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Study on Behaviour of Beam Column Joint with HSC & HPFRC

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Abstract:
Beam column joint is a significant structural element for which, have to give a almost care in order to uphold the structures when subjected to the reversal of forces during earthquake. To satisfy the intended function of beam column joint it is essential to ensure the factors such as ductility, stiffness degradation and energy absorption capacity. In due course the joint should be flexible enough to undergo substantial shear deformation. This study illustrates the performance of two exterior beam column joints which have been modelled to a one fourth scale from a two bay six storey moment resisting frame subjected to cyclic loading. The joints are detailed as per the provisions given in IS 13920:1993 using M60 High Strength Concrete (HSC) and High Performance Fibre Reinforced Concrete(HPFRC) and High Performance Fibre Reinforced Concrete(HPFRC) with modified spacing. 1% of steel fibre is added based on volume fraction to enhance the joint strength, ductility and energy absorption capacity.

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1. INTRODUCTION

1.1 GENERAL

The performance of beam column joint plays a major role while considering the consequences occurred during earthquake in moment resisting frame structures. There are mainly three types of joints that can be identified, namely, interior joint, exterior joint and corner joint. In these three types exterior joint is most crucially affected during the severe external loading applied. So that exterior beam column is taken into account in this study. The basic requirement of design is that the joint must be stronger than the adjoining beam and column member. It is important to see that the joint size is adequate in the early design phase; otherwise the column or beam size will have to be suitably modified to satisfy the joint shear strength or anchorage requirements. The design of beam column joint is predominantly focused on providing the joint shear strength and adequate anchorage within the joint. A review of the behaviour and design of different types of beam column joints in reinforced concrete moment resisting frames under seismic loading illustrates that design and detailing provisions for the joints in the current Indian seismic codes IS 13920:199 and IS 1893:2002 are available to ensure prevention of brittle failure due to large shear forces which develop in the joint during earthquake.

Besides these, there are a large number of investigations on the effect of addition of steel fibres on the strength and ductility of flexural members. That study indicates that ductility and ultimate resistance of flexural members are remarkably enhanced due to the addition of steel fibres. Also it was emphasised that the neglect of fibre contribution may considerably underestimate the flexural capacity of fibre reinforced concrete beams. In general, when fibres are added to the concrete, tensile strain in the neighbourhood of fibres improves significantly. In this investigation, there is a considerable improvement in strength, ductility and energy absorption capacity with the addition of steel fibre as compared with the normal high strength concrete.

1.2 SIGNIFICANCE OF CONCRETE

Concrete is one of the most durable building materials. It provides superior fire resistance compared with wooden construction and gains strength over time. Structures made of concrete can have a long service life. Concrete is used more than any other manmade material in the world. Concrete has high compressive strength, its tensile strength is very low. In situations where tensile stresses are developed, the concrete is strengthened by steel bars or short randomly distributed fibers forming a composite construction called Reinforced cement concrete (RCC) or fiber reinforced concrete. In addition to its good compressive strength, concrete has flexural and splitting tensile strengths too. Concrete is a non-combustible material which makes it fire-safe and able to withstand high temperatures.Plain concrete possess very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually trading to brittle failure of the concrete. In plain concrete structural cracks develop even before loading particularly due to shrinkage or other causes of volume change.

1.3 DRAWBACKS OF CONCRETE

- Concrete has low tensile strength and hence cracks easily.
- Concrete expands and contracts with the changes in temperature.
- Fresh concrete shrinks on drying. It also expands and contracts with wetting and drying.

- Concrete is not entirely impervious to moisture and contains and contains soluble salts which may cause efflorescence.
- Concrete prepared by using ordinary Portland cement disintegrates by the action of Alkalies, Sulphates, etc.
- The lack of ductility is inherent in concrete as a material is disadvantageous with respect to earthquake resistant design.
- To overcome this drawback fiber is used in concrete.

1.4 FIBER-REINFORCED CONCRETE (FRC)

Fiber reinforced concrete is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lends varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities.

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to150.

