EXPERIMENTAL INVESTIGATIONS OF SHEAR CAPACITY OF HIGH STRENGTH CONCRETE SLENDER BEAMS

PROJECT REPORT

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BONAFIED CERTIFICATE

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INTERNAL EXAMINER

EXTERNAL EXAMINER

ABSTRACT

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The shear capacity of the concrete beams having stirrups is assumed as the individual contribution of both the concrete and shear reinforcement. Different international building codes have suggested empirical relations for both of these contributions. The design equation in IS 456-2000 for shear strength of concrete does not consider the effect shear reinforcement present in reinforced concrete.

High-strength concrete (HSC) is becoming increasingly attractive for various construction projects since it offers a multitude of benefits over normal-strength concrete (NSC). Unfortunately, current design provisions for shear capacity of RC slender beams are generally based on data developed for NSC members having a compressive strength of up to 50 MPa, with limited recommendations on the use of HSC. The failure of HSC beams is noticeably different than that of NSC beams since the transition zone between the cement paste and aggregates is much denser in HSC. Thus, unlike NSC beams in which micro-cracks propagate around aggregates, providing significant aggregate interlock, micro-cracks in HSC are trans-granular, resulting in relatively smoother fracture surfaces, thereby inhibiting aggregate interlock as a shear transfer mechanism and reducing the influence of compressive strength on the ultimate shear strength of HSC beams.

Experimental investigations were carried out on the shear strength of High strength concrete beams, made using concrete with compressive strength 50 Mpa. Four numbers of beams were tested in two sets beams in each, without and with shear reinforcement to study the contribution of the stirrups in resisting the shear. The beams were tested under the two concentrated load at middle third points. The parameters investigated include compressive strength, amount of longitudinal reinforcement, and beam's depth.

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LIST OF SYMBOLS

a	= shear span
b	= width of beam
c	= depth of compression zone
c_c	= depth of failure surface compression crushing
d	= effective depth of beam
Ec	= Young's modulus of concrete
Es	= Young's modulus of steel
f'_t	= tensile strength of concrete affected by transverse compression
fy	= yield stress
f_r	= modulus of rupture
f_t	= tensile strength of concrete
f_{vy}	= yield strength of transverse web reinforcement
h	= depth of beam
Mcr	= cracking moment
Vc	= shear contribution of concrete
Vcc	= shear contribution of compression zone subject tc compression crushing
Vct	= shear contribution of compression zone subject to tensile cracking
Vd	= shear force required by flexural action of beam
Vs	= shear contribution of transverse Reinforcement
Vn	= shear strength of beam
Vu	= shear stress applied to compression zone of intact concrete
ε_o	= compressive strain corresponding compression Strength of concrete
ρ	= ratio of tensile reinforcement
ρ_v	= ratio transverse web reinforcement
μ	= Poisson's ratio
HSC	= high strength concrete
NSC	= nominal strength concrete

INTRODUCTION

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Extensive research has been made in last 20 years to understand the shear properties of reinforced concrete beams. The reinforced concrete beams are presently designed with the help of certain provisions of different international building codes, but the latest research has shown that most of these are un-conservative for beams with large sizes and lower values of longitudinal reinforcement.

According to experimental results, the shear strength of simply supported beams is significantly affected by the compressive strength of concrete, the ratio of tensile reinforcement, the shear span to depth ratio (a/d), and size of beam. In particular shear resistance mechanism start to change at a/d equal to 2.5. Based on this result, the shear resistance mechanism of slender beams with a/d > 2.5 is usually assumed to be different from that of deep beams with a/d < 2.5. It has also been observed that the stirrups contribution has also been adversely affected in large beams.

The shear strength of concrete beams mainly depends on the following variables:

- Depth of member or size effect
- Shear span to effective depth a/d or moment to shear ratio
- Longitudinal Reinforcement or dowel action,
- Axial Force,
- The tensile Strength of concrete,
- Crushing strength of the Beam web,
- Yielding of stirrups,
- The aggregates sizes leading to aggregate interlocking.
- Failure of Tension chord.
- Failure of Stirrups anchorage
- Serviceability failure due to excessive crack width at Service load.

The latest research has revealed that reduction in the shear capacity of all beams occur when the longitudinal reinforcement ratio is 1% or less for all sizes of beams and the provisions of different international building codes for the shear design are also not conservative for slender beams with a/d ratio > 2.5.

The shear strength contribution due to aggregates interlocking in high strength concrete is less than that of normal strength concrete as the strength of mortar matrix is more than the aggregates itself. Thus the aggregates crush before the cracking of high strength concrete and the aggregates interlocking is playing relatively little role. In this research, the effect of transverse steel ρv, 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 term high-strength concrete is generally used for concrete with compressive strength higher than 41 MPa. The use of high-strength concrete in the construction industry has increased steadily over the past years. This is because the use of high-strength concrete leads to the design of smaller sections. This in turn reduces the dead weight, allowing longer spans and more usable area of buildings and taller structures. Reduction in mass is also important for economical design of earthquake resistant structures.

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 to improve the workability of these concrete.

High strength concrete is a brittle material, and as the concrete strength increases the post-peak portion of the stress-strain diagram almost vanishes or descends steeply. The increase in concrete strength reduces its ductility- higher the Strength of the concrete lower it's ductility.

When principal tensile stresses within the shear region of a reinforced concrete beam exceed the tensile strength of a reinforced concrete, diagonal cracks develop in the beam, eventually causing failure. After the formation of the first crack, the brittle nature of concrete cause collapse in the unreinforced beam.

In spite of the numerous research efforts directed at the shear capacity of concrete, there is still great discord conceding the mechanisms that govern shear in concrete. Proposed theories Vary radically from the simple 45 degree truss model to the very complex non-linear Fracture mechanics. Yet nearly all the resulting design procedures are empirical or semi empirical at best and are obtained by a regression fit thrciugh experimental results.

Nowhere is this lack of understanding more evident than in the shear design provisions of the AC1 Code (AC1 committee 318-1995) which consists of 43 empirical equations for different types of members and different loading conditions. Moreover, there is great discrepancy between design codes of different countries. Many of these codes do not even account for some basic and proven factors affecting the shear capacity of concrete members. Of these factors, much confusion is expressed with regards to the effect of absolute member size on the shear capacity of beam elements. On this subject, there is a lack of consensus in the approach to the problem due to the limited amount of experiments dedicated to this effect, especially when it corneas to high-strength concrete elements.

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 analytical results.

1.2 THE MECHANISM OF SHEAR RESISTANCE IN REINFORCED CONCRETE BEAMS WITHOUT WEB REINFORCEMENT

1.2.1 The Formation of Diagonal Cracks

In reinforced concrete members, flexure and shear combine to create a biaxial state stress. Cracks form when the principal tensile stresses exceed the tensile strength of the concrete. 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 the region of high shear force, significant principal tensile stresses, also referred to as diagonal tension, may generated at approximately 45 deg. to the axis of the member. These may result in inclined (diagonal tension) cracks.

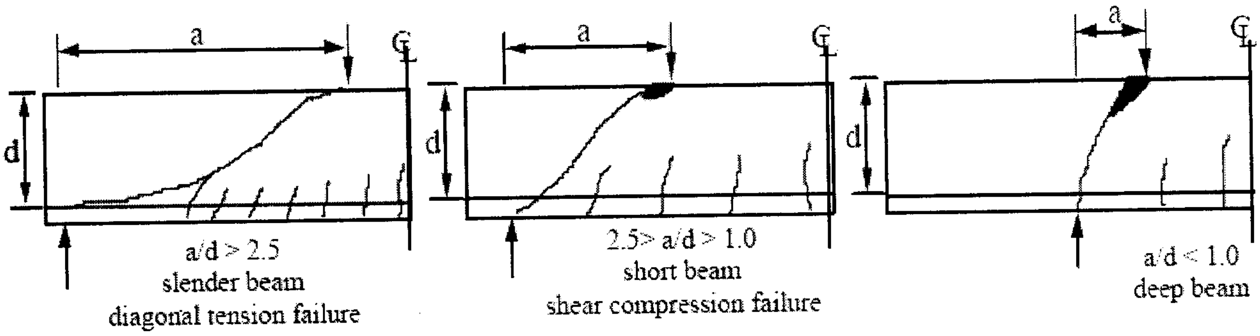

Fig 1.1 Typical shear failure modes of RC beams

The shear failure is one of the failure modes of RC structures of which the mechanism is much different from flexural failure. In actual RC structures, there is a combination of forces such as shear and flexural moment, axial force, torsion moment, and their failure modes are very complicated.

The shear failure follows a formation of diagonal cracks. It is brittle failure compared with flexural tension failure. Therefore, in the case of design involving the ductility of structures such as seismic design, this type of failure has to be avoided by assigning the safety factor greater than that for flexural failure.

1.2.2 Diagonal Cracking Capacity

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.

1.2.3 Equilibrium in shear span of a beam

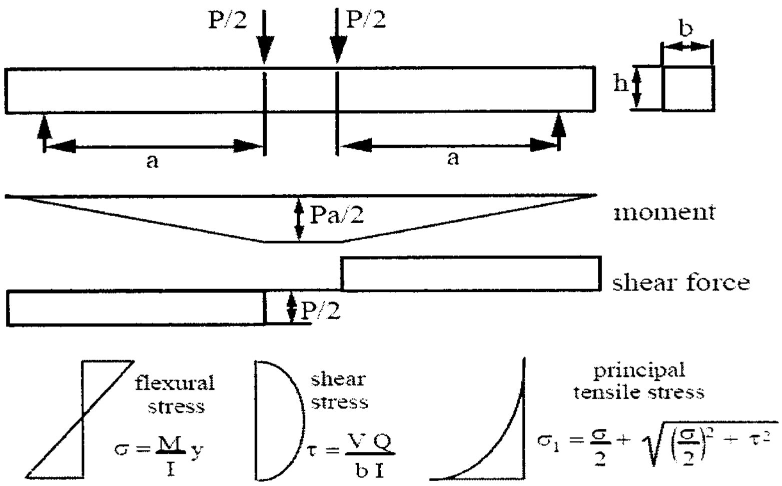

Fig. 1.2 Stress conditions in an elastic beam subjected to shear and moment

In the case of simply supported beam subjected to two-points loading, the moment and shear distribution is such that the moment is constant in the mid span and in two side spans, shear force is constant. These two side spans are called "shear span". For the elastic beam, the flexure stress σ, shear stress τ, and the principal tensile stress σ1 are determined according to the beam theory. Since concrete material is weak in tension, the magnitude and direction of principal tensile stresses are important. At the location of zero shear stress, i.e., the extreme tension fibre, the principal tensile stress takes the horizontal direction. At the point of zero normal stress, i.e., the neutral axis, the principal tensile stress is equal to shear stress, and its direction is 45 degrees with respect to the member axis.

The internal and external forces that maintain equilibrium for this free body, bounded on one side by a crack, can be identified. It may seen that the total external transverse force V, is resisted by the combination

- A shear force across the compression zone Vc,
- A dowel force transmitted across the crack by the flexural reinforcement Vd,
- To vertical components of inclined shearing stresses Va transmitted across the inclined crack by means of interlocking of the aggregates particles

The distribution of shear stress $\tau(y)$ is of parabolic curve within the flexural compressive zone of the cross section, i.e., between the extreme compression fibre and the neutral axis . At $\tau(0)$ becomes the maximum and equal to $V/(b\ j\ d)$. Since the tensile resistance of concrete is neglected, the shear stress below the neutral axis becomes constant. Here, the flexural stress is assumed to be zero, and hence the principal tensile stress is equal to the shear stress.

The diagonal cracking strength of RC beams is expressed by the

Maximum shear stress = $(V/\ (b\ jd))$.

