces before failure and of their developing mechanism of forces transfer is quite different from slender beams.

Shear strength of concrete beams mainly depends on following variable.

- depth of member or size effect.
- shear span to effective depth (a/d) ratio or moment to shear ratio.
- longitudinal reinforcement or dowel action.
- axial force
- tensile strength of concrete
- crushing strength of beam web
- yielding of stirrups
- the aggregate interlocking
- failure of tension chord
- failure of stirrups a change

- serviceability failure due to excessive crack width at service load.

In this research, the effect of transverse steel vs., on the shear properties of high strength concrete has been studied. Four beams have been tested in this research in two sets beams each. The test results and beam failure mechanism for both of beams has also been observed. The contribution of stirrups has also been investigated and is compared with the provision of ACI-318.

High strength concrete with compressive strength ranging to about 50 MPa can be made with carefully selected cement, sand, coarse aggregate and by using very low water cement ratio. High range water reducing admixtures (super plasticizer) can be used in this project.

The shear strength of reinforced high strength concrete deep beams with and without transverse reinforcement is analyzed in this study.

1.2 Literature Review

Kyoung - kyu - choi, Hong – Gun Park and James K right (March-2007)

A theoretical model was developed to predict the shear strength of RCC deep beams with and without shear reinforcement. It was assumed that the shear strength of concrete beams can be determined from the failure of compression zone of a beam cross– section; the shear strength of compression zone was evaluated, considering the interaction between the shear strength and normal stresses developed by the flexural moment. The failure mechanism of compression zone changes from a tension failure to a compression failure as the shear span to depth ratio (a/d) decreases.

Aurelio Muttoni and Mignel Fernandez Ruiz (March 2008)

This paper investigates the shear strength of beams without stirrups based on the opening of a critical shear crack. The shear carrying mechanisms after the development of this crack are investigated. On this basis, a rational model is developed to estimate the shear strength of members without shear reinforcement. The proposed model is based on an estimate of the crack width in the critical shear region, taking also into account the roughness of the crack and the compressive strength of the concrete. The proposed model is shown to properly describe a large set of available test data. A simplified method adopted by the Swiss code for structural concrete (SIA-262) is also introduced comparisons with other code of practice are finally presented, with the highlight as the main difference between them.

Michael D.Brown and Oguzhan Bayrak (September 2007)

A series of tests on deep beams was performed to examine the impact of load distribution and shear reinforcement on the behaviour of the beams. The specimen was subjected to single or double concentrated loads or uniformly distributed loads. Test results indicate differences in behaviour among specimens subjected to difference load distributions. The differences were apparent in the working patterns, failure modes, ultimate strengths and strain distributions within the beams. Those differences indicate that distributed loads are a much less severe loading type than concentrated loads. The nominal strength of specimens were determined by using strut and tie modeling provisions of both AASHTO LRFD and ACI 318-05 and then compared with the measured strengths.

Jung – Yoon Lee and UK – Yeon Kim (April 2008)

This paper presents the effect of longitudinal tensile reinforcement ratio and shear span – depth ratio (a/d) on the minimum shear reinforcement in reinforced concrete beams. 26 reinforced concrete beams having the minimum shear reinforcements required by ACI 318-05 were cast, instrumented and tested. Although minimum amount of shear reinforcement in the existing design codes (ACI 318-05, CSA A 23.3-04, AIJ 99 and Eurocode 2) depend on neither the longitudinal tensile reinforcement ratio nor the a/d, the test results indicated that the reserve shear strength (shear strength of the beam with minimum amount of shear reinforcement / shear strength of the beam without shear reinforcement) of the tested beams increased as the longitudinal tensile reinforcement ratio increased, but decreased as the a/d ratio increased.

Tan et al

Continuing along the experimental lines of Kong et al under took a study on shear strength of 19 deep beams with concrete cylinder strengths from 40 to 60 mpa. Comparing their results with the CIRIA Guide 2, ACI 318 Zsutty' model and the design of mau and Hsu, they concluded that both the ACI 318 model and CIRIA Guide 2 gave conservative predictions of the shear strength.

$$V_n = C_1 f_t bD + C_2 \sum_{i=1}^{n} \frac{A_i Y_i}{D} \sin^2 \alpha i$$

Stephen J.Foster and R.Ian Gilbert

In this study 16 high strength concrete deep beams were tested to destruction. Variables considered in the investigation are shear span to depth ratio, concrete strength (50 to 120 mpa) and the provision of secondary reinforcement. The investigation examines deep beam behaviours and compares the experimental results with the CIKIA guide 2 design methods, ACI 318 method. The result of Investigation concludes that the design methods given by CIRIA guide 2 and ACI 318 are generally conservative for deep beams.

Gaetano Russo, Raffaele enie, and Margherita Panletta (May 2005)

A new model for determining the shear strength of RCC deep beams is proposed in this paper. An explicit formula that considers the shear strength contributions provided by the strut and tie mechanism due to the diagonal concrete strut and he longitudinal main reinforcement is derived. The co-efficient of each contribution are calibrated on 240 test results relevant to both normal and high strength concrete deep beams. The obtained expression is compared to the ACI code and computing procedures.

Marti,Warravan and Lehwalter,and Leonhardt

developed various refined truss model. They reported that a/d is the primary design parameter that significantly affects the shear failure mechanism, and as a/d decrease, the shear strength considerably increases due to arch action.

Jung – Woong Park and Daniel Kuchma (December – 2007)

In this paper a strut and tie based method is presented for calculating the strength of reinforced concrete deep beams. The proposed method employs constitutive laws for cracked reinforced concrete, considers strain compatibility and uses a secant stiffness formulation. This method accounts for the failure modes due to crushing of the nodal compression zone at the top of the diagonal strut, yielding of the longitudinal reinforcement, as well as that of strut crushing or splitting. The proposed method consistently predicts the strength of deep beams with a wide range of horizontal and vertical web reinforcement.

ACI 318-95 code considers the shear capacity of slender reinforced concrete beams without stirrups as the shear stress at which diagonal cracking begins. The shear capacity can be calculated using one of two equations. The first one, ACI 11-3, only considers the compressive strength of concrete and the beam dimensions, while the second, ACI 11-6, also includes the influence of the longitudinal reinforcement. The compressive strength of concrete for both equations is limited to less than 70 MPa.

ACI 318–99 current design codes including ACI 318, and many researches including Zsutty, proposed various empirical shear strength equation, which are defined by functions of the primary design parameter ; the compressive strength of concrete, the ratio of tensile reinforcement, a / d, and the size of a beam. Although these equations are convenient for the use because of their simple forms, most of the empirical strength equations do not accurately predict the test result with a wide range of design parameters.

ACI 318-05 use the strut and tie model to evaluate the shear strength of deep beams. This model based on a firm theoretical background, and applicable to both slender and deep beams.

CSA simplified design method is similar to the ACI method except that it neglects the influence of the longitudinal reinforcement and the shear span to depth ratio. It does, however, include a term to account for the size effect for beam depths greater than 300 mm.

Zsutty's equation was developed in the 1970's using regression analysis of experimental data. It has proven to be relatively accurate in predicting the shear strength of NSC beams. Hence, this equation has become widely used in the literature.

The equation takes into account the compressive strength of concrete, longitudinal reinforcement ratio, and shear span to depth ratio. Zsutty's equation ignores the effect of the beam depth on the ultimate shear strength.

European code calculates the shear capacity of reinforced concrete beams without web reinforcement accounting for the influence of the concrete compressive strength, longitudinal reinforcement ratio, and the size effect.

1.3 Objectives:

The research objectives can be summarized as follows:-

- To investigate the effect of longitudinal reinforcement, shear span to effective depth (a/d) ratio and contribution of stirrups on the shear capacity of high strength concrete deep beams.