1.4.1 PROPERTIES OF FIBER REINFORCED CONCRETE

- Controls cracking due to plastic shrinkage and drying shrinkage.
- Reduce the permeability of concrete and thus reduce bleeding of water.
- Reduce steel reinforcement requirements
- Improve impact resistance and abrasion resistance.
- Improve ductility.
- Reduce crack widths and control the crack widths tightly, thus improving durability.

1.4.2 ROLE OF FIBER REINFORCED CONCRETE

- The use of fibers in reinforced concrete flexure members increases ductility, tensile strength, moment capacity, and stiffness
- It increases stiffness, torsional strength, ductility, rotational capacity and the number of cracks with less crack width
- Addition of fibers increases shear capacity of reinforced concrete beams up to 100 percent
- Addition of randomly distributed fibers increases shear-friction strength, the first crack strength, and ultimate strength
- The use of fibers helps in reducing the explosive type failure for columns.

1.4.3 TYPES OF FIBERS

There are various fibers are used in the concrete. Some of them listed below

- Steel fiber
- Glass fiber
- Carbon fiber
- Polypropylene fiber
- Natural fiber
- Basalt fiber
- Asbestos fiber
- Aramid fiber

1.4.3 (a) STEEL FIBER

The superior structural properties of SFRC have found it an ideal material for overlays and over slab of roads, pavements, airfields and bridge decks, industrial and other flooring units those subjected to wear and tear and attack due to chemical effects.

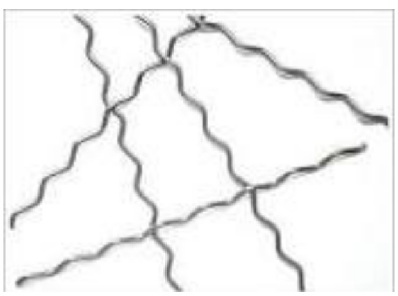


Fig 1.1 Steel Fiber

1.4.3(b) GLASS FIBER

Glass fibers are produced commercially in three basics forms, namely, ravings, strands and woven or chopped strand mat. There are however, two main problems is the use of glass fibers in Portland cement products, namely, the breakage of fibers and the surface degradation of the glass by the high alkalinity of the hydrated cement paste. Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites.

Fig1.2 Glass fiber

1.4.3(c) CARBON FIBER

Carbon fibers have high tensile strength and young's modulus, but also a high specific strength compared to steel and glass fibers. Increase in flexural strength, and stiffness are about 214 kg/cm^2 and 21420 kg/cm^2 respectively for the one percent of fiber. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports

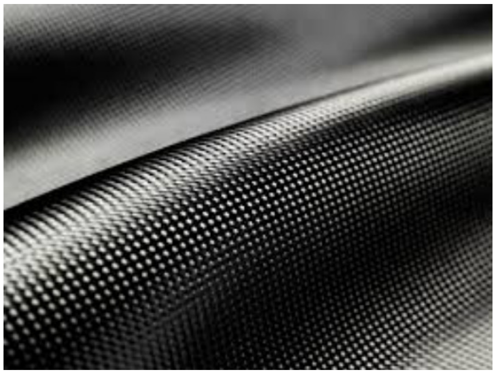


Fig 1.3 Carbon fiber

1.4.3(d) BASALT FIBER

Basalt is common extrusive volcanic rock formed by decompression melting of the earth's mantle. It contains large crystals in a matrix of quartz. Basalt steel fibers are used to create alternative building material to metal reinforcements like steel and aluminum. Basalt mesh is used the frame work in our panels for structural reinforcements and material integrity.

Fig 1.4 Basalt fiber

1.4.3(e) ASBESTOS FIBER

Asbestos is a naturally available mineral fiber. It has been successfully combined with Portland cement paste to form the product called asbestos cement. Asbestos cement has been the most widely used fiber reinforced concrete composite. The world consumption of asbestos fibers for making building products such as sheets, shingles, pipes, tiles and corrugated roofing elements is about 3.3 million tons. The reason for the wide use of asbestos fibers is many. They are naturally available and as a result are relatively in expensive. They have a desirable thermal, mechanical and chemical resistance.