The value of j in Equation is approximately equal to 7/8.

However, this maximum shear stress is only an index of the principal tensile stress, and often j is set to be 1 for the sake of simplicity. $V/(b\ d)$ is called "nominal shear stress".

Nominal shear stress, $\tau = (V/\ (bw\ /d))$.

where,

V : shear force

bw : the width of the web of cross-section

1.2.4 Shear stress at the formation of diagonal crack

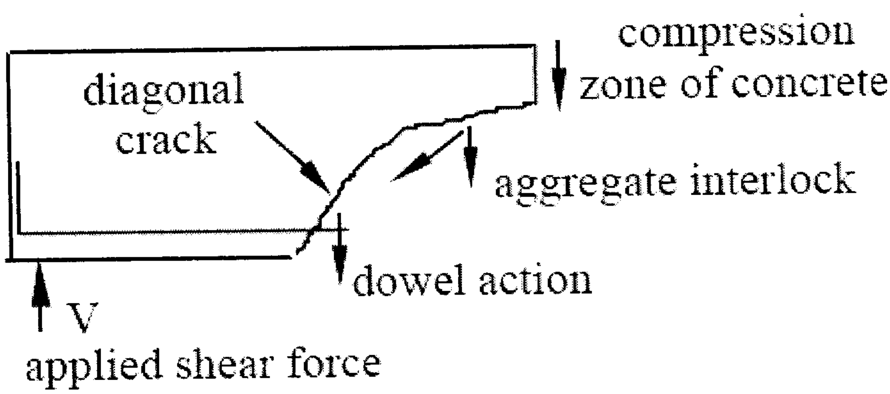

Fig. 1.3 Concept of truss analogy

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

1.2.5 Aggregate Interlock along Crack Plane

Along the diagonal crack of concrete, the shear transfer due to the effect of aggregate interlock can be expected. This effect is especially large, when the crack width is small and concrete strength is high. Since the crack width is proportional to the stress in steel which depends on the longitudinal reinforcement ratio, as the reinforcement ratio increases, the effect of aggregate interlock becomes larger.

The above discussion is based on the assumption of the same ratio of the dimension of section to the maximum size of coarse aggregates. The effect of aggregate interlock depends on the relation between the sectional dimension and the aggregate size, and for the same aggregate size, the effect of aggregate interlock on the small RC section is more pronounced than that in the large section. Since the maximum size of coarse aggregates in ordinary RC beams practically does not change even when the dimension of the section is increased, the nominal shear strength of large beams tends to decrease. This is a classical explanation for the size effect in the shear strength.

1.2.6 Dowel Action of Longitudinal Reinforcement

A part of the shear force can be transferred by the dowel action of longitudinal reinforcement. The main factors influencing this action are flexural rigidity of longitudinal reinforcement and flexural rigidity of surrounding concrete. Actually, there are additional factors involving this effect such as the number and arrangement of longitudinal reinforcement, spacing of flexural cracks, etc. However, the contribution of each factor has not been formulated so far. At present, the dowel action is represented by using the reinforcement ratio and concrete compressive strength.

1.2.7 Flexural Compressive Zone of Concrete

A part of shear carried by uncracked flexural compression zone of concrete is closely related to the area of compression zone. Since the position of the neutral axis after flexural cracking depends largely on the elastic modulus of concrete and reinforcement ratio of longitudinal steel, this effect can be represented by the reinforcement ratio and the strength of concrete which is also the function of the elastic modulus. (d) Main Factors Defining the Shear Strength .According to the above qualitative consideration, the shear stress corresponding to the diagonal cracking depends on the following main factors:

- Concrete strength f'c
- Reinforcement ratio of longitudinal steel pw
- Effective depth *d*

Besides these factors, the axial force and a/d ratio have also the strong effect.

1.3 THE MECHANISM OF SHEAR RESISTANCE IN REINFORCED CONCRETE BEAMS WITHOUT WEB REINFORCEMENT

1.3.1The role of web reinforcement

The inclusion of web reinforcement such as stirrups does not change fundamentally the previously described mechanism of shear resistance. The concrete cantilevers, which are the principle elements of the beam mechanism, will act as tied cantilevers. In addition to the force Δt' resisted by the combination of aggregate interlock, dowel, and flexural action of the cantilevers, another bond force Δt' can be sustained by what is traditionally termed "truss action".

The presence of stirrups is beneficial to beam action in a number of others aspects, as well. Stirrups contribution to the strength of the shear mechanisms by the following means:

- Improving the contribution of the dowel action. A stirrup can effectively support a longitudinal bar that is being crossed by a flexural shear crack close to stirrups.
- Surprising flexural tensile stresses in the cantilever blocks by means of the diagonal compression force c_d resulting from truss action.
- Limiting the opening of the diagonal cracks within the elastic range, thus enhancing and preserving shear transfer by aggregate interlock.

- Providing the confinement, when the stirrups are sufficiently closely spaced, thus increasing the compression strength of localities particularly affected by the arch action.
- Preventing the breakdown of bond when splitting cracks develop in anchorage zones because of dowel and anchorage forces.

1.3.2 The Truss Analogy

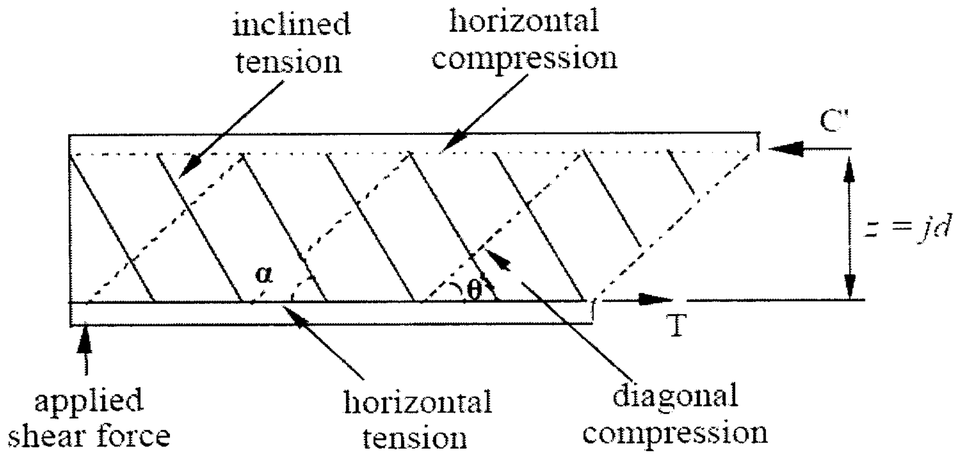

Fig. 1.4 Concept of truss analogy

A truss mechanism in beams can function only after the formation of diagonal cracks.(i.e., after the disappearance of diagonal tension in the concrete). The prime role of stirrups is to transfer the transverse (vertical) shear across a potential diagonal failure crack. The use of mesh reinforcement in the web is advocated from time and this is capable of resisting shear. This is because horizontal and vertical forces, but it is no more effective in resisting shear . This is because horizontal reinforcement in the web of normal beams cannot contribute to the resistance of transverse (vertical) forces apart from aiding crack control and increasing dowel action. Horizontal web reinforcement will strengthen the "contribution of the concrete "Vc but will not affect the strength of the truss mechanism Vs.

The relationship of applied shear force and tensile stress in stirrups shows that the tensile stress in stirrups is much smaller than that predicted by the classical truss analogy. In other words, after the diagonal cracking, it can be considered that the shear force is divided into two components, such as

- Shear force carried by the shear reinforcement
- Shear force carried by another mechanism than shear reinforcement (Contribution of concrete)

1.4 OBJECTIVES

- To investigate the effect of shear span to effective depth "a/d" ratio and contribution of stirrups on the shear capacity of concrete slender beams.
- To investigate the failure mechanism of high strength concrete beams
- To study the shear strength of High strength concrete reinforced concrete beams. Suggest the equation for calculating the shear strength of high strength reinforced concrete beams.
- To predict the shear strength of High strength reinforced concrete beams based on the analytical study by using ANSYS soft ware
- To compare the present analytical results with experimental test results.

1.5 ORGANISATION OF THE THESIS

In chapter 1, In chapter I, a general introduction about the High strength reinforced concrete slender beams and the mechanism of shear resistance in reinforced concrete beam without and with web the are given. The objectives of the present study are also given.

In chapter 2, the literature reviews on the shear strength of reinforced concrete beam are given .

In chapter 3, the experimental programme was clearly explained. This includes the material properties, testing procedure and experimental arrangement and crack pattern of the beam etc. The comparison between the experimental results from the predicted strength.

In chapter 4, analytical study on the shear strength of High strength reinforced concrete was outlined with the shear span to effective depth ratio. Steps involved in Analytical model using ANSYS software were also presented.

In chapter 5, the experimental results and the results obtained in theoretical model were presented. The comparison between the present experimental result and the analytical results were also given. This concludes on the main findings of the study and also points out on future work that was necessary for follow up.

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

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.

A. Shah and Ahmad The shear capacity of beams both with and without web reinforcement has been decreased with the increase in shear to depth (a/d) ratio but this decrease is not much pronounced in case of beams with web reinforcement. The failure of the beams with lower values of longitudinal steel is mainly due to flexure cracks and the shear reinforcement plays no or very little role in improving the shear capacity or restricting the beam failure. Hence the longitudinal steel level may be selected between 1% and 2% to ensure that the stirrups can play active role in resisting the shear failure.

ASCE-ACI committee 445 and Al-Nahlawi and Wight, however, the current strut – and –tie model does not accurate predict the strength of slender beams that fail by diagonal tensile cracking.

Bezant and Kim The size effect is very evident in both the normal-strength and high-strength concrete series. The shallower specimens were consistently able to resist higher shear stresses than the deeper ones developed a theoretical model based on fracture mechanics.

Wassim M.Ghannoum High-strength and normal-strength specimens of the same size and same reinforcement ratios had almost equal shear stresses at failure, showing no significant gain in shear strength with increased concrete compressive strength.

Nielsen developed a strength model based on the theory of plasticity. a specialized fracture-based model, such as the fracturing truss model, yields a realistic form of the size effect formula and intuitively explains the mechanism of size effect, this model is insuffient for predicting the dependence of size effect law coeffients on the shear span, reinforcement ratio, aggregate size, material strength, etc.

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.

M. Nehdi and T. Greenough A GA model was trained using 122 NSC and 45 HSC beams from the literature. A shear design equation was developed and proved to be more accurate in estimating the shear strength of both normal and high-strength reinforced concrete slender beams than the ACI 11-6, CSA simplified method, Eurocode-2, and Zsutty's equation.

Zden_ek P. Bazant and Qiang Yu The hypothesis that the maximum load in shear failure is controlled by propagation of cohesive fracture or softening damage leads to the same size effect law as established for other quasibrittle materials. The experimental evidence can be matched with this law as closely as one could desire in view of the inevitable experimental scatter.

Tim Stratford and Chris Burgoyne Whenever an assumption or simplification is made during analysis, a postulated equilibrium state is being used. With steel reinforcement, we are used to making assumptions about equilibrium conditions in a concrete beam, such as the assumption that the ‘‘stirrup’’ and ‘‘concrete’’ contributions can be superimposed in shear analysis

EXPERIMENTAL PROGRAMME

CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 INTRODUCTION

In the present work the experimental program consisted of testing Four High Strength Reinforced Concrete (HSC) rectangular beams of identical cross section (100x150mm). The span length of the beam was 2000 mm. All the beams were singly reinforced. The mix was designed to resist the cylinder compressive strength of 50Mpa. The major variables were the shear span to effective depth ratio. Fig.3.2 shows that the experimental set up of the beams. Mix proportions of the concrete used for the test are presented in Table.3.2 and Table.3.3.