- To check the assumption of summing the individual concrete and stirrups contribution for the combined shear capacity of reinforced concrete beams with transverse reinforcement is experimentally proved or not.

- To investigate failure mechanism i.e., diagonal tension failure or compression crushing failure due to decreased depth to shear span ratio (a/d).

1.4 Organization of Thesis:

Chapter (1)	General introduction, review of the past literatures and objectives of the project.
Chapter (2)	Theory of shear strength of concrete deep beams.
Chapter (3)	Modeling of the specimen as per codes and testing of specimens to achieve the objective
Chapter (4)	Test procedure for the experimental investigations are explained. Results and discussion.

CHAPTER – 2

Theory of Shear

2.1 General:

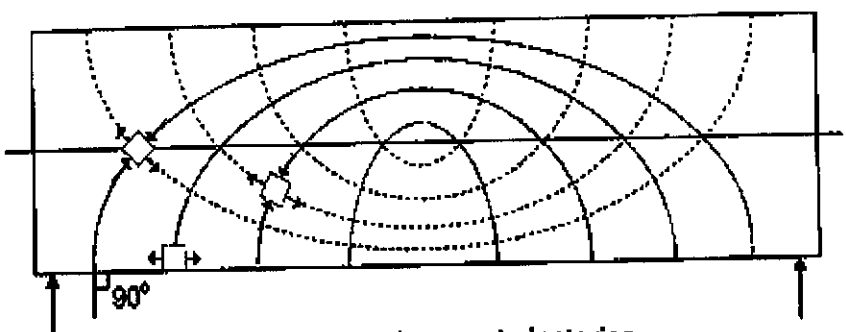
The goal of the code provisions that the permissible shear values that have larger factor of safety against shear failures than the bending failures.

Because today's reinforced concrete designer is to produce ductile member that provide warning of impending failure. Thus the member with fail in bending under loads that load smaller than the load, that would cause shear failure. As a result, the under reinforced members will fail ductitely. They may crack and sag before failure. when shear failures are possible before flexural failures, they can be quite dangerous because they can occur without warning.

In reinforced concrete member flexure and shear combine to create a biaxial state stress. The principal stresses so generated are illustrated.

2.2 Concept of Shear Stress:

Consider a simply supported rectangular beam is subjected to uniformly distributed load. Then the stress paths are determined by using experimental methods, these stress trajectories are as shown in figure.



principal stress trajectories

Figure 2.1

These stress trajectories intersect the neutral axis at 45^0. When the principal tensile stress (called diagonal tension) becomes excessive, i.e., principal tensile stress exceeds the tensile strength of concrete, crack develop approximately at right angles to these principal tensile stress trajectories.

In a region of large bending moments these stresses are greatest at the extreme tensile fibre of the member and are responsible for the initiation of flexural cracks perpendicular to the axis of the member.

In a region of high shear force, significant tensile stresses also referred to a diagonal tension may be generated at approximately 45^0 to the axis of the member. These may result in inclined (diagonal tension) cracks.

Shear Strength of Concrete

Many researches has been on the subject of shear and diagonal tension for non homogeneous reinforced concrete beams and many theories have been developed. From all the results no one has been able to provide clear explanation of the failure mechanism involved. As a result, design procedures are based primarily on test data.

Nominal or theoretical shear strength of a member is equal to the strength provided by the concrete and by the shear reinforcement.

$$V_n = V_c + V_s$$

V_n = nominal shear strength

V_c = Shear strength provided by concrete

V_s = Shear strength provided by transverse reinforcement.

2.3 Shear Strength of Deep Beams

A flexural member is said to be a deep beam, when its length should be less than 5 times depth (ACI code section 11.8). Also define the beams as deep when span / depth ratio of simply supported beam is less than 2, and for continuous beams it should be 2.5.

The traditional principles of stress analysis are neither suitable nor adequate to determine the strength of reinforced concrete deep beams. Most commonly, those structures are encountered in rectangular suspended containers such as silos and bunkers with pyramidal hoppers, in foundation walls supporting strip footings or raft slabs, in parapet walls and in shear wall structures that resist lateral forces in buildings.

2.4 Principal Shear Mechanism:

Well – known relationship between shear and bending moment is

"Rate of change of bending moment is shear"

$$V = \frac{dm}{dx} = \frac{d}{dx}(Tjd) = jd\frac{dT}{dx} + T\frac{d(jd)}{dx}$$

The term $jd\left(\frac{dT}{dx}\right)$ express the behaviour of a true prismatic flexural member in which the internal tensile force T acting on a constant lever arm jd changes from point to point along the beam, to balance exactly the external moment intensity. The term $\frac{dT}{dx}$ the rate of change of internal tension force (i.e, bond force = 'q' or shear flow) applied to the flexural reinforcement per unit length of beam. From the assumption of elastic theory analysis of flexural members the internal lever arm remain constant so $\frac{d(jd)}{dx} = 0$

Then

$$V = jd\frac{dT}{dx} + T\frac{d(jd)}{dx} \quad \left(\frac{d(jd)}{dx} = 0\right)$$

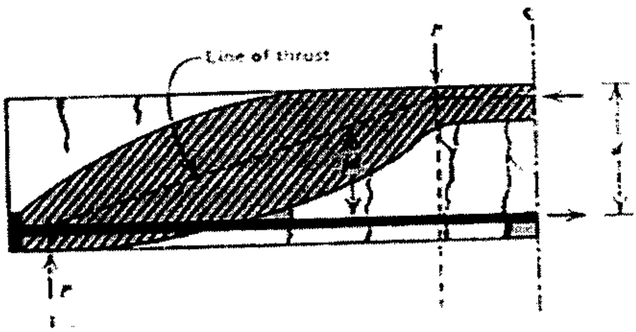
$$V = jd\frac{dT}{dx} \qquad \therefore \textbf{ perfect beam action.}$$

When for any reason the bond between steel and concrete is destroyed over the entire length of the shear span, the tensile force 'T' cannot change hence ,

$\frac{dT}{dx} = 0$, under such circumstances the external shear can be resisted only by inclined internal compression. The extreme case may be termed "arch action".

$$V = T\frac{d(jd)}{dx} = C\frac{d(jd)}{dx}$$

Figure 2.2



Arch mechanism

In arch action mechanism

The diagonal compressive stresses depends on the indication of line of thrust. The shear span to depth ratio (i.e., moment to shear ratio) is a measure of this inclination. It also can be expressed as

$$\frac{a}{d} = \frac{M}{V}$$

When the line of thrust is steeper i.e, when a/d ration is less than 2, considerable reserve strength may be available due to more efficient arch action. Failure may eventually be due to diagonal compression crushing or splitting.

2.5 Evaluation of Shear Strength

ACI 318-05 and Euro code 2 use the strut and tie model to evaluate the shear strength of deep beams.

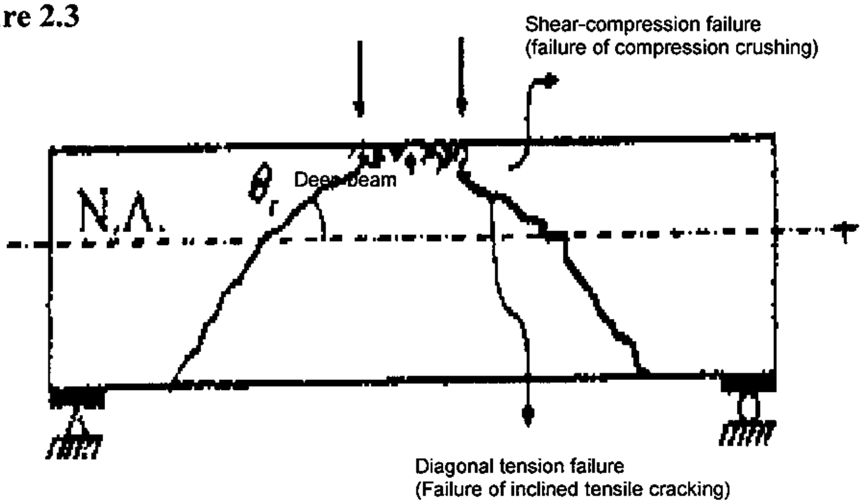
This model is based on a firm theoretical background. Marti, Walravan, Lehwalter and Leonhandt developed various refined truss model.