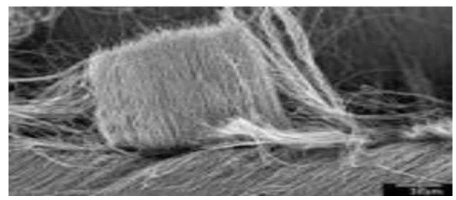


Fig 1.5 Asbestos fiber

1.4.3(f) POLYPROPYLENE FIBER

It is used as short discontinuous fibrillated material for production of fiber reinforced concrete or a continuous mat for production of thin sheet components. Since then the use of these fibers has increased tremendously in construction of structures because addition of fibers in concrete improves the toughness, flexural strength, tensile strength and impact strength as well as failure mode of concrete.

Fig 1.6 Polypropylene fiber

1.5 FRAMED JOINTS

Beam column joints can be critical regions in reinforced concrete frames designed for inelastic response to severe seismic attack. As a consequence of seismic moments in columns of opposite signs immediately above and below the joint, the joint region is subjected to horizontal and vertical shear forces whose magnitude is typically many times higher than in the adjacent beams and columns. If not designed for, joint shear failure can result.

1.5.1 JOINT TYPES

According to geometrical configuration

Interior, Exterior, Corner

According to loading conditions and structural behavior

Type-I, Type-II

Interior joint:- An interior joint has beams framing into all four sides of the joint. To be classified as an interior joint, the beam should cover at least ¾ the width of the column, and the total depth of shallowest beam should not be less than ¾ the total depth of the deepest beam.

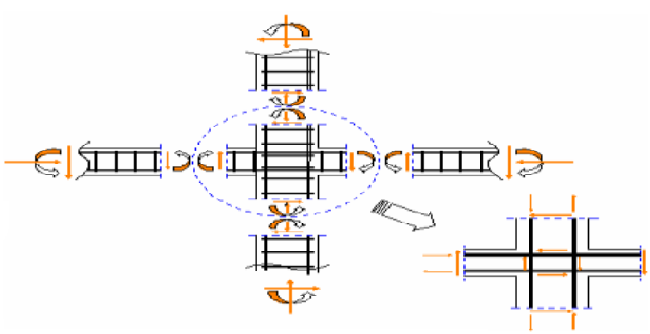


Fig 1.7 Interior beam column joint

Exterior Joint:- An Exterior joint has at least two beams framing into opposite sides of the joint. To be classified as an exterior joint, the widths of the beams on the two opposite faces of the joint should cover at least ¾ the width of the column, and the depths of these two beams should not be less than ¾ the total depth of deepest beam framing in to the joint.

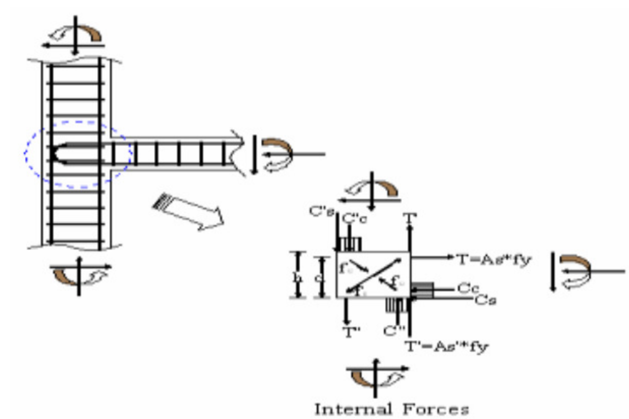


Fig 1.8 Exterior beam column joint

Corner Joint:- A Corner joint has at least one beam framing into the side of the joint. To be classified as a corner joint, the widths of the beam on the face of the joint should cover at least ¾ the width of the column.

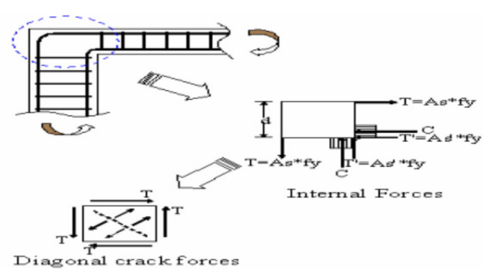


Fig 1.9 Corner beam column joint

Type1- Static loading Strength important, Ductility secondary A type-1 joint connects members in an ordinary structure designed on the basis of strength, to resist the gravity and wind load.