3.2 PROPERTIES OF CONSTITUENT MATERIALS

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

3.2.1 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.

3.2.2 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 3.1

Table 3.1 properties of Fine Aggregate and Coarse Aggregate

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

3.2.3 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.

3.2.4 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.

3.2.5 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

3.3.1 Specification

Specified 28 days works cube strength = 50 N/mm^2

Very good degree of control; control factor = 0.80

Degree of workability = very low

Type of cement = ordinary Portland cement

Type of course aggregates = crushed granite (Angular) max size 20 mm

Type or fine aggregates = Natural sand

Specific gravity of cement = 3.15

Specific gravity of fine aggregates = 2.68

Specific gravity of course aggregates = 2.77

The fine and course aggregates contain 2% and nil percent moisture respectively.

3.3.2 Design of Mix

Average strength = 50/0.80

= 63 N/mm^2

Reference number = 25

Water / cement ratio = 0.36

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

Aggregates / cement ratio for the desired workability = 3.6

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.

Cement	Fine aggregates	Course aggregates	water
1	25/100 *3.6)	(25/100 *3.6)	0.36
1	0.9	2.70	0.36

Then,

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

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

$$1.955C = 1000$$

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

INGREDIENT	DRY AGGREGATES Kgs	MOIST AGGREGATES Kgs
CEMENT	511. 51	511. 51
WATER	184 .14	174. 93
FINE AGGREGATES	460. 36	469. 57
COURSE AGGREGATES	1381. 08	1381. 08

CEMENT	FINE AGGREGATES	COURSE AGGREGATES	WATER
1	0.92	2.70	0.34

Table.3.2 Concrete Mix Proportions of the test beams

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

3.4 STRENGTH RELATED PROPERTIES

3.4.1 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.

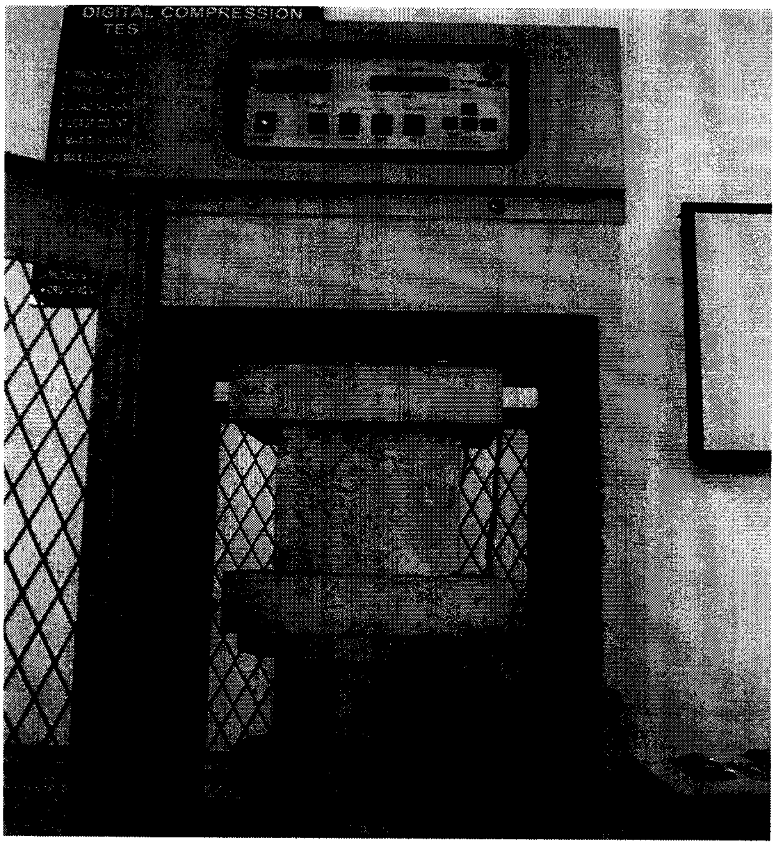

Fig 3.01 Test set up for cube

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

3.4.2 Cube test results

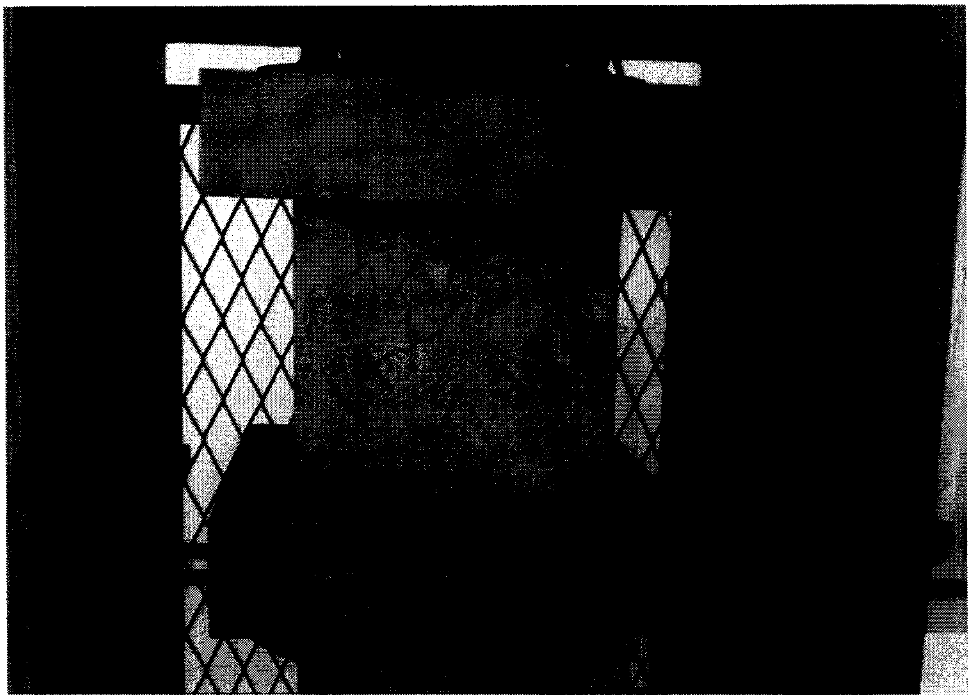

Fig 3.02 Testing of cubes at initial crack load

Fig 3.03 Testing of cubes at failure load

Table.3.3 Compressive strength results in 7 days

Sl. No	Cube size mm	Ultimate load KN	cube compressive strength in MPa
1	150x150x150	954	42.40
2	150x150x150	912	40.53
3	150x150x150	971	43.16

Average cube compressive strength = 42.03 Mpa

Table.3.4 Compressive strength results in 7 days

Sl. No	Cube size mm	Ultimate load KN	cube compressive strength in MPa
1	150x150x150	1272	56.53
2	150x150x150	1258	55.91
3	150x150x150	1230	54.67

Average cube compressive strength = 55.70 Mpa

3.5 PREPARATION OF TEST SPECIMENS

All the reinforced beam specimens were cast at the structural laboratory. The raw materials for concrete mixes already described in the previous section were mixed by a rotary mixer. The wooden mould were prepared and lubricated with oil before the concrete was poured. The reinforcement bars were cut to the required lengths. The longitudinal bars and stirrups were secured to each other at correct spacing by means of binding wires. A mixing time of 3 to 5 minutes was given to ensure uniform mixing. Then the steel rebar's were tied and put into the oil. The specimens were remoulded after 24 hours and cured for 28 days using gunny bags. After curing period, the beams were kept for 24 hours in a dry state. After drying they were cleaned with a sand paper to remove all grit and dirt. Then all the specimens were prepared by white washing from all sides. White washing was done to facilitate easy detection of crack propagation.

In the present work, experimental investigation has been carried out to study the performance of HSC with and without web reinforcement. The water binder ratio (w/b) of 0.34 for all mixes was maintained.

3.6 EXPERIMENTAL SET UP

All the four beams were tested at the age of 28 days in a two point loading conditions, with load applied to the test beam as the two equal concentrated loads by means of a steel beam with shear-span to effective death ratio of 3.75 as shown in Fig.3.1. Two point loads were applied to the beams by 300KN hydraulic testing machine, up to the failure. The deflection was measured at the three points using dial gauge, one at the mid span and the other under at the loading points. Details of the beam designation along with the test results of the beams are presented in Table 3.2.

The loads were applied in small increments and at every increment of loading, the deflection, strain gauge readings, were recorded. 150mm cube were used to calculate the cube compressive strength of the concrete.