They reported that a/d is primary design parameter that significantly affects the shear failure mechanism, and as a/d ratio decreases the shear strength considerably increases due to the arch action.

Generally those existing strength models apply different theories to determine the shear strength of deep beams. Therefore they do not properly explain the gradual transition of the failure mechanism which various according to a/d ratio.

The results of experiments done by the above said authors declare that the slender beams with a/d >2.5 the inclined tensile crack penetrates the compression zone and cause diagonal tension failure. Also for deep beams with a/d ratio less than 2.5 after an inclined tensile crack, a crack propagates into the compression zone the appear region of the compression zone is crushed by compression and a shear compression failure occurs.

Figure 2.3



Shear compression failure of Deep Beam

Diagonal Cracking Capacity

As described earlier, the diagonal tension failure occurs immediately after the diagonal crack is formed. Therefore, the shear stress at the diagonal cracking can be assumed to be the ultimate shear strength in the case of the diagonal tension failure.

From numerous experimental data on the shear strength of RC beams without shear reinforcement, the empirical equation was proposed by Okamura and Higai (Okamura & Higai's equation) in 1980. Based on this equation, the modification has been made to incorporate the size effect directly in 1986. This modification was proposed by Niwa and Okamura. This revised equation has been adopted into JSCE Shear Design Specification.

In a RC beam without shear reinforcement under shear force, once diagonal crack is formed, the beam will fail very suddenly. However, the nominal shear stress at the formation of diagonal crack cannot be obtained by the elastic theory, because it involves many factors such as concrete strength, shear span-effective depth ratio (a/d), longitudinal reinforcement ratio, effective depth, etc. After a flexural crack occurs, the shear stress along the crack plane is considered to be resisted by the following effects.

- direct shear resistance in the flexural compression zone
- aggregate interlocking along the crack surface
- dowel action of longitudinal steel

CHAPTER – 3

Modeling the Deep Beam:

3.1 General

The beam has to be modeled, which satisfies the code provision of IS 456-2000, ACI 318-05, BS 8110. The model has to designed with and without shear reinforcement. The concrete grade and steed grade used are M50 & Fe415 respectively.

In beams without shear reinforcement the component Vst is absent altogether. Moreover, in the absence of stirrups enclosing the longitudinal bars, there is little restraint against splitting failure, and the dowel force is small. Further more the crack propagation is unrestrained and hence resulting in a fall in the aggregate interface force and also reduction in the area of the uncracked concrete.

However in relatively deep beams tied – arch action may develop following inclined cracking thereby transferring part of the load to the support and so reducing the effective shear force at the section. In beams without shear reinforcement the breakdown of any of the shear transfer mechanisms may cause immediate failure, as there is little scope for redistribution. Further owning to uncertainities associates with all the above effects, it is difficult to predict the behaviour and strength beyond the stage of diagonal cracks formation.

In beams with moderate amount of shear reinforcement, shear resistance continuous to increase even after included cracking until the shear reinforcement yields in tension. The failure of shear reinforced beams is gradual and ductile is nature. However if excessive shear reinforcement is provided, it is likely that the shear compression mode of failure, this is undesirable, failure will occur suddenly without warning.

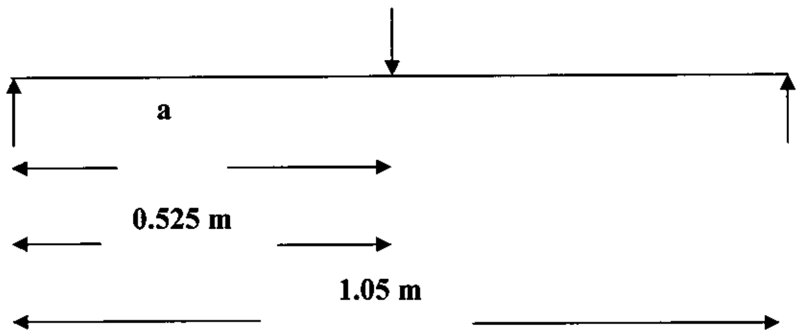
3.2 Experimental Modeling

According to IS 456-2000, BS-8110 and ACI 318-05 the following conditions to be satisfied for deep beams.

For simply supported beam $a/d < 2.5$

Where a = Shear span

d = effective depth.



Then

$$\frac{0.525}{d} = 1.75$$

d = 0.3 m

Adopt the beam size as 0.23 x 0.3 x 1.05 m

Minimum Steel for Crack Control

We should also check weather the tension steel provided is enough for control of tension cracks due to beam action which should be at least not less than 0.2 to 0.3% of the gross area of concrete.

- Take steel percentage as 0.4
- Area of tension reinforcement $= 235.5\ mm^2$

Minimum Transverse Reinforcement

As per IS 456- 2000 cl 32.5

= 0.0020 x 230 x 1000

= 460 mm^2

Transverse reinforcement is 8mm ϕ @ 250 mm c/c on both sides

Minimum web reinforcement

As per IS 456-2000 cl 32.5

= 0.0012 x 230 x 300

= 74.52

Web reinforcement as 8mm ϕ @ mid of the beam side face on both sides.

PROPERTIES OF CONSTITUENT MATERIALS

The properties of the constituents used in this experimental investigation are given below.

Cement

Cement is the most important ingredient in concrete. One of the important criteria for the selection of cement is its ability to produce improved microstructure in concrete. Unlike conventional cement concrete, the HSC incorporates chemical or mineral admixtures or both. Moreover, the effect of characteristics of cement on water demand is more noticeable in HSC. Some of the important factors which play vital role in the selection of cement are compressive strength at various ages, fineness, heat of hydration, alkali content, tricalcium aluminate (C_3A) content, tricalcium silicate (C_3S) content, dicalcium silicate (C_2S) content etc. It is also necessary to ensure compatibility of the chemical and mineral admixtures with cement.

Aggregates

Aggregates are important constituents of concrete. They give body to the concrete, reduce shrinkage, and affect economy. Aggregates occupy 70 to 80 percent of volume of the concrete. The aggregates combine with the binder (cement and pozzolano) and water to produce concrete. Basically there are two types of aggregates, the fine aggregate and the coarse aggregate. The properties of Fine aggregate and Coarse aggregate are given in Table

Properties of fine aggregate and coarse aggregate

Table 3.1

S.No	Property	Natural Fine Aggregate	Coarse Aggregate
1.	Specific Gravity	2.68	2.77
2.	Bulk density (gm/cc)	1.603	1.452
3.	Water Absorption %	0.402	0.251
4.	Fineness Modulus	2.6	7.1

Water

Water is an important ingredient of concrete as it actively participates in the chemical reactions with cement to form the hydration product, calcium-silicate-hydrate (C-S-H) gel. As per Neville (2000), the quantity of water added should be the minimum requirement for chemical reaction of unhydrated cement, as the excess water would end up only in the formation of undesirable voids (capillary pores) in the hardened cement paste of concrete.

Admixture

The admixtures interact with the hydrating cementitious system by physical, chemical or physio-chemical action, modifying one or more properties of the concrete, mortar or paste in the fresh, setting, hardening or hardened stage.
(Villarreal, 1997) Materials such as fly ash, slag, pozzolonas or silica fume which can be constituents of cement and/or concrete. Incorporation of mineral admixtures can lead to benefits like improvement in rheological properties.

