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An Experimental Investigation on Structural Behaviour of Beam Column Joint

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Abstract- Conventional concrete loses its tensile resistance after the formation of multiple cracks. However, fibrous concrete can sustain a portion of its resistance following cracking to resist more loading. The strength of concrete is appreciably increased by the crack arresting mechanism of the fibres and the ultimate strength is also increased because extra energy is needed to cause fracture of the fibre reinforcing the concrete. Beam-column joints have a crucial role in the structural integrity of the buildings. For this reason they must be provided with adequate stiffness and strength to sustain the loads transmitted from beam and columns. For adequate ductility of beam-column joints, use of closely spaced hoops as transverse reinforcement was recommended. In the present study an attempt has been made to investigate the behaviour of exterior beam-column joint with different detailing of reinforcement, different spacing of connecting ties and with different percentage of steel fibres. Initially three specimens (SP1, SP2 and SP3) with different detailing of reinforcement were tested. Then specimen SP2 was selected for further investigation based on its structural performance and ease of detailing. Two more Specimens were tested with different spacing of ties/stirrups. Finally, to investigate the effect of addition of fibres on behaviour of performance of joints, three specimens (SP6, SP7 and SP8) with volume fractions of 0.5%, 1.0% and 1.5% steel fibres were cast and tested. The results obtained from the investigation indicated that addition of steel fibres in the concrete mix improved structural performance of beam column joints measured in terms of ultimate load carrying capacity, stiffness, crack width, deflection and curvature ductility factor. Steel fibre reinforced concrete is one of the possible alternative solutions for reducing the congestion of transverse reinforcement in beam column joints. Thus with the reduction of congestion of reinforcement in the joint core helps in the ease of construction difficulties, while maintaining ductile behaviour of the frame, With the increase in the percentage of fibres from 0.05% to1.5% in the joint core the deflection and curvature at peak load increased. Specimen SP8 containing 1.5% of steel fibre in the joint core have higher value of rotation (φ), as compared with conventional specimen SP2.This clearly shows that the congestion of reinforcement in the core of beam column joint can be reduced by the addition of steel fibre in the joint core with increase in the spacing of hoops/ties. It was also observed in the study that the deflection and curvature also increases with the decrease in spacing of hoops/tie.

Keywords- Fibre, SP6, SP7

I. INTRODUCTION

Concrete is one of the most widely used construction material. It has good compressive strength, durability, fire resistance and can be cast to fit any structural shape.

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The quickness and ease of construction in the concrete is a great advantage, but it has its own shortcomings.
It has poor tensile strength and limited impact resistance. An important feature of the coarse aggregate matrix interface is that it contains very fine cracks even before any load has been applied to the concrete. Further shrinkage and external loading causes stress concentration at the aggregate paste interface due to different elastic modulus of the aggregate and paste phase, which results in propagation of micro cracks. This cracks propagation continues up to a stress strength ratio of 0.7 to 0.9, when the cracks open through the mortar so as to bridge the existing bond cracks, and continuous cracks pattern results. It has been established by the results that the tensile strength of ordinary concrete varies from 8 to 15% of the compressive strength.

II. REINFORCED CONCRETE

Tensile strength of concrete is typically 8% to 15% of its compressive strength .This weakness has been dealt with over many decades by using a system of reinforcing bars (rebars) to create reinforced concrete; so that concrete primarily resists compressive stresses and rebars resist tensile and shear stresses. The longitudinal rebar in a beam resists flexural (tensile stress) whereas the stirrups, wrapped around the longitudinal bar, resist shear stresses. In a column, vertical bars resist compression and buckling stresses while ties resist shear and provide confinement to vertical bars. Use of reinforced concrete makes for a good composite material with extensive applications. Steel bars, however, reinforce concrete against tension only locally.

III. FIBRE REINFORCED CONCRETE

Fibre reinforced concrete can be defined as a composite material consisting of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres. Fibre can de circular or flat. Fibres are often described by a convenient parameter called ‘Aspect Ratio’. The aspect ratio of the fibre is the ratio of its length to an equivalent fibre diameter. Typical aspect ratio ranges from 50 to 150. Each type of fibre has its own characteristic properties and limitations. Steel fibre is one of the most commonly used fibres. Generally, round, straight fibres are used.
The diameter may vary from 0.25 to 0.75mm.Several studies have been conducted on Fibrous Reinforced Concrete Structure. Fiber material can be steel, cellulose, carbon, polypropylene, glass, nylon, and polyester.