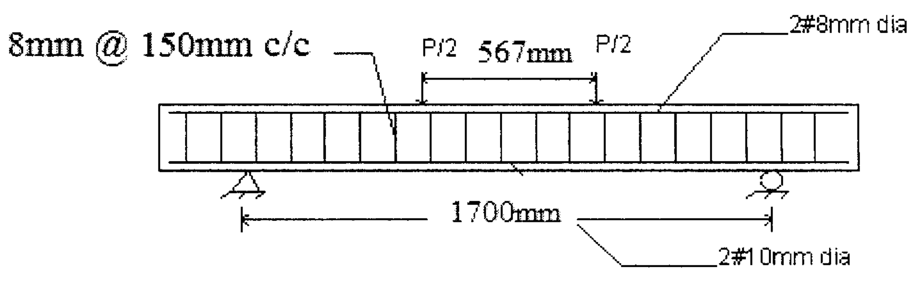

Fig. 3.04 Details of Test Specimen with web reinforcement

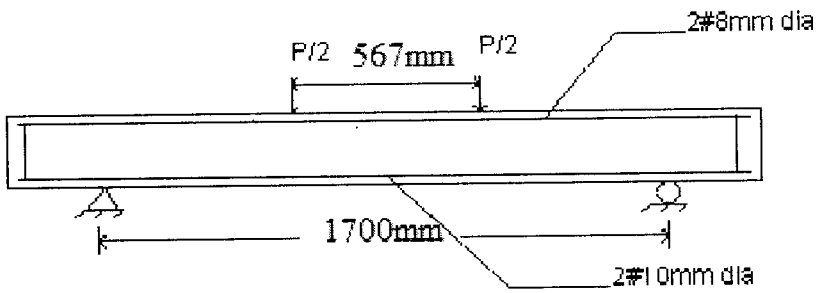

Fig. 3.05 Details of Test Specimen without web reinforcement

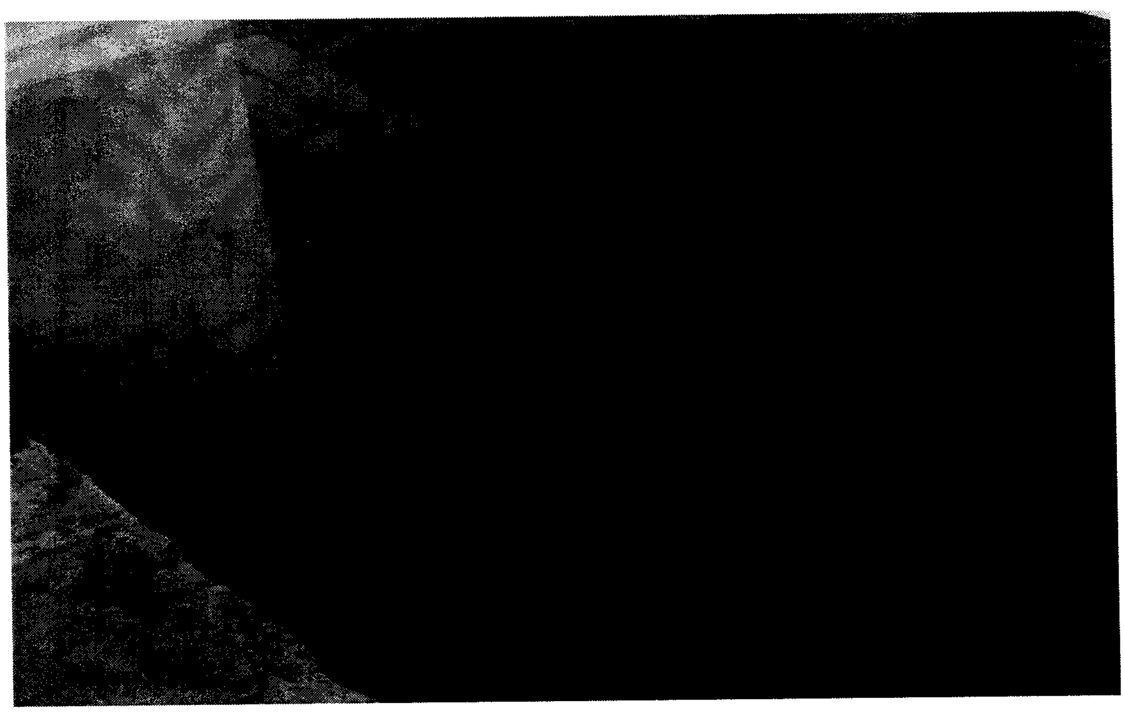

Fig. 3.06 Test Specimens under curing

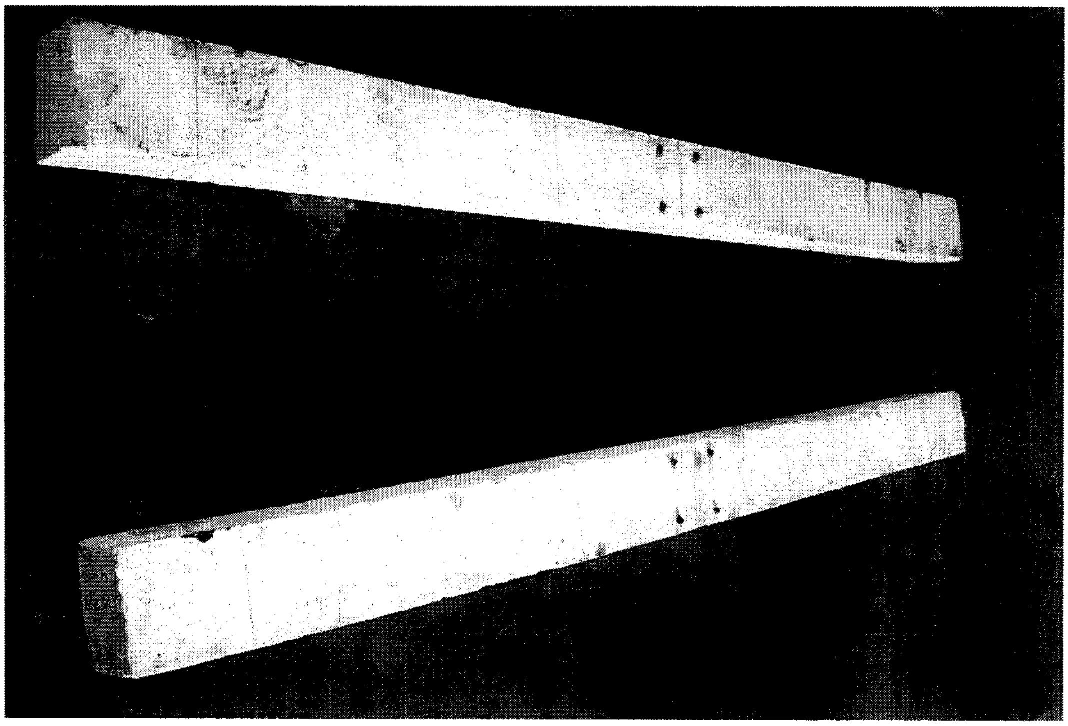

Fig. 3.07 Test Specimens

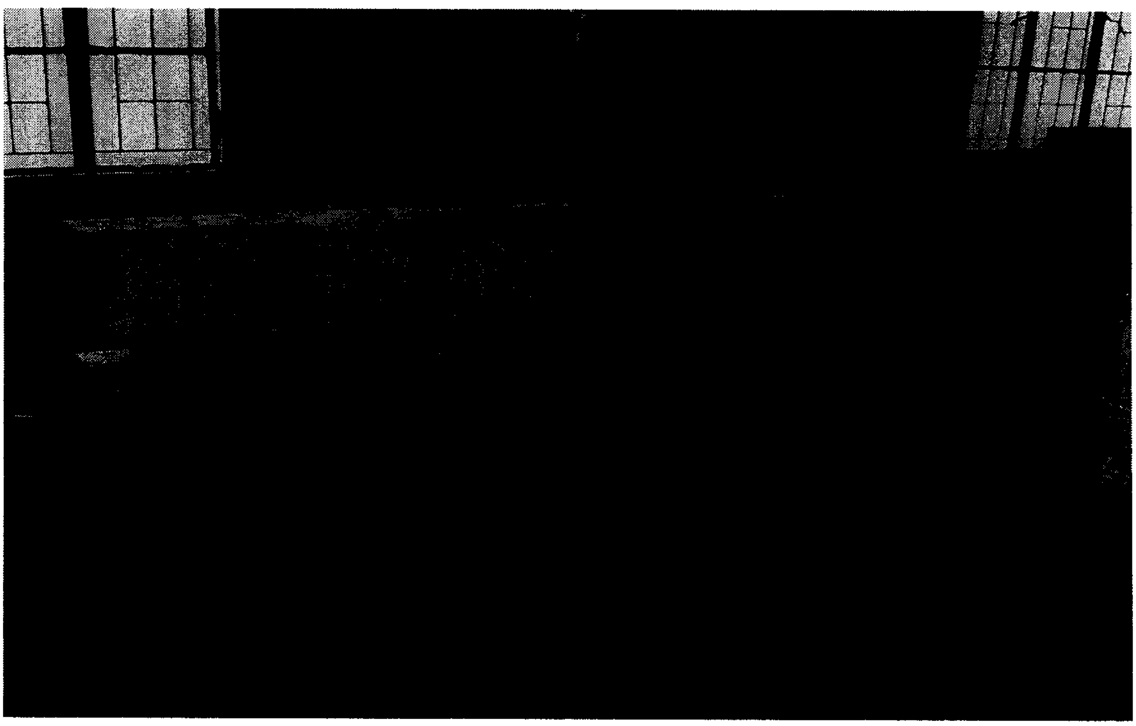

Fig.3.08 Testing arrangement of beam

3. 7 SHEAR STRENGTH OF RC BEAMS

3.7.1 Beam without web reinforcement

Table.3.5 Test result for beam without web reinforcement

Beam	ρ	a/d	fc'	fsp	V EXP.
WOWR1	.01	3.78	50	4.94	1.27
WOWR 2	.01	3.78	50	4.94	1.40

Fig.3.09 Crack pattern of beam without web reinforcement (WOWR1)

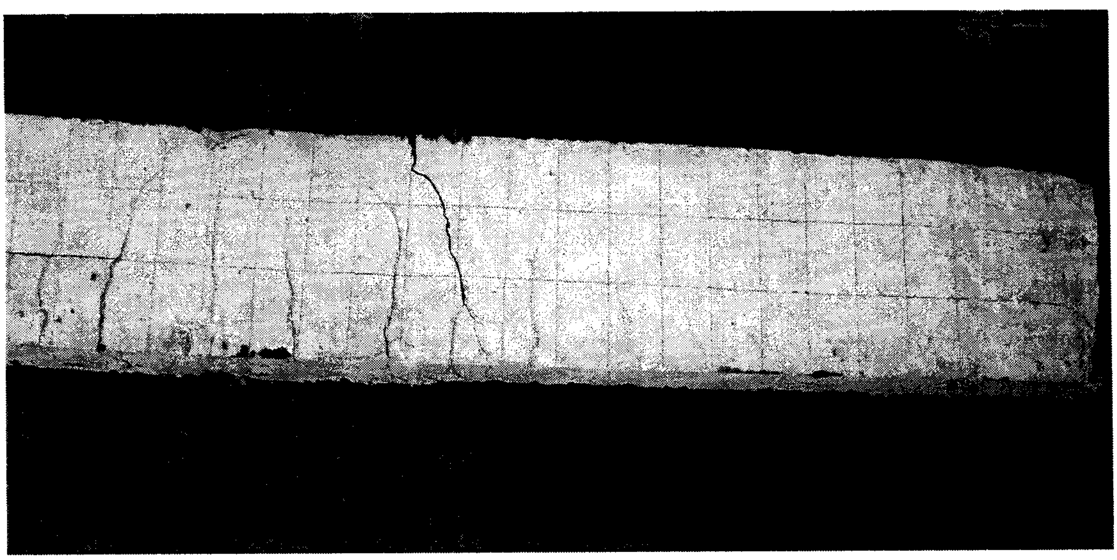

Fig.3.10 Crack pattern of beam without web reinforcement (WOWR2)

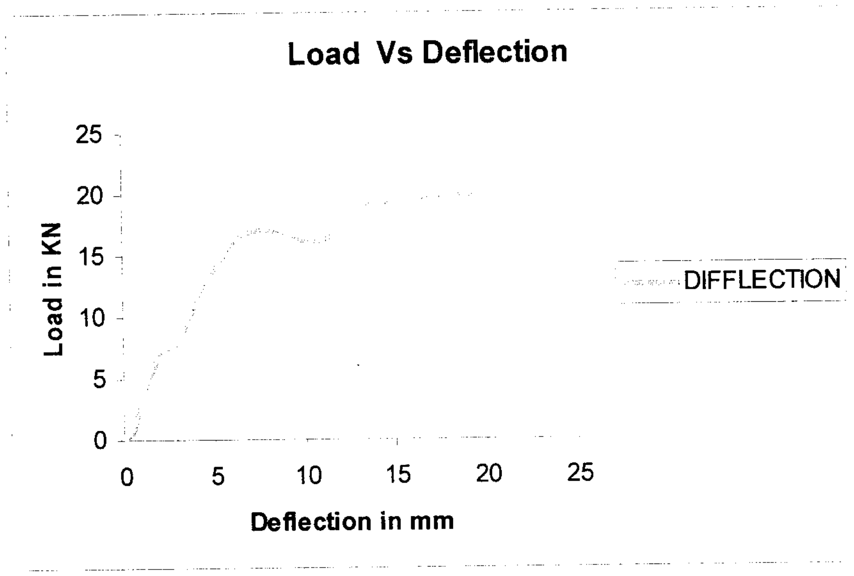

Fig.3.11 Load Deflection of beam without web reinforcement (WOWR1)

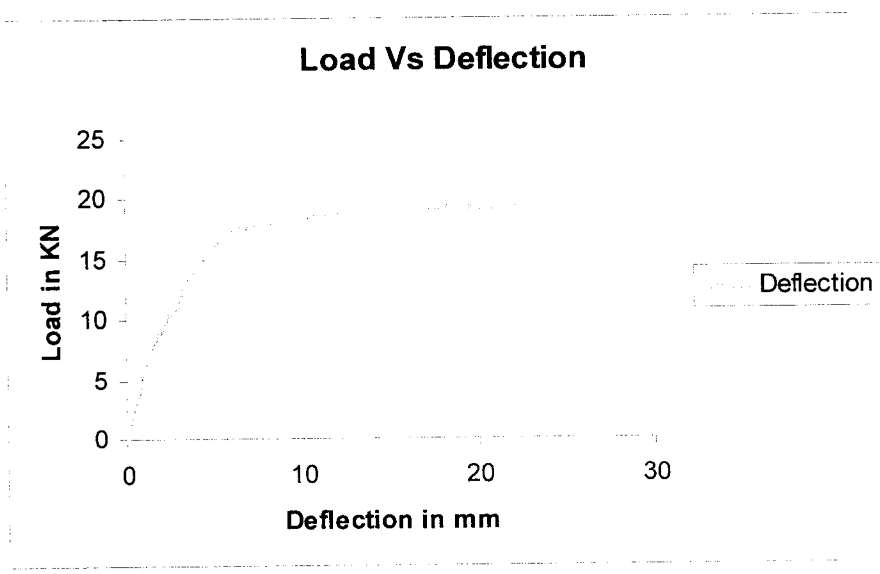

Fig.3.12 Load Deflection of beam without web reinforcement (WOWR2).

