Enhancement of Seismic Behaviour of Beam-Column Joints – A Literature Review

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ABSTRACT:

Beam-column joints contribute significantly for the seismic behavior of reinforced concrete members. Among the various factors that influence the performance of beam-column joints, reinforcement detailing has drawn the attention of many researchers due to its inevitable impact on the behavior of Reinforced Concrete joints and structures subjected to seismic loads. In this literature study, works carried out by various researchers to enhance the seismic performance by employing different techniques are presented. The discussion covers the influence of SMA reinforcement, super-elastic SMA rebars in the joints, utilization of fibre-reinforced concrete, horizontal stiruups and Concrete-encased-and–filled tubular members. The impact of these techniques on the cyclic behavior of the beam-column joints is illustrated by the hysteresis curves. All these techniques proved to be efficient in increasing the Load carrying capacity and Energy Dissipation capacity of the members..

. ***Keywords:*** **Seismic behavior, Hysteresis curve, Energy Dissipation Capacity, Plastic zone**

1. INTRODUCTION

Studies about the building failures due to earthquakes have demonstrated that even when the beams and columns in a reinforced concrete frame remain intact, the integrity of the whole structure is undermined if the joint where these members connect fails. During earthquake, inelastic deformations occur in the members without significant loss in bearing capa-city which is considered as energy dissipation capacity of the members. Enhancement of ductile behavior in the beams is considered as a preferable option for such condition, and improving the elastic range for beam-column joint is important for the structural stability under cyclic load of the earthquake. The beam-column joint during the application of seismic lateral loads, is exposed to the flexural and shear forces with a non-uniform distribution, The shear stress produced in the joint zone should belesser than the shear strength of the joint zone, if the joint is to remain elastic without interfering the plastic rotation of its adjacent members.

The emphasis of this literature study is to expolore the possible ways to enhance the seismic performance of the beam column joints. With the increasing applications of smart materials in civil engineering structures, conventional design philosophies and practices shall be revised to take into account the differences in properties between conventional reinforcement and smart materials. Shape Memory Alloy (SMA), a class of smart materials,is being utilized in the design of smart structures subjected to seismic loads. The use of SMA, is primarily focused on the enhancement of energy dissipation capacity for structures prone to earthquake and extreme vibrations.[1-9]

The intrinsic problem of normal concrete is its brittle nature which may cause collapse in non-seismically detailed structural members after the first crack during a large earthquake. A good seismic performance of beam-column joint depends on the detailing of beam longitudinal reinforcement and confinement in joint. Entroducing transverse reinforcements in the beam-column joint provides concrete confinement, increases the shear strength and increases the bond of the longitudinal reinforcement with concrete.All these factors result in the formation of a flexural plastic hinge in the beam and the ductile behavior of the structure under seismic cyclical loads. [10,11]

The use of steel fibres may convert the brittle characteristics to ductile ones. The principle role of fibres is to bridge cracks and resist their formation. Therefore a considerable improvement in tensile strength and higher ultimate strain can be obtained. Many researches have been conducted to investigate the flexural behaviour of steel fibre reinforced beam-column joints, such as using steel fibre to replace the lateral reinforcement in the plastic hinges of beam-column joints. Based on the improvement in bond between rebars and concrete after using steel fibers, it is reported that the steel fibers are capable of increasing the anchorage capacity of hooked rebars embedded in the beam-column joints.. Steel fibers are well recognized for the ability to enhance the flexural strength, shear strength, fracture toughness, and better energy dissipation capacity. Steel fibers can act also as crack arrester, which delays the dilation of concrete and prevents the development of cracks thereby suppressing a brittle shear failure in favour of more ductile behavior.[12-14]

2.1 SMA REINFORCEMENT

Shape memory alloy(SMA) undergoes large deformations but sustains low permanent strain upon loading. SMA is used in cases where there are extreme loads. It responds both mechanically and thermally. It is used where there is extreme vibration and earthquake waves.

However, SMA poses a few challenges like less concrete bond interface and there is poor understanding of the fundamental properties of the SMA material.

Due to the shape memory effect (SME) an SMA can recover its original shape when it is heated. SMA shows excellent energy dissipation capacity while attaining an elastic behavior upon loading. Modulus of elasticity of a SMA reinforced concrete is 15 to 42% of conventional concrete and the elongation at failure ranges from 5 to 50%. [1]

Oudah and El-Hacha [1] suggested that mechanical anchoring was the most suitable method for introducing SMA bars in concrete. Hook anchorage wasn't preferred because of the difficulty in bending of bars and development length method could not be used due to the smoothness of SMA bars.The mechanical properties of the SMA materials undergo a change due to heat released during welding. Therefore, the screw-lock technology is used which also proves to be cost effective.