Super plasticizer

For processing HPC, the most important chemical admixture is the super plasticizer, which is the High-Range Water-Reducing Admixture (HRWRA). There are four types of super plasticizers. Super plasticizers are water reducers which are capable of reducing water content by about 30 percent. For this present investigation, a super plasticizer namely CONPLAST SP430 has been used for obtaining workable concrete at low w/b ratio. CONPLAST SP 430 complies with BIS: 9103-1999 and BS: 5075 part 3 and ASTM C 494, Type B as a HRWRA. CONPLAST SP 430 is based upon NSF condensates.

3.3 Mix Design for High Strength Concrete.

Design Mix : M50 grade concrete

Design stipulations:

a. Characteristic compressive strength required = 50 N/mm^2

b. Max size of aggregate = 20 mm

c. Degree of workability = 80% (comp)

Test Data for Materials

Cement	=	OPC
Specific gravity of cement	=	3.15
Specific gravity of aggregate	=	2.77
Fine aggregate	=	2.68

Design of Mix

Average Strength	=	50/0.80
	=	63 N/mm^2
Preference Number	=	25
Water / Cement Ratio	=	0.36

For 20mm max. size aggregates and very low workability.

Aggregates / cement ratio for the desired workability.

So that 30 percent of the material passes through the 4.75 mm IS Sieve.

Ratio of the fine to total aggregates =25%

Required proportions by weight of dry materials

Table 3.2

Cement	Fine Aggregates	Course Aggregates	Water
1	25/100 *3.6)	(0.75/100*3.6)	0.36
1	0.9	2.70	0.36

Then,

$$(C/3.15) + (0.9C/2.68) + (2.7C/2.77) + (0.36C/1) = 1000$$

$$0.286C + 0.335C + 0.973C + 0.36C = 1000$$

$$1.955C = 1000$$

$$C = 511.51\text{Kgs.}$$

Quantity of ingredient materials

Table 3.3

Ingredient	Dry Aggregates Kgs.	Moist Aggregates Kgs.
Cement	511.51	511.51
Water	184.14	174.93
Fine Aggregate	460.36	469.57
Course Aggregates	1381.08	1381.08

Mix proportions

Table 3.4

Cement	Fine Aggregates	Course Aggregates	Water
1	0.92	2.70	0.34

Concrete Mix Proportions of the test beams

Table 3.5

Material	Quantity
Ordinary Portland Cement	511.51 Kg/m^3
Fine Aggregate	469.57 Kg/m^3
Coarse Aggregate	1381.08 Kg/m^3
Water	174.93 Lit $/m^3$
Plasticizer (Conplast-SP 430)	5.12 Lit $/m^3$
Water / Binder Ratio	0.34

Strength Related Properties

Cube Compressive Strength Test

For cube compression testing of concrete, 150mm cubes were used. All the cubes were tested in saturated condition, after wiping out the surface moisture. For each trial mix combination, three cubes were tested at the age of 3 days, 7 days, 28 days of curing using compression testing machine of 3000 KN capacity.

The tests were carried out at a uniform stress of 140 kg/cD2/minute after the specimen has been cantered in the testing machine. Loading was continued till the dial gauge needle reversed its direction of motion. The reversal in the direction of motion of the needle indicates that the specimen has failed. The dial gauge reading at that instant was noted which was the ultimate load. The ultimate load divided by the cross sectional area of the specimen is equal to the ultimate cube compressive strength

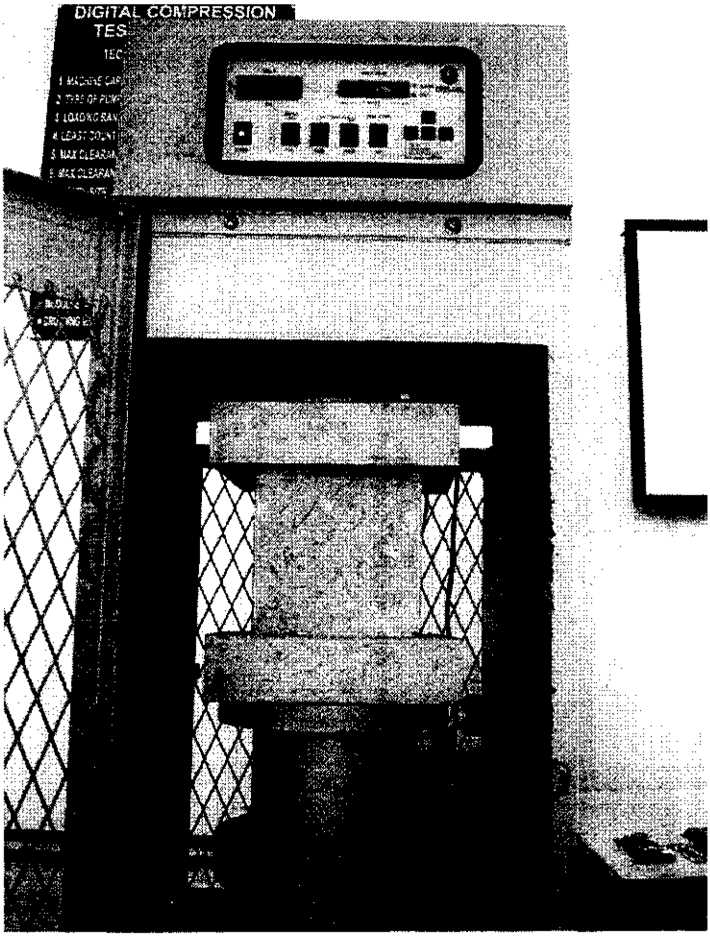


Figure 3.1 **Test set up for cube**

Cube Strength

7th Day Strength **Table 3.6**

SL.No.	Specimen Identification	Wf of Cube	Load taken	Comp stress N/mm^2
1	S-1	8.192	630 Kn	28.00
2	S-II	8.118	612 Kn	27.20
3	S-III	8.010	635 Kn	28.22

28^{th} Day Strength **Table 3.7**

SL.No.	Specimen Identification	Wf of Cube in Kg	Load taken in kn	Compressive Stress in N/mm^2
1	S-IV	8.050	1237	54.9
2	S-V	7.950	1159	51.51
3	S-VI	8.100	1192	52.9

3.4 Crack Load Calculation

Concrete = M50

Steel = Fe 415

Es = $2x10^5$ N/mm^2

Ec = $5000\sqrt{fck} = 35355.34 \ N/mm^2$

According to BS 8110 the value of m should be based on Es/Ece; considering Ece as half the short term elastic modulus of concrete.