3.7.2 Beam with web reinforcement

Table.3.6 Test result for beam with web reinforcement

Beam	ρ	a/d	fc'	fsp	$V_{EXP.}$
WWR1	.01	3.78	50	4.94	1.67
WWR 2	.01	3.78	50	4.94	1.72

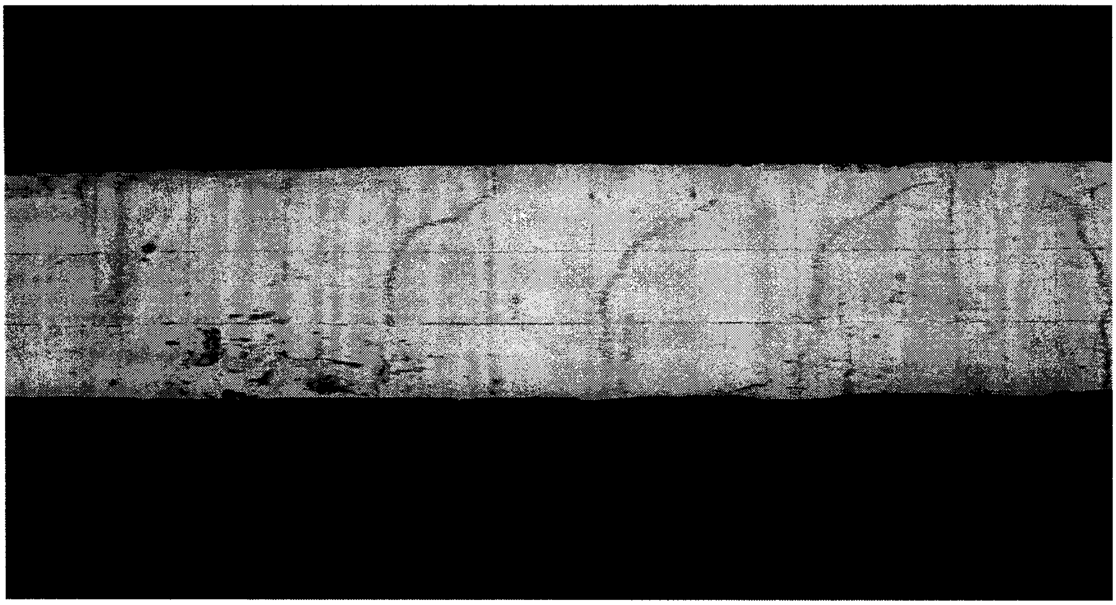

Fig.3.13 Crack pattern of beam with web reinforcement (WWR1)

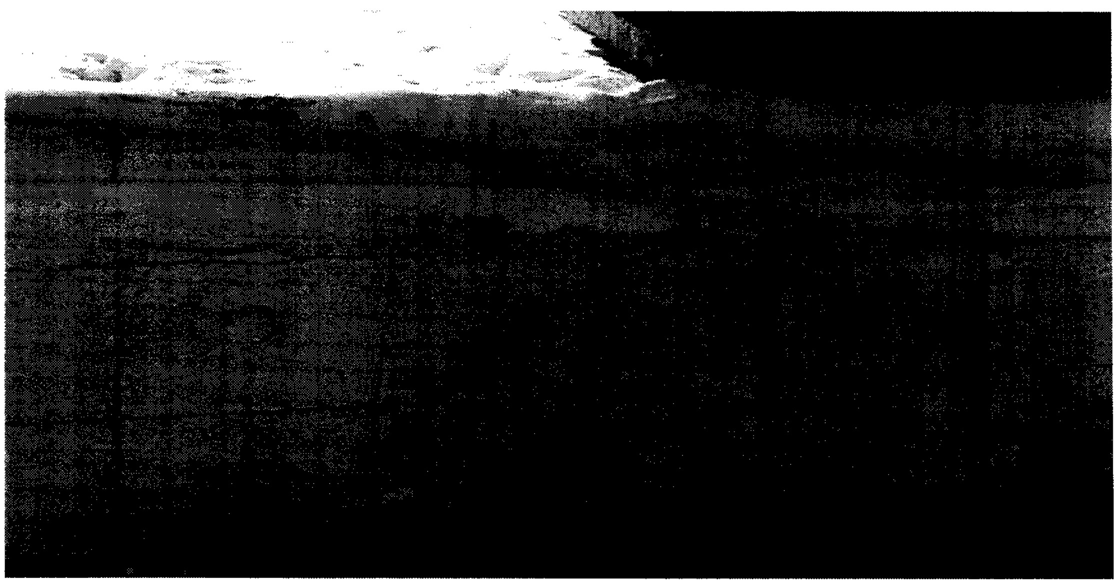

Fig.3.14 Crack pattern of beam with web reinforcement (WWR2)

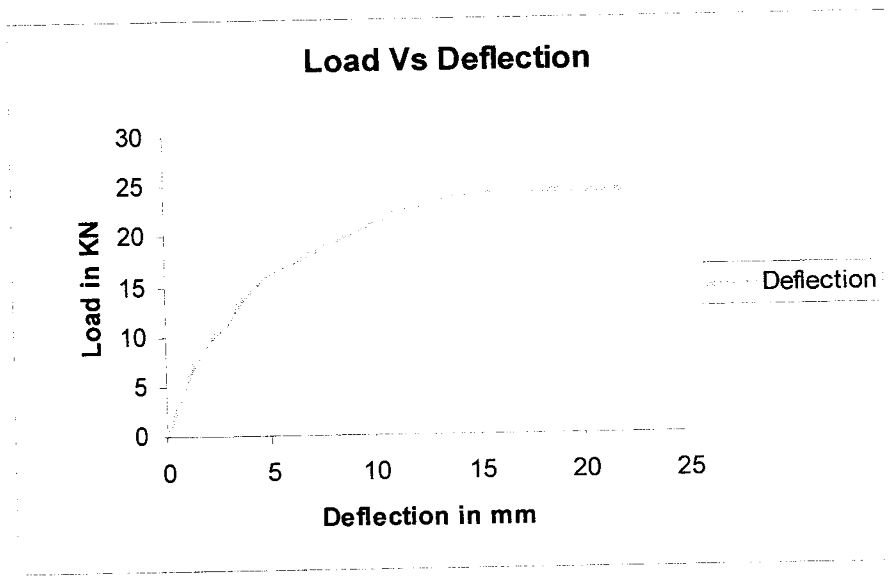

Fig.3.15 Load Deflection of beam with web reinforcement (WWR1)

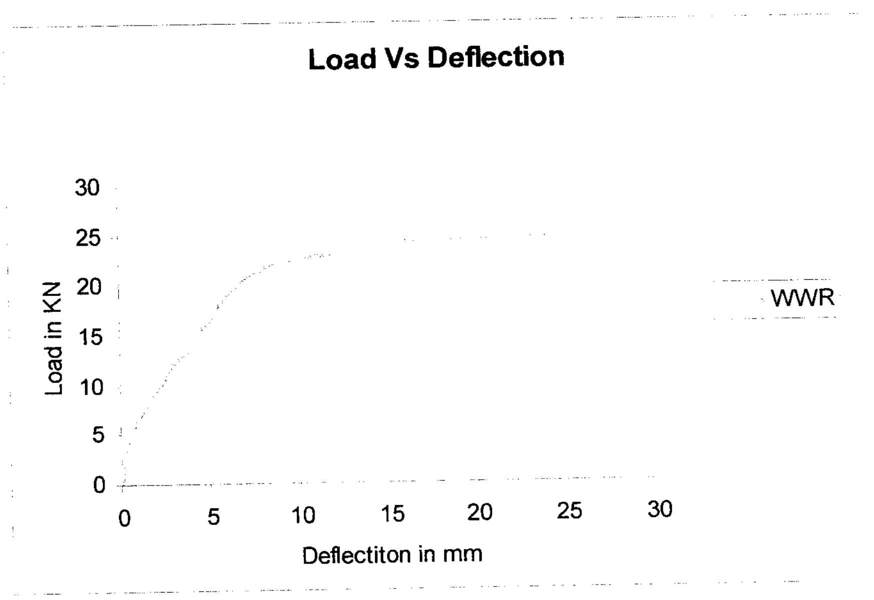

Fig.3.16 Load Deflection of beam with web reinforcement (WWR2)

ANALYTICAL MODELLING OF BEAMS

CHAPTER 4

ANALYTICAL MODELING OF BEAMS

4.1 INTRODUCTION

The aim of this study was to gain a better understanding of the structural behaviour of High Strength Reinforced Concrete (HSC) beams under two point loading condition. The essential steps required for the formulation of the analytical model are presented. The model utilized to compute the shear strength of reinforced concrete beams must satisfy three basic requirements. First, it must truly reflect the configuration of the structure under consideration. Next, the elastic and inelastic behaviour must be realistically represented in the model. The requirement is that the support condition as well as the application of load. Of equal importance is the requirement that the modelling technique employed in the analysis reduces the given problem to a simpler exercise, which readily lends itself to a solution.

4.2 ANSYS SOFTWARE

The ANSYS finite element analysis software that has an element library consisting of more than 150 differential element formulations can be used for all types of structures either one , two or three dimensional. It has a comprehensive graphical user interface that gives users an easy and interactive access. The ANSYS has many finite element analyses capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

It has three phases, viz., Pre-processing, Solution and Post processing. The Pre-processing is used to define the problem, Solution is for applying forces and boundary conditions and to run the software and Postprocessor is used to examine and interpret the results.

4.3 STEPS INVOLVED IN THE ANALYSIS

Pre – processing

1. Set preferences.
2. Define element types and options.
3. Define real constant.
4. Define material properties.
5. Create Beam using concrete with steel fibres
6. Create steel bars.
7. Set element attributes and meshing controls.
8. Mesh the beam.

Solution

9. Define analysis type and options.
10. Apply boundary condition and load.
11. Solve for static.

Post processing

12. View the result in result viewer

4.4 FINITE ELEMENT ANALYSIS

4.4.1 General

Finite element analyses give the possibility to understand how and not just that, a parameter affects the results. This means that the need for experiments can be greatly reduced by using the finite element method. However the experiments are still needed to verify that the finite element analyses correspond to the actual behaviour. Accordingly, when experiments and nonlinear finite element are used together they can become very powerful tools in gaining a better understanding of the structural behaviour of the HSC beams.

Program analysis is capable of handling dedicated numerical models for the nonlinear response of the concrete under static load. Eight-node solid brick element (Solid 65) was used to model the concrete with. These elements include a crack analogy for cracking in tension zones and a plasticity algorithm to account for the possibility of concrete crushing in compression regions. Internal reinforcement was modelled using 3D spar elements (Link 8) and these elements allow the elastic plastic response of the reinforcing bars.

4.4.2 Element Types

4.4.2.1 Reinforced concrete

The solid element (Solid 65) has eight nodes with three degree of freedom at each node and translations in the nodal x, y, z direction. The element is capable of plastic deformation, cracking in three orthogonal directions and crushing. The geometry and node locations for this element type are shown in Fig 4.1.