2.2 SMA MATERIAL PROPERTIES:

Oudah and El-Hacha [1] used three methods to calculate the strain value of which the Digital Image Correlation Technique(DCIT) gave accurate results by dividing the original area into subdivisions.

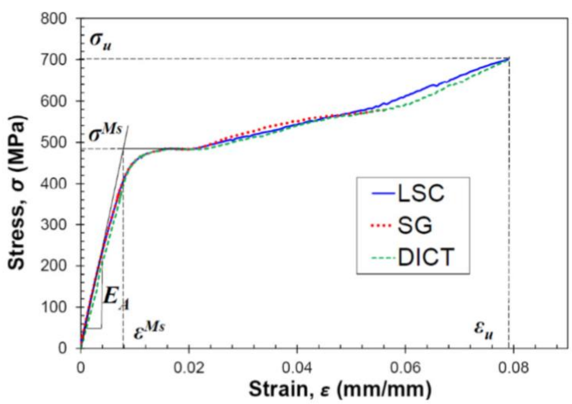

Fig.1. Stress strain relationship of SMA material

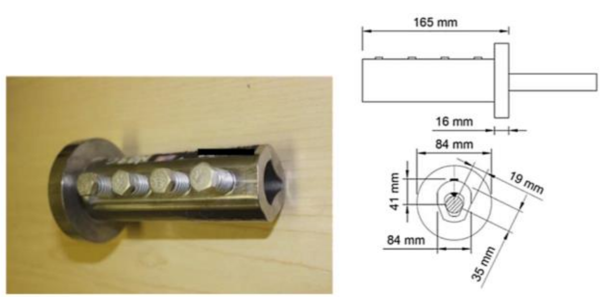

Fig.2. Mechanical anchor used [1]

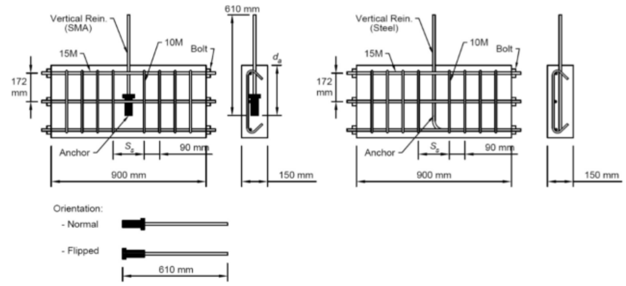

Fig.3. Detailed of joint like specimen [1]

Two types of reinforcement were tested: one with steel reinforcement and the other with SMA reinforcement. Two anchor orientations were followed- normal and flipped.The spacing distances were 65mm at the joint and 180mm is double the value at the column.Two types of reinforcing bars were used as the vertical reinforcement-15M steel and 14.9M steel.

A tension-tension quasi-static cyclic loading was applied and the amplitude of stroke displacement kept increasing by 1mm slowly until the specimen failed. The steel reinforced specimen failed by cup and cone fracture while the SMA reinforced failed either due to fracture on spillage.

There was a linear increase in moment until it reached the corresponding splitting crack in steel reinforced and flexural crack in SMA reinforced specimen.

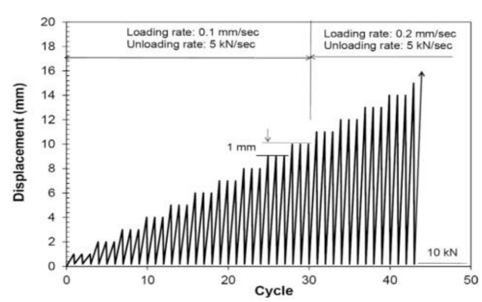

Fig.4. Loading from the tension-tension cyclic test [1]

TABLE 1

Testing matrix of the joint like specimens

Group	Specimen ID	Vertical Rein.	S_s (mm)	d_a (mm)	Orientation
Steel-reinforced	AN-S-1	Steel	65	NA	NA
	AN-S-2	Steel	180	NA	NA
SMA-reinforced	AN-P-1	SMA	65	370	Normal
	AN-P-2	SMA	65	305	Normal
	AN-P-3	SMA	65	370	Flipped
	AN-P-4	SMA	180	305	Normal

Since the stirrups were placed closer to the vertical reinforcement in the first steel reinforced specimen(AN-S-1) it can withstand more strain than the second steel reinforced,specimen(AN-S-2).

The maximum stress and strain in the steel reinforced specimens was greater than that in the SMA reinforced specimens.

SMA has higher fatigue resistance than steel and it has a strain value higher than 0.6. Modifications were used to the SMA anchor and tests were conducted in four different phases. The phases consisted of modifications to the anchor. Phase 1 has no modification.The first phase had the lowest stress-strain value while phase 4 had the highest stress-strain value.