Modular ratio m = Es / Ece

Ece = 35355.34 / 2= 176677.67

= $2x10^5$ / 176677.67

= 11.31

Depth of neutral axis

From SP 16 $d'/d = \frac{30}{270} = 0.11 \simeq 0.1$

$P_t = \frac{235.5x100}{230x270}$ = 0.38%

mpt = 11.31 x 0.38

= 4.298

for the values d'/d & mpt **from sp 16 table 92**

$x_u/d = 0.253$

$x_u = 0.253 \times 270$

$= 68.31$ mm

$$acr = \sqrt{(75/2)^2 + 25^2}$$
$$acr = 45mm$$

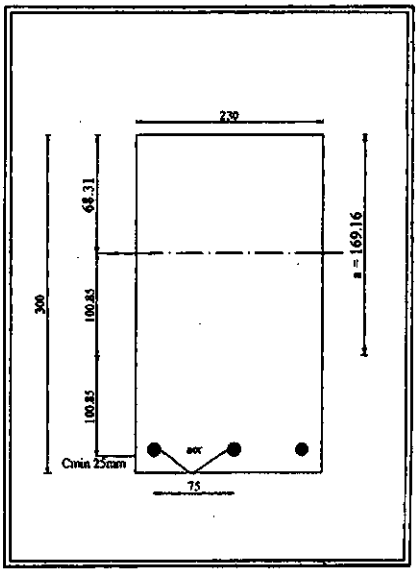


Figure 3.2

Crack Load:

Crack width W_{cr} = constant x acr x ε_m

Constant for deformed bars are 3.33

Take crack width is 0.1 mm

$0.1 = 3.33 \times 45 \times \varepsilon_m$

Mean strain $\varepsilon_m = 6.673 \times 10^{-4}$

Mean strain $\varepsilon_m = \varepsilon_1 - \dfrac{b(D-x)(a-x)}{3E_s A_s (d-x)}$

Where ε_1 = Strain at the level considered

$$6.673x10^{-4} = \varepsilon_1 - \frac{230(300-68.31)(169.15-68.31)}{3x2x10^5x235.5x(270-68.31)}$$

$$6.673x10^{-4} = \varepsilon_1 - 1.885x10^{-4}$$

ε_1 = $8.558 \text{ x } 10^{-4}$

Cracked Moment of Inertia:-

$$Icr = \frac{bx^3}{3} + m.Ast(d-x)^2$$

$$= \frac{230x68.31^3}{3} + 11.31x235.5x(270-68.31)^2$$

$$= 132.785x10^6 mm^4$$

Cracked Moment:-

$$\varepsilon_1 = \left[\left\{\frac{M}{Icr}\right\}x\left\{\frac{D-x}{Ec}\right\}\right]$$

$$8.558x10^{-4} = \frac{M}{132.785x10^6}x\frac{300-68.31}{35355.34}$$

M = $17.34 \text{ x } 10^6$ N-mm

M = 17.34 KNM

Crack Load:-

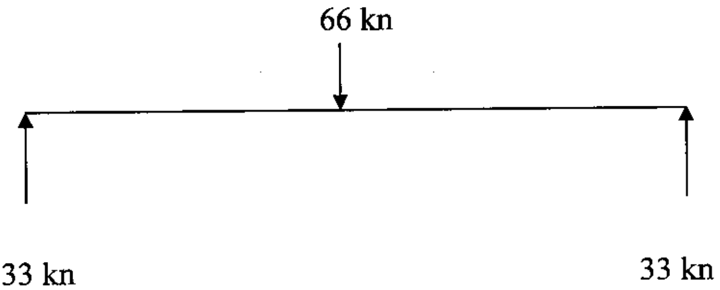
For simply supported beam $BM = \frac{Wl}{4}$

$$17.34x10^6 = \frac{Wx1050}{4}$$

W = 66 KN

W = 6.6 tonnes

Shear Capacity of Beam:-



Nominal Shear stress $= \dfrac{V_u}{tD_u}$

$= \dfrac{33x1000}{230x500}$

$= \tau_c < \tau_c \text{ max } \ (0.8\sqrt{fck})$

$= 0.48 \text{ N/mm}^2 < 5.65 \text{ N/mm}^2$

Ultimate Shear V_u $= V_c + V_s + V_{sh}$

Shear taken by concrete

$V_c = 0.72\ (D - 0.35\ a_v)\ f_t \times t$

$V_c = 0.72(300 - (0.35x525))0.5\sqrt{50}x230$

$= 68$ KN

Shear taken by tension steel

$$V_s = C_2 \sum_1^n A_1 \frac{Y_1}{D} \sin^2 \alpha$$

$$C_2 = 230 N/mm^2 for \;\; fe415$$

$$\tan \alpha = \frac{D}{a_v} = \frac{300}{525} \qquad \alpha = 29.74$$

$$Sin^2 \alpha = 0.246$$

then

$$V_s = 230x235.5x\frac{270}{300}x0.246$$

= 11.99 KN

= 12 KN

Shear taken by transverse reinforcement

$$V_s = 0.87 f_y \, x \, A_{sv} x \frac{d}{s_v}$$

$$= 0.87x415x(1x50.24)x\frac{270}{250}$$

$$= 19.5 KN$$

Shear Capacity of Beam

With Shear reinforcement	=	V_c+V_s+V_{st}
	=	68+12+10.5
	=	99.5 KN
Without out sheen reinforcement	=	V_c + V_s
	=	68 + 12
	=	80 KN

3.5 Casting of Model

Concrete with target compressive strength of M50 grade is used for casting the proposed deep beam model. The mix proportions for the M50 grade concrete were designed in this chapter. i.e., mix ratio of 1:0.91:2.70 with water cement ratio of 0.34.

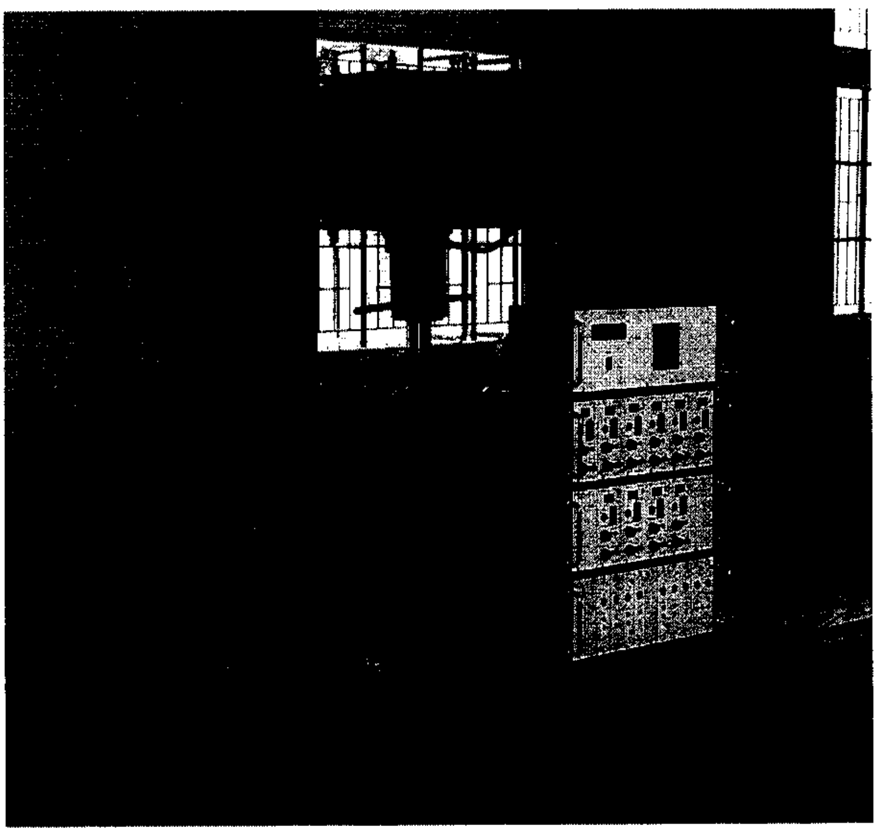
Weigh batching is used to measure the quantities of concrete ingredients. Plasticizer are added to the mix with 1% of wt of cement. Mixing of the ingredients in the mixer machine is continued till concrete of uniform colour and consistency is obtained. Needle vibrator is used to obtain proper compaction, so as to avoid any honey combing due to improper vibration. Care was taken to avoid over vibration and disturbance of the reinforcement position. Reinforcement gauge is fabricated. The concrete is started from one end of the end block and placed in two layers. Each layer being well compacted by a 20 mm dia needle vibrator. Controlled specimen of 6 Nos. of 150 mm cube were casted along with the test specimens. Top surface is smoothened by a trowel. The side shutters of the specimens and moulds of cubes were demoulded after 24 hours. Curing is done in tanks, the specimen immersed continuously for 21 days.