IV. STEEL FIBRE REINFORCEMENT

The important properties of steel fibre reinforced concrete (SFRC) are its superior resistance to cracking and crack propagation.

As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking. The net result of all these is to impart to the fibre composite pronounced post – cracking ductility which is unheard of in ordinary concrete. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeatedly applied, shock or impact loading. Fiber shapes are illustrated in Figurer 1.1

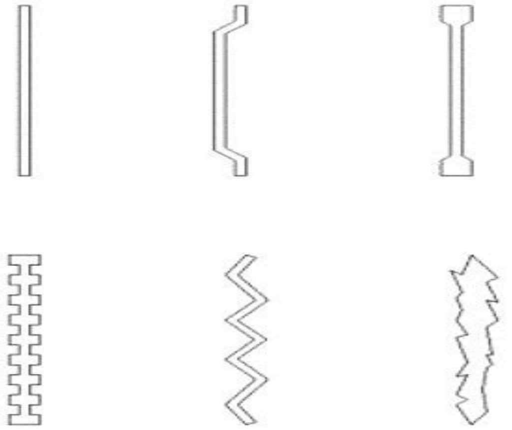

Figure 1.1 Shapes of steel fibres

V. USES OF STEEL FIBRES

The use of steel-fibres as reinforcement in plain concrete enhances the tensile strength of the composite system, reduces the amount of cracking under serviceability conditions and improves resistance to material deterioration as a result of fatigue, impact, shrinkage and thermal stresses. As a result, fibre-reinforced concrete can be used to improve the performance of structural members such as columns, floors on grade and pavements and to reduce the section thickness of the members. Fibre-reinforced concrete is also used in applications such as slabs in nuclear reactors, gravity dams and large furnace supports where thermal stresses could be significant.

VI. ADVANTAGES OF STEEL FIBRES

(1) Creates more ductile concrete with reduced cracking.
(2) Reduce the effect of shrinkage curling.
(3) More economical than conventional steel solutions.
(4) Fast installation thereby reducing schedule time.
(5) Easy material handling.
(6) Supported by large manufactures.
(7) Very durable
(8) Does not interfere with guide wire signals.
(9) Does not cause concrete delaminations.
(10) Can replace wire mesh in most elevated slabs.

VII. BEAM COLUMN JOINTS

The behavior of reinforced concrete moment resisting frame structures in recent earthquakes all over the world has highlighted the consequences of poor performance of beam column joints. Beam column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads effectively between the connecting elements (i.e. beams and columns) in the structure. In the analysis of reinforced concrete moment resisting frames, the joints are generally assumed as rigid. For adequate ductility of beam-column joints, use of closely spaced hoops as transverse reinforcement was recommended in the ACI-ASCE Committee 352 report (ACI, 2002). Due to the congestion of reinforcement, casting of beam column joint will be difficult and will lead to honeycombing in concrete In Indian practice, the joint is usually neglected for specific design with attention being restricted to provision of sufficient anchorage for beam longitudinal reinforcement. Beam-column joints have a crucial role in the structural integrity of the buildings.

Thus, beam column joints must be designed to resist earthquake effects. In fact failure due to over loading should occur in beams through large flexural cracking and plastic hinging and not in columns. The shear in the joint is equal to:

$V_j = \sigma_y A_s - V_{col}$

Where

V_j =Shear in the joint
A_s =Area of tension steel
V_{col} =shear in column

The joint shear causes diagonal tension and compression in the joints.

VIII. TYPES OF JOINTS IN FRAME

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint. When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behaviour. These forces develop complex mechanisms involving bond and shear within the joint.

(1) Interior joint
(2) Exterior joint
(3) Corner Joint

IX. REQUIREMENT OF BEAM COLUMN JOINT

The essential requirements for the satisfactory performance of a joint in an RC structure can be summarized as follow:-

(1) A joint should exhibit a service load performance equally to or greater than that of the members it joins, that is, the failure should not occur within the joints. If at all, failure due to overloading should occur in beam through larger flexural cracking and plastic hinge formation, and not in column. (2) A joint should posses a strength that corresponds at least to the most adverse load combinations that the adjoining members could possibly sustain repeatedly several times, if possible.