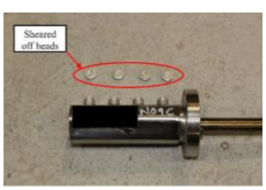

Fig.5. Phase1

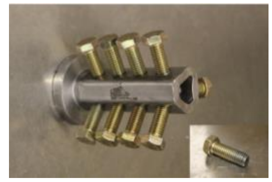

Fig.6. Phase2

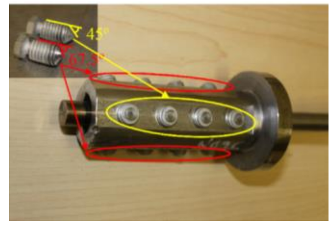

Fig.7. Phase3

Fig.8. Phase4

Results suggest that even though the modified anchors could withstand higher stress and strain,they did not prove to stop premature failure.The slip was very small before the material reached the martensite temperature(MS) temperature stage.Martensite phase has less stiffness when compared to Austensite phase. Therefore the resistance to slippage decreased when the SMA material reached the MS tempreature stage.

The joint rotation should be kept minimal to avoid non-ductile shear failure at the joints.

From the tests conducted by Oudah and El-Hacah the third SMA reinforced specimen is recommended for joint structures as it has the highest and post-cracking stiffness and lowest curvature.When the anchor depth is increased the post-cracking stiffness is increased and curvature is decreased.

2.3 SEISMIC PERFORMANCE EVALUATION OF CONCRETE BEAM-COLUMN JOINT REINFORCED WITH DIFFERENT SUPER ELASTIC SMA REBARS

Steel normally fails due to inability to adequately dissipate energy amd results in permenant deformation. Abdulridha [9] stated that the memory of the previous shape is 78% more than conventional reinforced concrete. Chowdhury [15] showed that using shorter SMAs proved to be more effective than bigger ones (the shorter ones showed more energy dissipation).

Billah and Alam [16] stated that SMAs reduced residual drift and showed good energy dissipation capacity. A study by Pareek et al [17] showed that the usage of Cu-based SMA bars improves strength and energy dissipation. When retrofitting is done using SMA bars, it can prove to be stronger or undergoes less deformation when compared to conventional RC. The performance of shear walls can be improved when SMAs are used as stated by Abraik and Youssef [18].

Ni-Ti has been widely used as a SMA because of its good resistance to corrosion, superelasticity and low residual strain. Cu-based SMAs are cheaper and has good workability,machinability and large transformation hysteresis but Cu-based SMAs(13) are poorly ductile in nature.

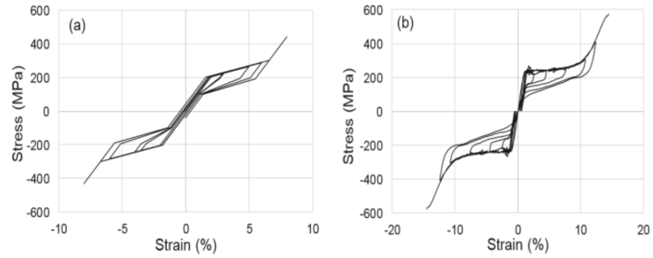

Fig.9.Behaviour of SMA under cyclic tension and compression (a) SMA (Ni-ti) (b) FeNCATB) [9]

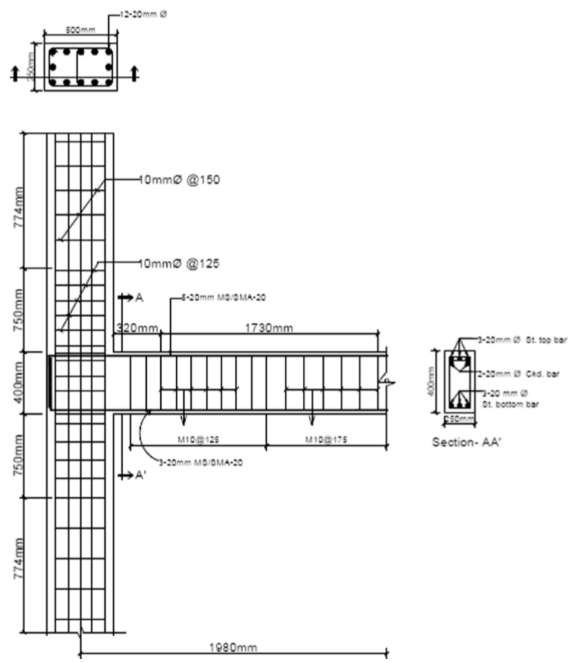

Fig.10.Reinforcement pattern of the beam-column joint [9]

In this study, five different forms of SMA bars were taken. A multi-story building in Dhaka was selected as the specimen for this experiment. Reinforcement details of beam-column joints are shown in figure( ). Different types of SMA bars were placed in the plastic hinge regions while the remaining portion of the beam is reinforced with steel. SMA-RC-3 has the highest load bearing ability.