CHAPTER – 4

Observation and Structural Behaviour

4.1 General

To predict the behaviour and shear strength of deep beam with and without shear reinforcement by experimental investigation were planned. Two set of beams with and without shear reinforcement are casted and tested. The test procedures and results are discussed in this chapter.



Test Setup for deep beam

Figure 4.1

When the load is applied and gradually increased, flexural cracks appear in the beams which are more or less vertical in nature. With further increase of load inclined shear cracks develop in the beam is called primary shear crack. Again the gradual increase of load the second branch of inclined shear crack, initiates from the tip of the first crack and it penetrate the compression zone. The nominal shear stress at the diagonal tension cracking at the development of the second branch of inclined crack is taken as the shear capacity of the beam.

4.2 Test Procedure and Result

Beam without Shear Reinforcement

First set of specimen without shear reinforcement was selected in the test set up. The load is applied through hydraulic jack. And the deflections are measured with help of LVDT and compressive and tensile strain are measured with help of mechanical strain gauges. Then the load was applied and gradually increased in steps.

The increments @ 10 Kn till the theoritical recommended load capacity (80 Kn). The compressive strain and tensile strain were observed in each step of load increments, also the deflection.

Up to the load of 60 Kn no visible cracks are observed. Load is further increased at an increment of 5 Kn. After the load of 70 Kn the visible cracks are observed. The cracks are flexural cracks. Further increase of load about 80 Kn the diagonal tension cracks appears at 150 mm from the support. The development of above crack confirms the development of tension in the concrete. Due to further increment of load, the crack develops and the cracks penetrate the compression zone at the loading point the concrete were crushed.

LVDT and load cell are connected with the 20 channel data logger. (Load cells, LVDTS are calibrated before taking readings).

For ease of calculation average values are taken to plot the results.

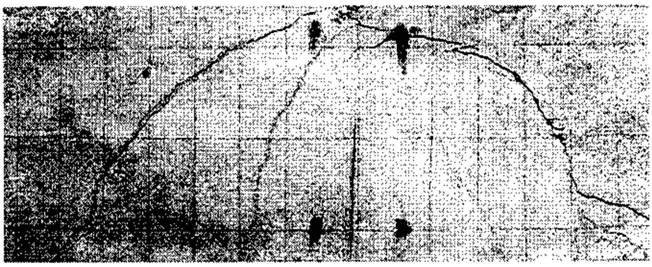
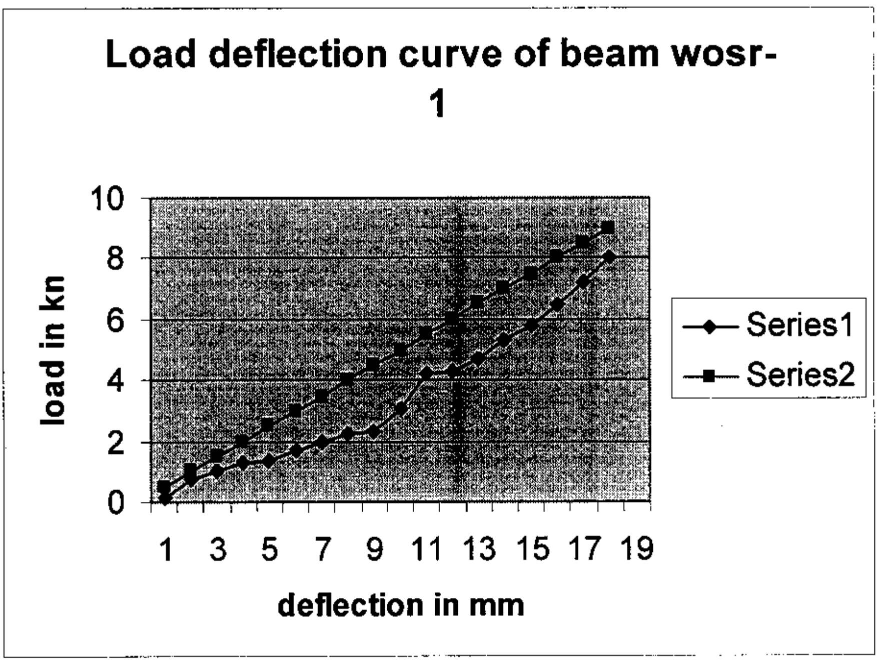


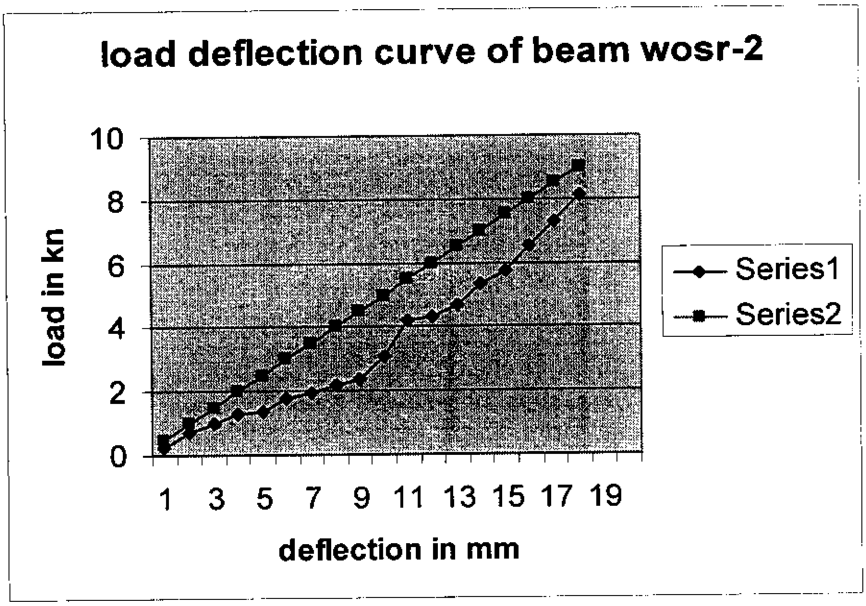
Figure 4.2

Crack pattern of Beam without shear reinforcement



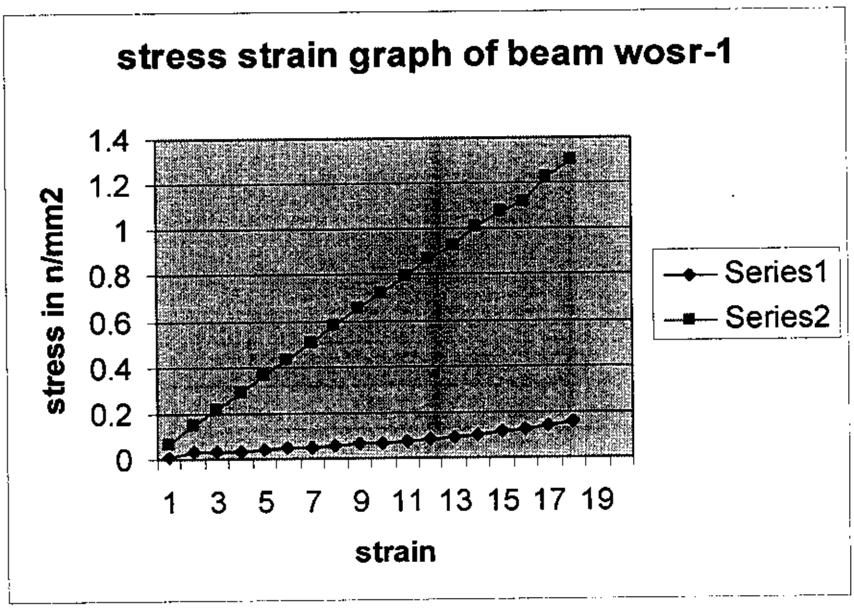
Graph shows the load deflection curve

Figure 4.3



Graph shows the load deflection curve

Figure 4.4



Stress strain graph

Figure 4.5

Stress Result of beam without shear reinforcement

Table 4.1

SL. No.	Beam title	Steel ratio in %	Shear span in mm	a/d	Shear Stress in N/mm^2
1.	WOSR-1	0.38	525	1.75	0.684
2.	WOSR-2	0.38	525	1.75	0.71

Beams with Shear Reinforcement:

Second set of specimen with shear reinforcement was placed in the test setup. The load is applied through hydraulic jack and the deflection are measured with the help of LVDT. The compressive strain and tensile strain are measured with mechanical strain gauges. The load cell and the LVDT are connected with 20 channel data logger. (Load cell and LVDT are calibrated before taking the measurements).