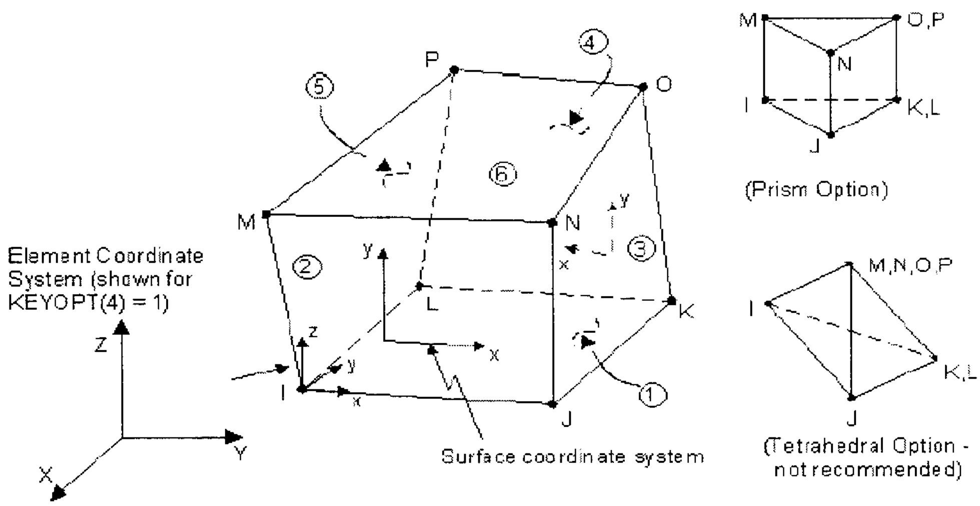

Fig.4.01 Solid 65 3-D Reinforcement concrete Solid

4.4.2.2 Steel Reinforcement

The geometry and node locations for Link 8 element used to model the steel reinforcement a shown in Fig.4.2. Tow nodes are required for this element. Each node has three degree of freedom, translation the nodal x, y, z directions. The element is also capable of plastic deformation.

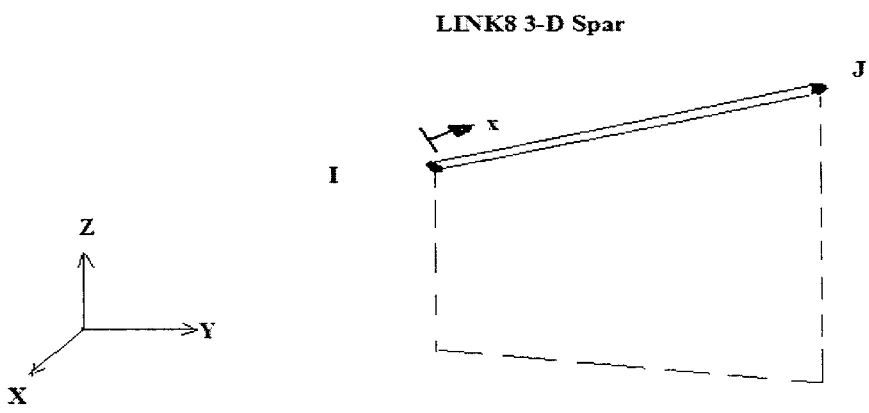

Fig.4.02 Link 8 3-D Spar Element

The bond strength between concrete and steel reinforcement is very important. To provide perfect bond, the link element for the steel reinforcing was connected between nodes of each adjacent concrete solid element, so the two materials should be in same node

The shear transfer co-efficient for open crack β_t represents the conditions at the Crack face. The value of β_t ranges from 0.0 to 1.0 with 0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). For closed cracks, the shear transfer co-efficient assumed to be equal to 1.0. This represents the shear stiffness reduction in the model is set to zero.

4.4.3 Material Properties

4.4.3.1 Concrete

For concrete, ANSYS requires input data for material properties as follows:

- Elastic modulus (Ec).
- Poisson ratio (μ).

The ultimate compressive and tensile strength for each beam model were based on experimental results, and elastic modulus was calculated from the formula based on IS456 2000 given below,

$$E_c = 5000 \sqrt{f_{ck}}$$

The properties for inclusion of steel fibres was given with the concrete property, the amount of steel fibre added was given in real constant value.

4.4.3.2 Steel

The steel for the finite element model was assumed to be an elastic-perfectly plastic material and identical in tension and compression. Poisson's ratio of 0.3 was used for the steel reinforcement in this study.

Material properties for the steel reinforcement for the models are as follows,

- Elastic modulus, (Es)
- Yield stress, (fy)
- Poisson's ratio, (μ).

\

4.4.4 Boundary conditions and Loading

The boundary conditions were exactly simulated as in the test set up as shown if Fig3.2. Horizontal and vertical restraints, representing a pin connection were applied at one end of the beam. At the other end, only vertical restrains were provided to simulate the roller support conditions used in the test.

4.4.5 Nonlinear Solution

In nonlinear analysis, the total load applied into a finite element model is divided into a series of load increments called load steps. At the completion of each incremental solution, the stiffness matrix of the model is adjusted to reflect nonlinear changes in structural stiffness before proceeding to the next load increment. The analysis program uses Newton-Raphson equilibrium iteration for updating the model stiffness.

Newton-Raphson equilibrium iteration provides convergence at the end of the each load increment within tolerance limits. In this study, for the reinforced concrete solid elements convergence criteria were based on force and displacement, and the convergence the ANSYS program initially selected tolerance limits. It was found that convergence of solution for the models was difficult to achieve due to the nonlinear behaviour of reinforced concrete. Therefore the convergence tolerance limits were increased to a maximum of 5 times the default tolerance limits (0.5% for force checking and 5% for displacement checking) in order to obtain convergence of the solution.

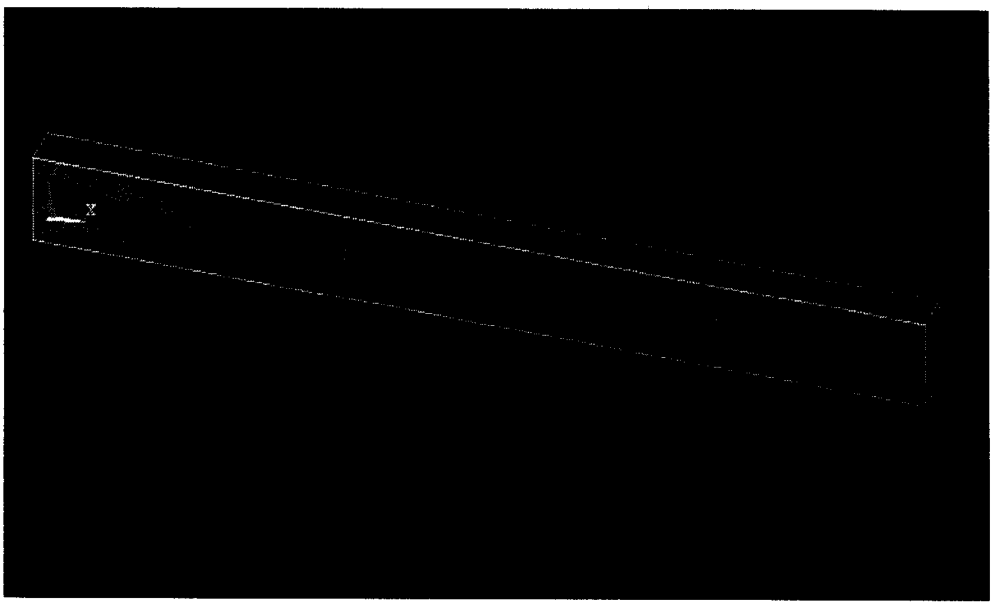

Fig 4.03 Cross-sectional Profile of beam (WOWR)

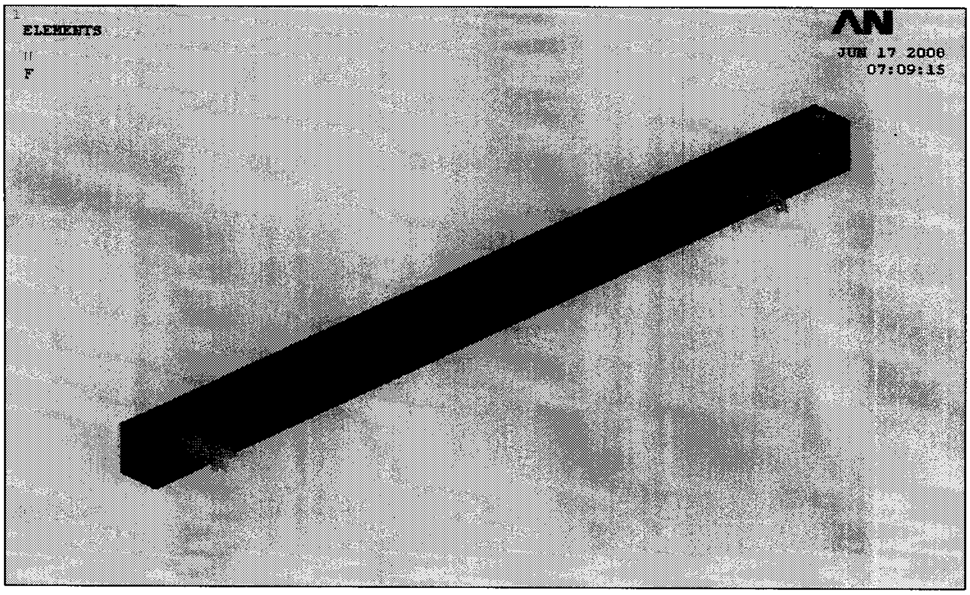

Fig 4.04 Loading Profile of beams (WOWR)

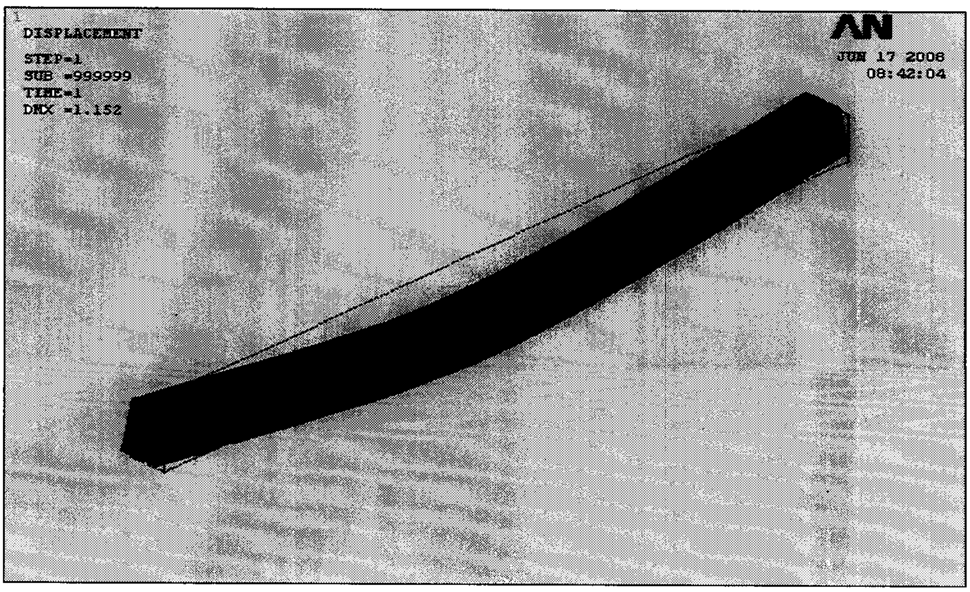

Fig 4.05 Displacement Profile of beams (WOWR)

Fig 4.06 Cracks Profile of beams (WOWR)