Type2-Earthquake and blast loading Ductility + strength, inelastic range of deformation, Stress reversal A type-2 joint connects members designed to have sustained strength under deformation reversals into the inelastic range, such as members designed for earthquake motions, very high wind loads, or blast effects

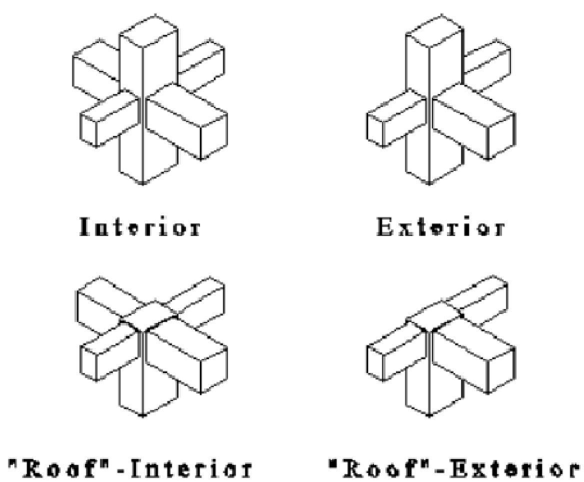
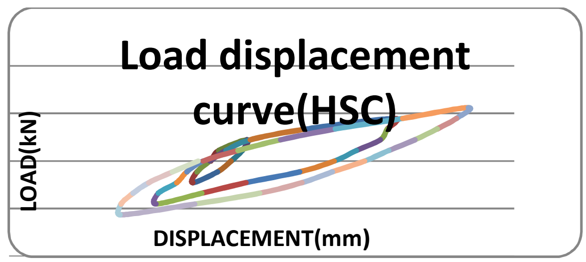


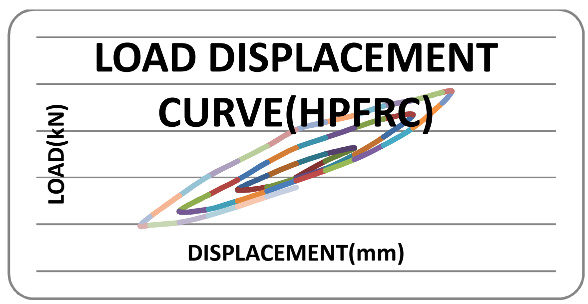
Fig 1.10 Typical beam column joints

LOADING AND LOAD DEFLECTION BEHAVIOUR

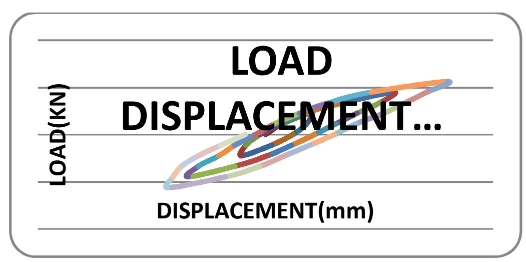
The exterior beam column joint specimen was subjected to cyclic loading simulating earthquake load. The load deflection behaviour of High Strength concrete beam column joint,High Performance Fibre Reinforced Concrete beam column joint and Modified spaced High Performance beam column joint are shown in fig. The beam column joint gradually loaded by increasing the load level during each cycle the load sequence consists of 1.5kN , 3kN, 4.5kN,etc… upto failure load. The deflection are measured using dial gauge for farward and reverse cycle of loading.