The load was applied and gradually increased in steps. The increments @ 10 Kn till the theoretical recommended load capacity (99.5 Kn). The compressive strain and tensile strain were observed in each step of load increments, also the deflection.

Up to the load of 70 Kn no visible cracks are observed, with further increased in load at an increment of 5 Kn. After the load of 85 Kn cracks observed. The Cracks are flexural cracks with further increase of load the diagonal tension cracks appears at 140 mm from the support. The development of above crack confirms the development of tension in the concrete. Due to further increment of load, the crack probagates along the tension reinforcement. The diagonal cracks does not penetrate the compression zone. The crack pattern is like an arch as shown in Figure. For ease calculation average values are taken to plot the results.

Crack pattern of Beam with shear reinforcement

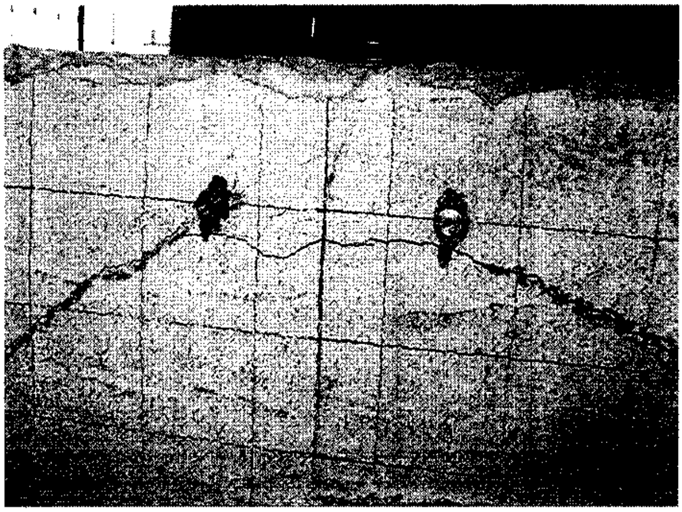
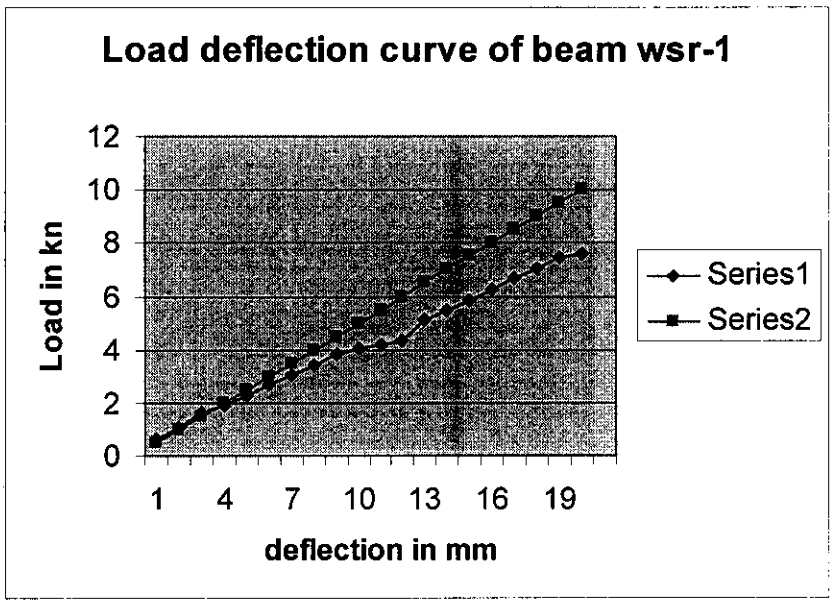
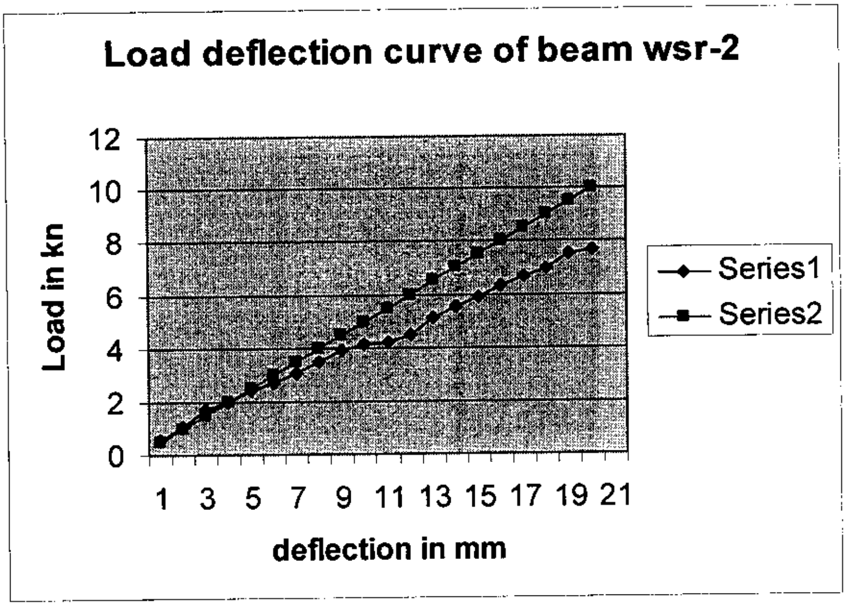


Figure 4.6



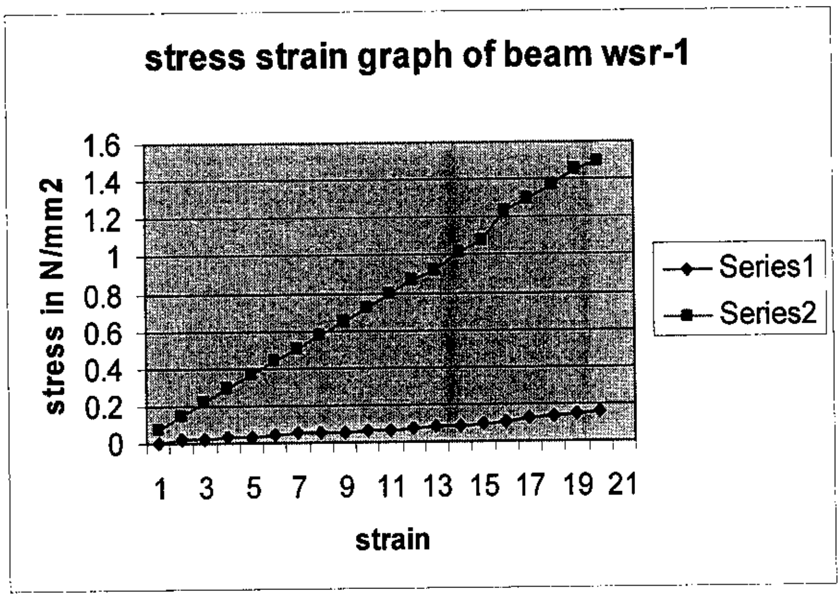
Graph shows the load deflection curve

Figure 4.7



Graph shows the load deflection curve

Figure 4.8



Stress strain graph

Figure 4.9

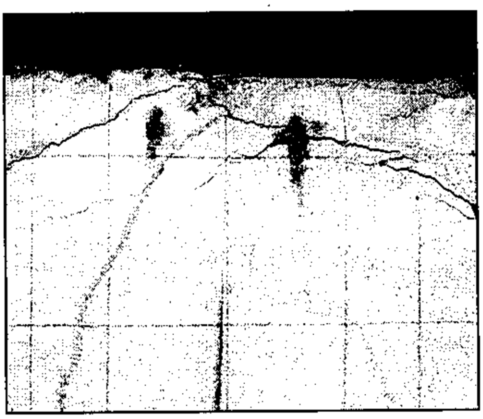
Stress Result of beam with shear reinforcement