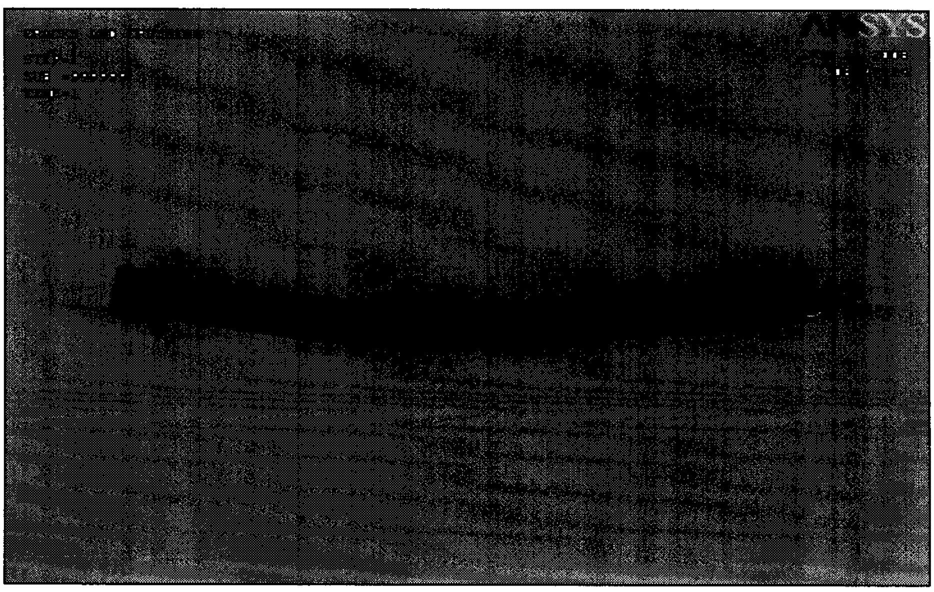

Fig 4.07 Cracks Profile of beams (WOWR)

Fig 4.08 Stress Profile of beams (WOWR)

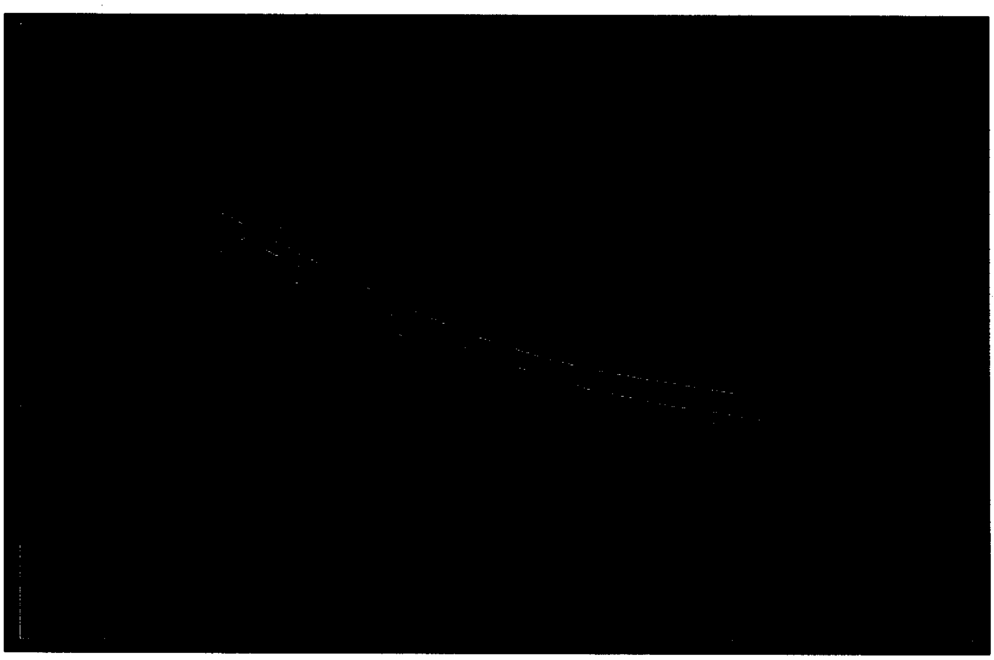

Fig 4.09 Beam with web reinforcement model

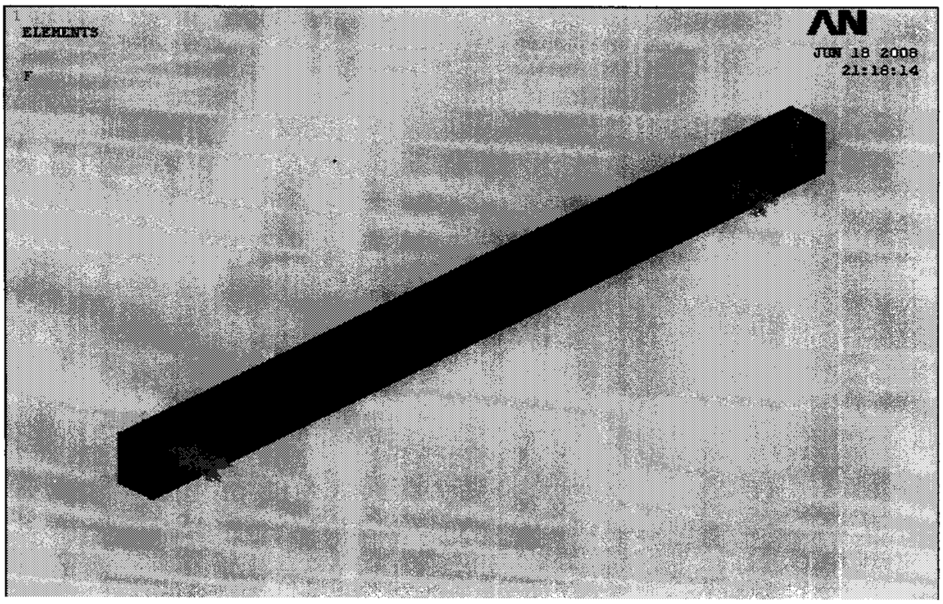

Fig 4.10 Cross-sectional Profile of beam (WWR)

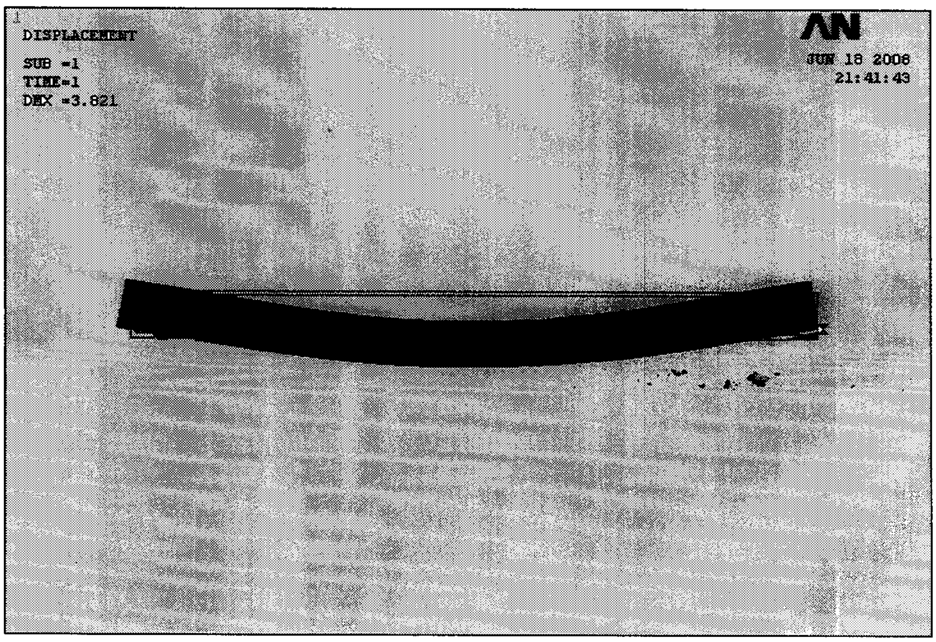

Fig 4.11 Displacement Profile of beams (WWR)

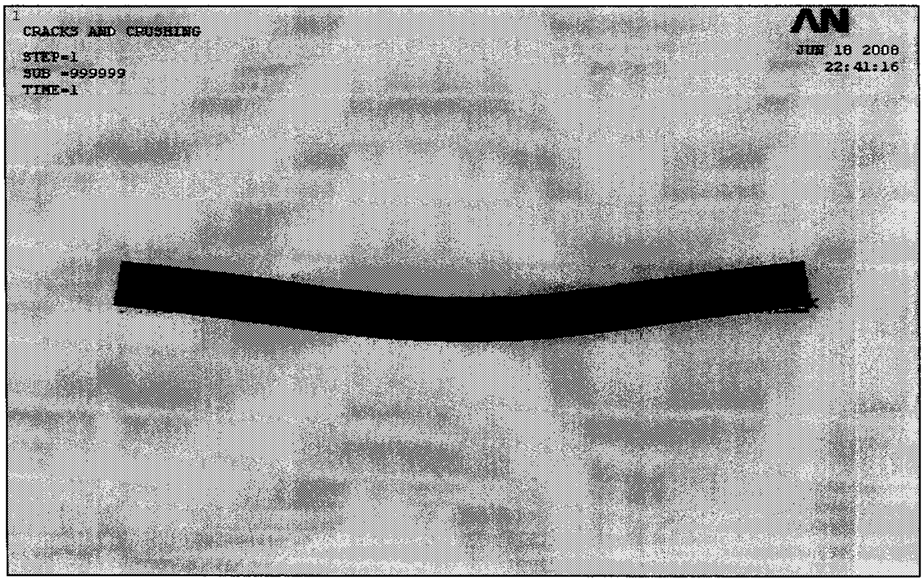

Fig 4.12 Cracks Profile of beams (WWR)

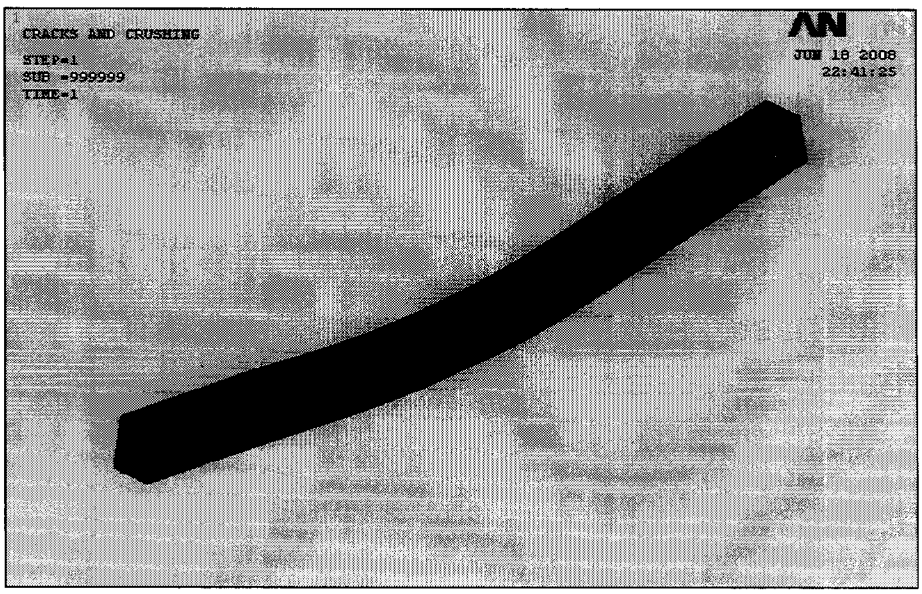

Fig 4.13 Cracks Profile of beams (WWR)