load deflection behaviour of high strength concrete



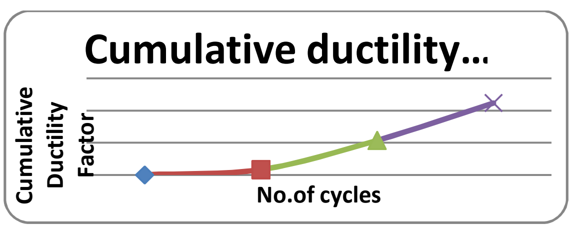
load deflection behaviour of HPFRC



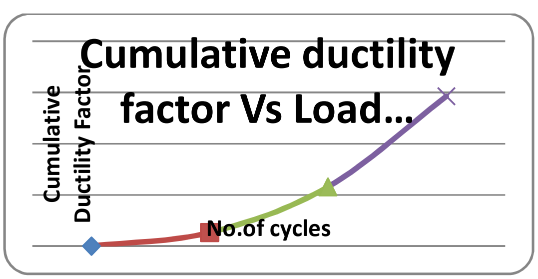
load deflection behaviour of HPFRC modified spacing

DUCTILITY FACTOR AND CUMULATIVE DUCTILITY FACTOR

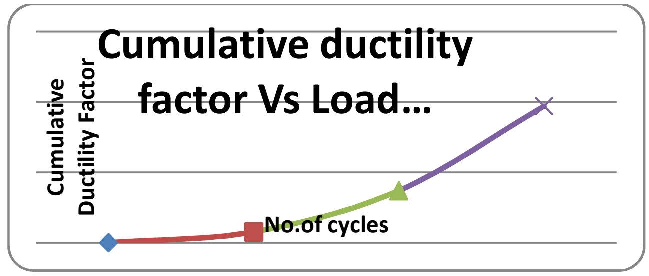
Ductility may be broadly defined as the ability of a structure to undergo inelastic deformations beyond the initial yield deformation with no decrease in the load resistance. A quantitative measure of ductility has to be with reference to the bilinear load deformation. The ration of ultimate deformation to the yield deformation at the beginning of the horizontal path of first yield can give a measure of ductility. The ductility factor for various load cycle of High Strength concrete beam column joint, High Performance Fibre Reinforced Concrete beam column joint and Modified spaced High Performance beam column joint are shown in fig. This is an important parameter to be considered for earthquake resistant structures.



Cumulative ductility factor with Load Cycle for HSC



Cumulative ductility factor with Load Cycle for HPFRC



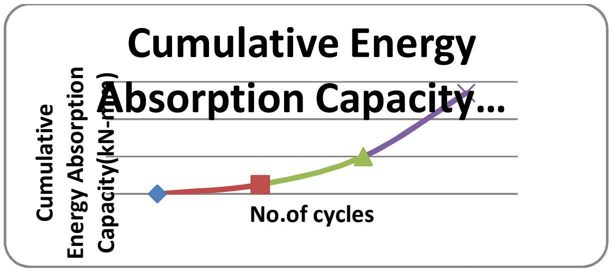
Cumulative ductility factor with Load Cycle for HPFRC

With modified spacing

CUMULATIVE ENERGY ABSORPTION CAPACITY

When the beam column joint is subjected to cyclic loading, such as those experienced during heavy wind or earthquake, some energy is absorbed in each load cycle. It is equal to the work in straining or deforming the structure to the limit of deflection. The relative energy absorption capacities during various load cycles were calculated as the sum of the areas under the hysteric loops from the load deflection diagram.

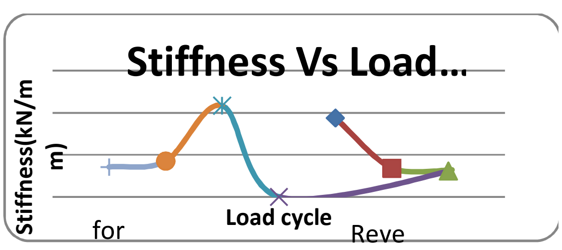
The cumulative energy absorption capacity of the beam column joint was obtained by adding the energy absorption of the beam column joint during each cycle considered and the values are plotted and it is as shown in fig.