(3) The strength of the joint should not normally govern the strength of the structure, and its behaviour should not hinder and development of the full strength of the adjoining members.

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(4) Ease of fabrication and good access for placing and compacting concrete are the other significant parameter of joint design.

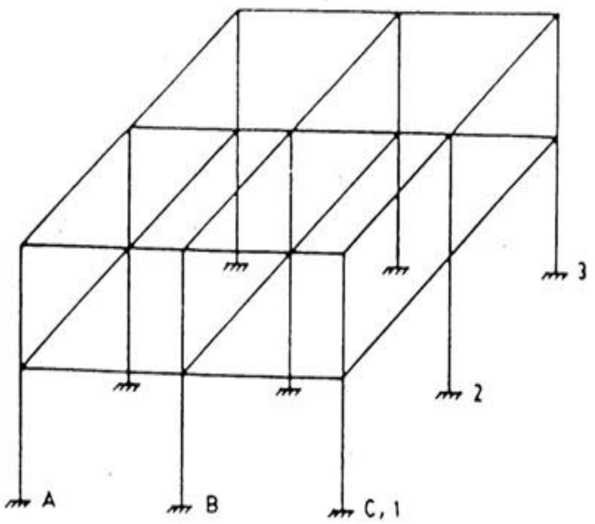
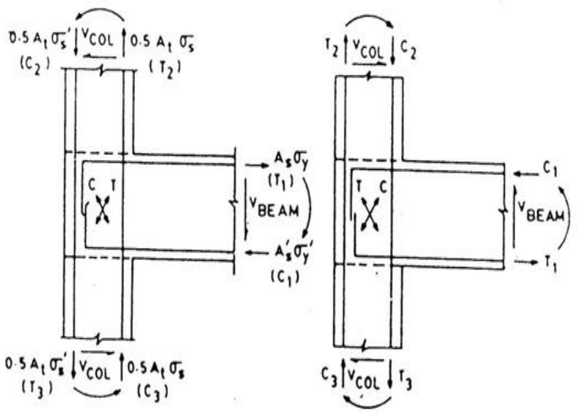
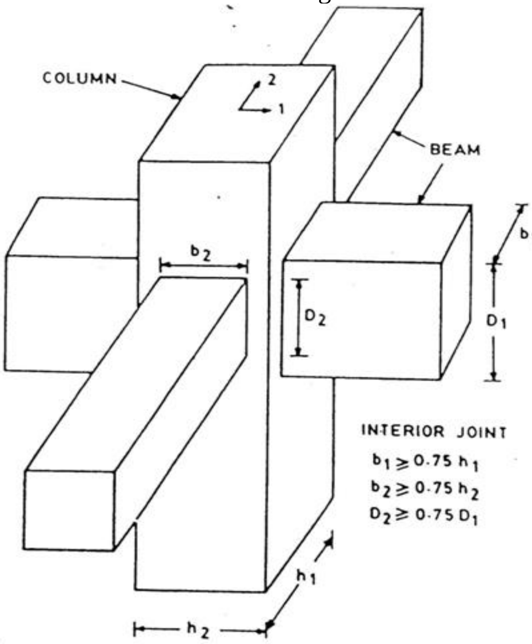


Figure. 1.2 A Typical Frame Structure

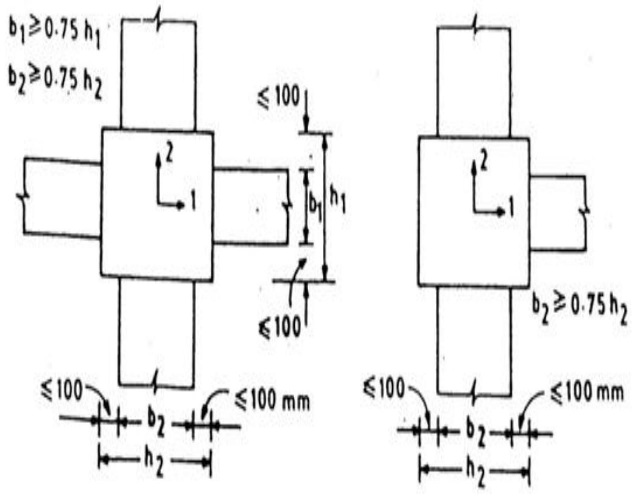


(a) Exterior Joint (b) Reversal of Forces

Figure. 1.3 Transfer of Force Through a Beam Column Joint



(a) Interior Joint



(b) Interior joint in plan (c) Exterior joint in plan

TEST PROGRAMME

The experimental work involved casting and testing of conventionally reinforced beam-column joint and steel fibre reinforced concrete beam-column joints. The work was carried out in following steps:

- Analysis of salient properties of the materials to be used.
- Designing of a workable mix of M25 grade using graded coarse aggregate of 20 mm maximum size.
- Fabrication of test specimens and test cubes and cylinders.
- Testing of specimens.
- Comparing test results of conventional and steel fibrous reinforced concrete beam - column joint in terms of First crack load, Maximum crack width, Load-deflection behaviour, Moment-rotation behavior, Ultimate load carrying capacity and Curvature ductility factor q.

INSTRUMENTATION

The tests were carried out using UTM machine and hydraulic jack. The other instruments used are described in succeeding parts.

Mechanical Strain Gauges

DEMEC strain gauges of 4 inches size were used for measuring surface strains at different points of the specimen. The least count of the gauge was 0.0001 inches. The gauge was used with stainless steel studs of 10mm diameter having a punch mark on one surface. The plain surface of each stud was pasted to the specimen by quick fix cementing solution. The punch mark on the study was to accommodate the conical point knob of the strain gauge.

Deflection Dial Gauges

Baty dial gauges with magnetic bases were used to measure deflection at different points of the specimen. The least count of the gauges was 0.01mm. The deflection of beam at point of loading as shown in figure.4.5 was recorded using dial gauge.

Crack Measuring Instrument

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A crack measuring instrument manufactured by W.H.Mays, U.K. was used for measuring the width of cracks at each stage of loading. The least count of the instrument was 0.1 mm.

Inclinometer

Inclinometer procured from W.H.Mayes, were used for measuring rotation. The least count of these Inclinometers was 60".

Figure 1.4 Confinement of a Beam-Column joint

X. CONCLUSIONS

In the present study, initially three specimens (SP1, SP2 and SP3) with different detailing of reinforcement were tested under monotonically increasing load. Then specimen SP2 was selected for further investigation based on its structural performance and ease of detailing. Two more Specimens were tested with different spacing of ties/stirrups. Finally, to investigate the effect of addition of fibres on behaviour of performance of joints, three specimens (SP6, SP7 and SP8) with volume fractions of 0.5%, 1.0% and 1.5% steel fibres were cast and tested. Based on the results obtained from the present study, following conclusions can be drawn:

MAIN CONCLUSIONS

(1) Closer spacing of transverse reinforcement resulted in large number of closely spaced cracks. The width of such cracks was smaller than specimens with nominal spaced ties. Moreover the first crack load increased in specimen SP4 with closely spaced ties as compared with specimens SP2 and specimen SP5. And maximum crack width for specimen SP4 with closely spaced stirrups also reduced as compared with specimen SP2 and specimen SP5.

(2) Ultimate load carrying capacity was considerably increased by addition of steel fibres to the core of the joint. In case of SP8 type of specimen the ultimate load was increased by 40 percent as compared to specimen without fibres (SP2).

(3) Addition of steel fibres to the core of the joint resulted in large number of closely spaced cracks. The width of such cracks was smaller than that in conventional reinforced concrete joints. Also the first crack load was appreciably increased. In case of SP8 type of specimen, first crack load was increased by 44.4 percent as compared to SP2 type of specimen. Maximum crack width in case of fibrous concrete specimens was reduced as compared to conventional concrete specimens.

(4) Addition of steel fibres to the core of the joint makes the joint stiffer. Specimens containing steel fibres in the joint core achieved much higher values of rotation as compared to the conventional concrete specimens.

(5) By using steel fibre reinforced concrete, the spacing of stirrups/ties provided in the beam-column joint can be increased while maintaining ductile behaviour of the frame. Value of curvature ductility factor of SP8 type of specimen, having 6mm diameter ties spaced at 125mm was 2.85 while that of SP4 type of specimens, having 6mm diameter ties spaced at 100mm was 2.32. This shows that the spacing of ties at the core of the beam-column joint can be increased effectively by the addition of steel fibres thereby improving the behaviour of the joint with respect to strength and ductility.

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