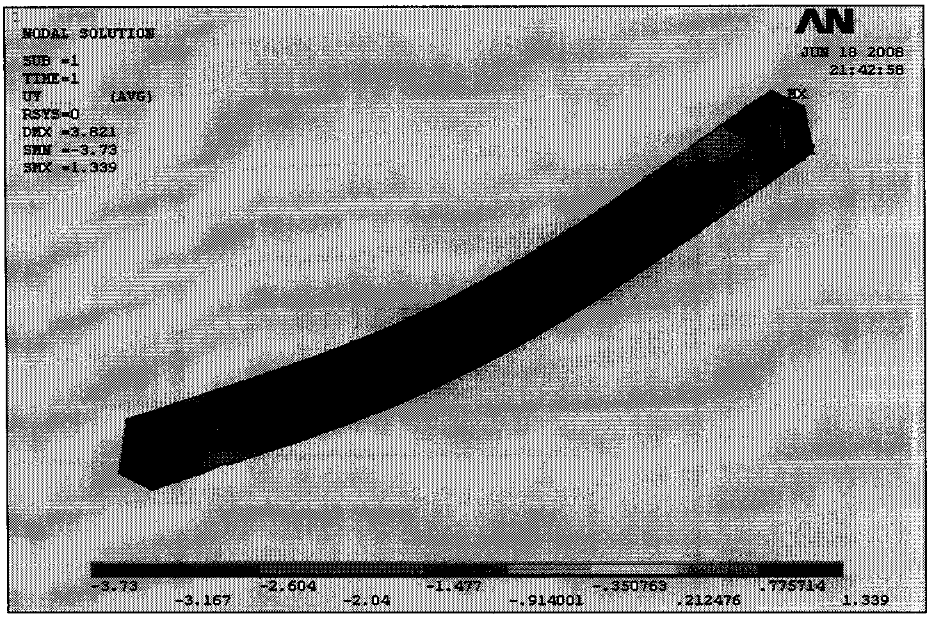

Fig 4.14 Stress Profile of beams (WWR)

RESULTS AND DISCUSSIONS

CHAPTER 5

RESUL T AND DISCUSSION

5.1 EXPERIEMNTAL RESULTS

Table.5.1 Experimental Test Results

Beam	ρ	a/d	fc'	fsp	V EXP.
WOWR1	.01	3.78	50	4.94	1.27
WOWR 2	.01	3.78	50	4.94	1.40
WWR1	.01	3.78	50	4.94	1.67
WWR1	.01	3.78	50	4.94	1.72

5.1.1 Load Deflection curve

The deflection was measured at three points using the dial gauge, one at the mid span and other two at the near the support. The deflection increased according to the load increases. The maximum of 24 mm deflection was obtained for beam WWRI, which is for shear span to effective depth ratio of 3.78. The minimum of 16 mm deflection was obtained for beam WOWR2, which is for shear span to effective depth ratio of 3.78.Similarly the deflection of 17.25 and 22.5 mm were obtained for beam WOWR1 and WWR2 beam respectively.

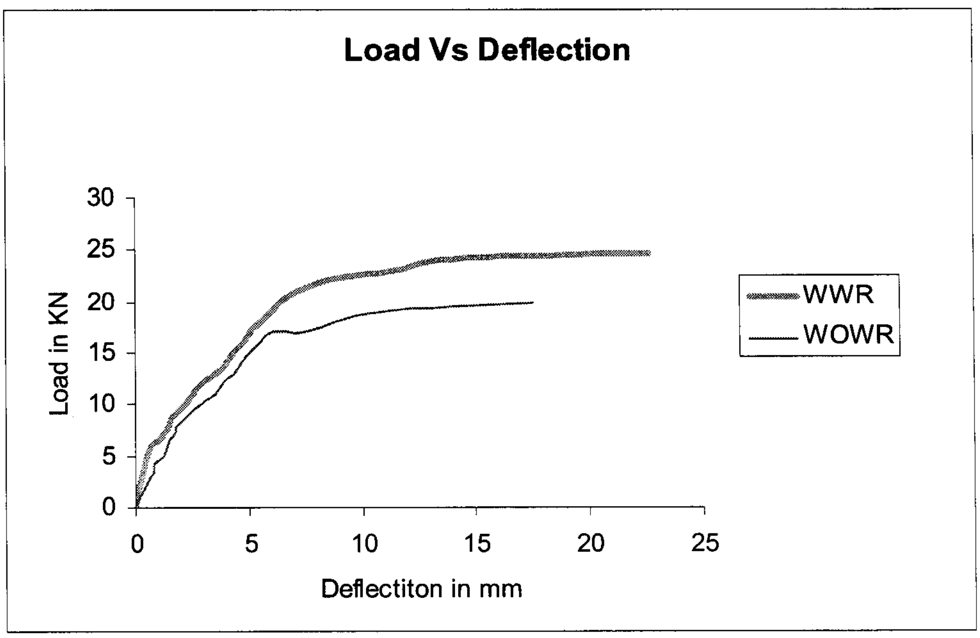

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Fig 5.1 Load Deflection diagram for the beams with and without longitudinal

5.2 ANALYTICAL RESULTS

Table.5.3 Analytical Results

Beam	ρ	a/d	fc'	fsp	VAnly
WOWR1	.01	3.78	50	4.94	1.21
WOWR 2	.01	3.78	50	4.94	1.35
WWR1	.01	3.78	50	4.94	1.58
WWR1	.01	3.78	50	4.94	1.67

5.3 COMPARISON OF ANALYTICAL RESULT WITH EXPERIEMNTAL RESULT

Table.5.4 Comparison of Analytical Results with Experimental result

Beam No	a/d	Experimental value VExp. *N/mm²*	Analytical value using ANSYS VAnly *N/mm²*	VExp./ V Anly .
WOWR1	3.78	1.27	1.21	1.049
WOWR 2	3.78	1.40	1.35	1.037
WWR1	3.78	1.67	1.58	1.057
WWR2	3.78	1.72	1.67	1.030

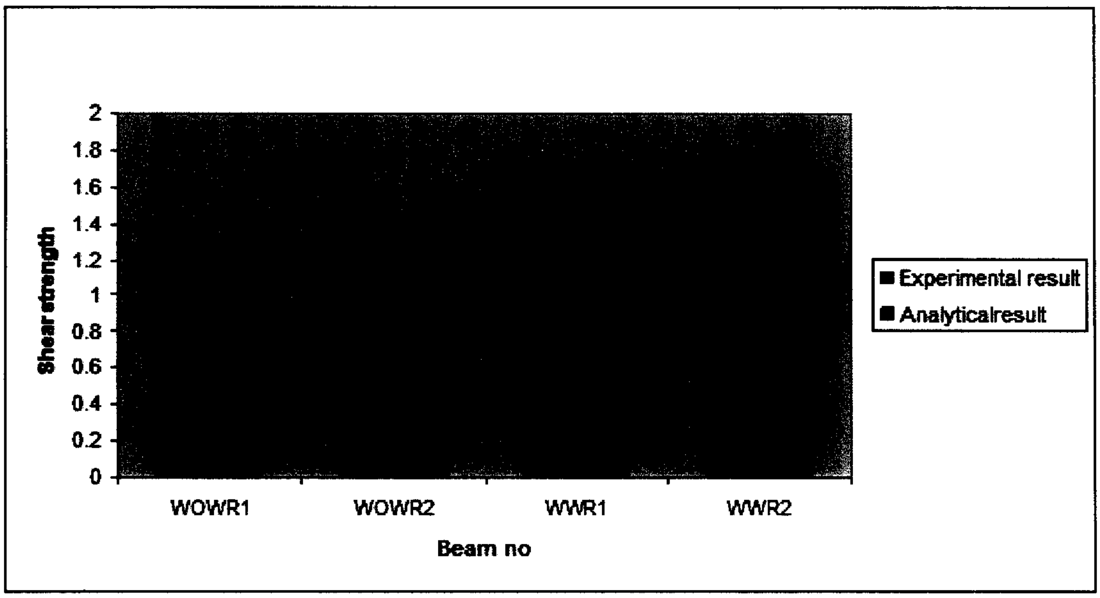

Fig.5.8Comparison of Analytical Results with Experimental result

CONCLUSION

5.4 CONCLUSIONS

The aim of this project is to assess the progress of the shear strength on high strength concrete slender beams with and without shear reinforcement. A series of tests on the shear strength of high strength concrete with and without shear reinforcement is carried out. Comparisons have been made with the results obtained from other researchers with different a/d ratios. Based on the results and discussions, the following conclusions can be drawn.

- The shear capacity of beams both with and without web reinforcement has been increased with the increase of the longitudinal steel. This fact is well illustrated by ACI code.
- The shear capacity of beams both with and without web reinforcement has been decreased with the increase in shear to depth (a/d) ratio but this decrease is not much pronounced in case of beams with web reinforcement.
- The traditional approach of summing up the individual concrete and steel contribution for determining the shear strength of the reinforced beams is also not proved by the experiments.
- The transverse reinforcement is provided; the beam not fails suddenly and gives to warning.
- The transverse reinforcement is not provided; the beam fails suddenly without giving any warning. This sudden fails can be avoided by providing shear reinforcement.
- The High strength concrete has more shear capacity compared to nominal strength concrete

5.5 RECOMMENDATION FOR FUTURE WORK

The present study can be extended for future research with consideration to the following points.

- Behaviour of Reinforced Concrete Beams with Loss of Bond at Longitudinal Reinforcement.
- The Size Effect on Shear Strength of RC Beams Using High Strength Concrete with and without Shear Reinforcement.
- The study of Slender beams with various strengths of concrete, longitudinal steel ratios, shear reinforcement ratios, shear span-depth (a/d) ratios, and geometrical sizes.

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Annexure A

CRACK LOAD CALCULATION

Crack width calculation using IS 456-2000(Clause 35.3.2)

DATA:

Size of beam = 2000*100*150

$Fc = M40$

$Fy =$ Fe415(TMT Steel)

$Es = 200000\ N/mm^2$

$Ec = 35355.34 N/mm^2$

Crack width (assumed) = .1mm

Step:1

MODULAR RATIO:

$m = Es/Ec$

$= 200000/35355.34\ N/mm^2$

Step:2

NEUTRAL AXIS:

$(b* xa^2\ / 2 = m *Ast*(d - xa)$

$(100*xa^2 / 2 = 5.66*157.08\ (124- xa)$

$50 *xa^2 = .11*10^6 -157.08$

$xa = 38.84$ mm

Step:3

□m = □I – b (h – xa) (a-x)/ 3 Es As (d – x)

Wcr = 3 acr □m / 1+2 (acr –C min) / (h-x)

Acr = 15+6 = 21

.1= 3 acr □m

$.1 = 3*21*\square m$

$.0015873 = \square I - 100\ (150 - 38.84)\ (150 - 38.84\ ) / 3*2*10^{5*}\ 157.08\ (\ 124-38.84\ )^2$

$\square I = 1.741*10^{-3}$

$Icr = (\ b*\ xa^3) / 3 + m\ Ast\ (d-x)^2$

$= (100*38.84^3) / 3\ 5.66 * 157.08*(124 - 38.84)^2$

$= 8.4 * 10\ mm^4$

$\square I = (\ M / Icr\ )*(\ (\ D - xa\ )/\ Ec\ )$

$1.741*10^6 = (\ M / 8.4 * 10^6\ ) * (\ (\ 150 - 38.84\ ) / 35355.34)$

$M = 4.65*10^6\ N.mm$

$M = W\ l / 6$ (Max. two point load moment)

$W = (\ 4.65*\ 10^6 * 6\ \ ) / 1700$

W = 16.42 KN (1.674 tonnes)