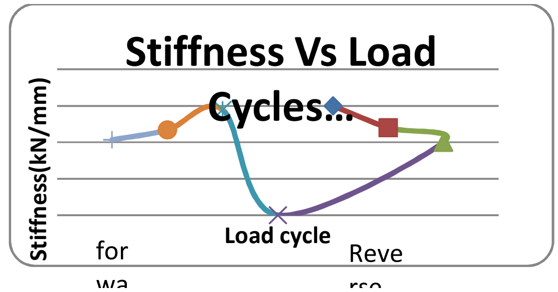
Cumulative EnergyAbsorption Capacitywith Load Cycle for HSC

STIFFNESS

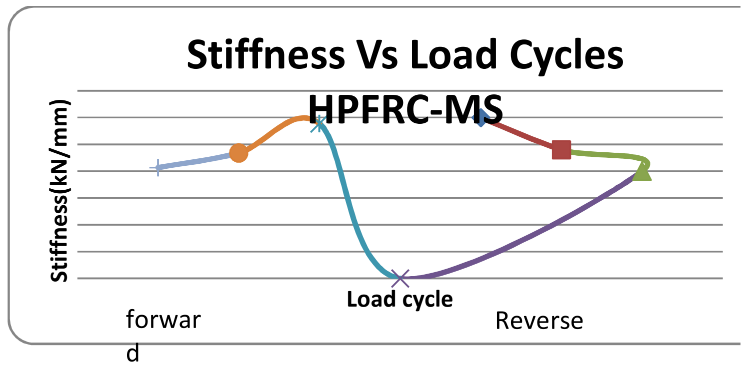
Stiffness is the load required for causing unit deformation of structural elements like beam column joint. The procedure for calculating Stiffness was as follows.,A tangent drawn for each cycle of the hysteric curves at a load of $P=0.78P_u$ where P_u was the maximum load of that load cycle. Determine the slope of the tangent drawn to each cycle, which gives the stiffness of that cycle.In general, with the increase in the load there is degradation of stiffness and that was shown in fig.



Stiffness Vs Load Cycles HSC



Stiffness Vs Load Cycles HPFRC



Stiffness Vs Load Cycles HPFRC with m/s

Table 1Experimental Results of Beam column

type	Cycle no	Maximum load in KN	Max deflection in mm	Ductility Factor	Relative energy absorption in KN-mm	Stiffness in kN/mm
HSC	F1	9	1.78	0.59	7.4	3.75
	F2	18	9.15	3.05	90	1.36
	F3	22.5	12.73	4.24	104	1.23
	R1	9	0.9	0.23	5.6	4.33
	R2	18	2.72	1.5	64	1.71
	R3	22.5	4.5	1.573	144	1.42
HPFRC	F1	9	3.15	0.9	10.5	3
	F2	18	6.7	1.91	43.5	2.4
	F3	24	9.23	2.64	87	2
	R1	9	1.3	0.43	9	2.89
	R2	18	3.65	1.22	35.25	2.34
	R3	24	5.2	1.73	86.25	2.07
HPFRC Modified Spacing	F1	9	2	1.02	9	3.43
	F2	18	5.65	3.845	33	2.69
	F3	22.5	8.01	7.855	56.25	1.62
	R1	9	1.05	0.525	6.75	3.75
	R2	18	1.75	2	35.25	3
	R3	22.5	2.95	4.15	68.25	2.4

Table2 Experimental Results of Beam column

type	Cycle no	Cumulative Ductility Factor	Cumulative Energy Absorption in KN-mm
HSC	1	0.82	12.5
	2	5.37	50
	3	11.183	135
HPFRC	1	1.33	19.5
	2	5.79	98.25
	3	14.62	271.5
HPFRC Modified Spacing	1	1.55	15.75
	2	7.39	84
	3	19.4	208.5

CONCLUSION

The structural behaviour of 3 varieties of exterior beam column joint are studied experimentally. Experimental investigation shows that the use of steel fibers arrests the crack and the depth of the crack was found to be less. The addition of steel fibers on concrete tends to increase the load carrying capacity by about 7% while comparing the HSC. While considering the other parameter like ductility and stiffness degradation use of steel fibre is recommended in the high earthquake zone rather than increasing the grade of concrete. The conclusion is arrived after studying the properties of ductility, stiffness and energy absorption parameters and more importantly the failure pattern of the specimens.

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