Table 4.2

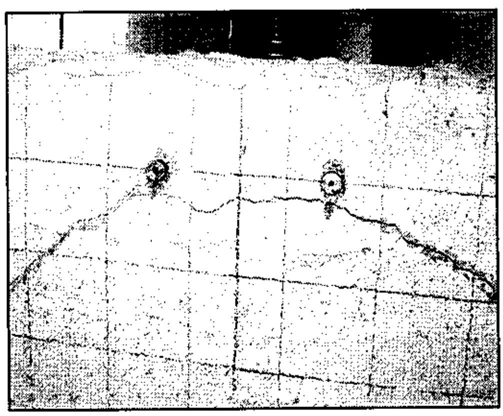
SL. No.	Beam title	Steel ratio in %	Shear span in mm	a/d	Shear Stress in N/mm²
1.	WSR-1	0.38	525	1.75	0.84
2.	WSR-2	0.38	525	1.75	0.82

4.3 Discussion of Test Results:

The crack formed in the specimen of with out shear reinforcement, it confirms the development of tension in concrete. The diagonal cracks probagates through the compression zone, at the point of application of load the concrete has crushed due to compression. This happens because of small a/d ratio. In the second specimen of with shear reinforcement the diagonal tension cracks probagates through the compression zone, at the loading point the concrete will not crushed but the crack forms arch, and some depth above the crack will not undergo any damage. These two crack pattern of with and without shear reinforcement beams are compared as below.



Compression crushing of Beam without shear reinforcement

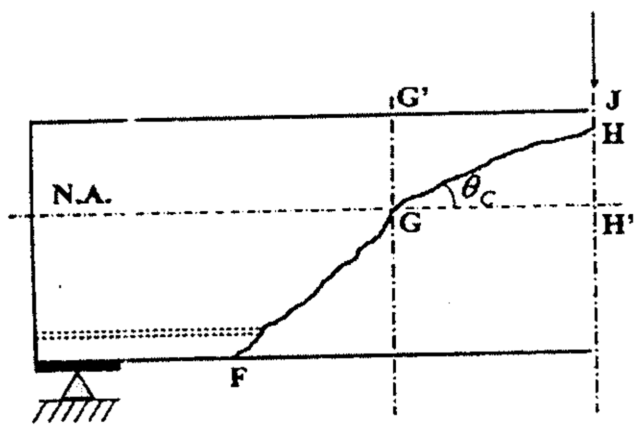


Compression zone of beam with shear reinforcement

Figure 4.10

In specimen with shear reinforcement been take further more load after crack formation and up to compression zone has to crush, because the shear reinforcement placed in the upper compression zone cannot develop its yield strength. Therefore it was assumed that the shear reinforcement placed with in depth Cc did not contribute to shear resistance.

Therefore the overall shear strength of a deep beam is determined by the combined failure mechanism of tension and compression.



Conclusions

From the experimental investigations before the formation of crack the shear force is resisted by the entire cross – section, then the beam behaves elastically. Once a tensile crack initiates in the tension zone, an inclined tension crack immediately probagates to the neutral axis of a cross section. When the tensile crack reaches the neutral axis, the shear capacity of the section reaches its minimum. After this stage the shear force is resisted primarily by the compression zone of intact concrete.

The shear capacity controlled by compression is greater than that controlled by tension. The compression zone is expected to fail compression crushing rather than by inclined tensile cracking. However the inclined tensile cracking develops in the direction perpendicular to the principal tensile stress axis. Sufficient shear span is required for the inclined tensile cracking to penetrate the compression zone for the small value of a/d ratio the inclined tensile cracking cannot penetrate the compression zone. The intact concrete of the upper compression zone, which is not damaged by the inclined tensile cracking, is subjected to compression crushing. Therefore the upper compression zone can develop the shear resistance controlled by compression which is greater than that controlled by tension. Therefore the overall shear strength of deep beam is determined by the combined failure mechanism of tension and compression.

The principal findings of the study are summarized as follows.

[1] The shear capacity of deep beam with and without shear reinforcement will not give much variation.

[2] The shear span is short an inclined tensile crack cannot penetrate the entire depth of the compression zone and the upper compression zone is subjected to compression crushing.

[3] The shear reinforcement will improves the depth of intact concrete compression zone, will take further more load.

[4] Overall strength of deep beam is determined by the combined mechanism of tension and compression.

In further, the shear strength of deep beam with different values of a/d ratio, tensile reinforcement with and without shear reinforcements can be investigated.

REFERENCES

1. kyoung – kyu choi , nong – gun park, james wight " unified shear strength model for reinforced concrete beams " ACI structural journal V.104, no 2,mar-apr 2007.

2. Aurelio muttoni and Mignel fernandaz ruiz "shear strength of members with out transverse reinforcement as a function of critical shear crack width" ACI structural journal V.105, no 2, Mar-Apr 2008.

3. Micheal D brown and Oguzhan bayrak "Investigation of deep beams with various load configurations," ACI structural journal V.105, no 5, Sep-oct 2007.

4. Jung-yoon lee and UK-yeon kim "Effect on longitudinal tensile reinforcement ratio and shear span-depth ratio on minimum shear reinforcement in beams," ACI structural journal V.105, no 2, April 2008.

5. Stephen J foster and R.Ian gilbert "Test on high strength concrete deep beams," project report, The University of new southwales, Sydney, Australia.

6. Gaetano russo, Raffaele venir,and Margherita pauletta "Reinforced concrete deep beam- shear strength model and design formula," ACI structural journal V.102, no 3,May-June 2005

7. Jung- woong park and Danial kuchma "Strut and tie model analysis for strength prediction of deep beams," ACI structural journal V.104, no 6, Dec 2007.

8. Shah and ahmad "Experimental investigation into shear capacity of high strength concrete beams," Asian journal of civil engineering," vol 8, no5, 2007.

9. Zararis.P.D, "Shear compression failure in reinforced concrete deep beams," Journal of structural engineering, ASCE, v.129, no4-2003.

10. Clark A.P. "Diagonal tension in reinforced concrete beams," ACI journal proceedings, V.48, no 10, Oct 1951.

11. Ramirez J.A. and Breen J.E. "Evaluation of modified truss model approach in shear," ACI structural journal V.104, no 6, Dec 2007.

12 IS 456-2000, Indian standard code of practice for concrete.

13 R.Park and Paulay "Reinforced concrete structures" A willey -interscience publication, Newyork, USA.

14 Jack C.McCormac "Design of reinforced concrete" Harper & Row publishers, Newyork, USA.

15 S.Unnikrishnan pillai and Devadas menon "Reinforced concrete design" Tata McGraw Hill publications.

16 V.L.Shah and S.R.Karve "Limit state theory and design of reinforced concrete"structure publications.

17 N.Krishnaraju "Advanced reinforced concrete design" CSB publications.

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