Cracking of concrete, spalling and yielding of SMA rebars and crushing of concrete were the four parameters considered in this experiment. Static push-over analysis used in this study can be used for seismic tests. As the SMA bars have very less stiffness, the joints that have SMAs undergo maximum deflection before it yields. When SMA reinforced concrete specimen(SMA-RC-3) is used, the core concrete fails by crushing which is not a preferred method of failure.

Flexural cracking occurred at a negligible scale(12%). Concrete spalling varied from 0.73% to 0.98% and this damage cannot be repaired. Spalling in SMA specimens started only after SMA starts to yield.

An axial load was produced at the tip of the beam an it was subjected to reverse cyclic loading. SMA-RC-5 (SMA reinforced concrete specimen) withstood high drifts before concrete undergoes crushing which shows that a good amount of drift dissipation before failure of concrete can be achieved by using SMAs.On usage of SMAs, the residual strain in the joints has been reduced and the maximum value has been found out to be 0.29%.Energy dissipation of steel-RC-beam column joint is 65% greater than SMA-RC joint.

3. MECHANICAL PROPERTIES OF FRC WITH RECYLCED FIBRES 12-14, 18-22]

FRC is created by adding fibres to concrete. The addition of fibres to concrete reduces the brittle nature of concrete structural members and in some cases the ductility of concrete has beam increased. Concrete is mostly not used in cases where there are tensile stresses because cracks develop as concrete is poor in withstanding tensile stresses which lead to crack formation.

There are two ways to increase the tensile strength of concrete-one is the addition of reinforcement bars and the other is mixing the durable fibres throughout the volume of concrete. Steel fibres are predominantly used but other fibres like glass, polypropylene,graphite and Kevlar fibres were used. Bondage between the concrete and the concentration of the fibres, length-diameter ratio affect the material's properties. Fibers with small hooks or heads are used to improve the shape of the fiber anchorage

The addition of fibers helps in plastic deformations and the fibers usually bridge the cracks and increase the flexural strength,resistance to dynamic effects, tensile strength, ductility and crack resistance (5). Cracks are avoided when fibers reduce the stress concentration at the crack's end(6).

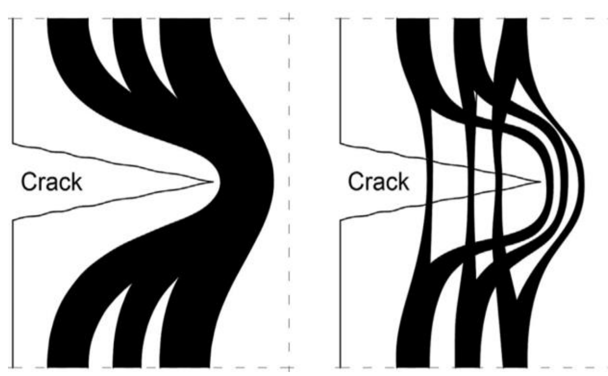

Fig.11.Stress concentration in cracked concrete(left) and crack bridging by fibres in FRC [12]

Fibers prevent the development of micro-cracks but when it comes to macro-cracks the fibers absorb energy which improves the strength of concrete.

The energy absorbing capacity of fibre reinforced concrete is much greater than that of conventional concrete. FRC exhibits a behavior called strain-hardening which means that the load bearing capacity of the structure increases due to the energy that has been absorbed by the fine cracks whereas normal reinforced concrete fails due to the one major crack that has been formed. Cracks caused due to shrinkage can be avoided by using polypropylene fibers. The Young's modulus of the material is reduced on addition of fibers due to the structural disturbances caused by the addition of fibers, especially the fibers that are parallel to the direction of loading. It also decreases the compressive strength as the concrete becomes more porous. It has been observed that the fibres(thin and short) obtained from tyres in the form of rubber with steel reinforcement gives better results. Polypropylene and PET are recycled waste that are used. Tests on FRC are different from those done on conventional concrete due to the non elastic behavior of FRC.

Recycled fibres that have an average width of 0.86mm and height of 0.37mm were used. They were cut in a way that their aspect ratio was 75. The test showed a tensile strength of 581.4 MPa but this value was not stable. Recylcled fibers fractured easier than normal fibers because of their low fatigue resistance. 3 specimens were taken. The first one was of plain concrete, the second was with steel fibers and the third was with recycled fibers.

Compressive strength, flexural strength and split tensile tests were done on those materials.

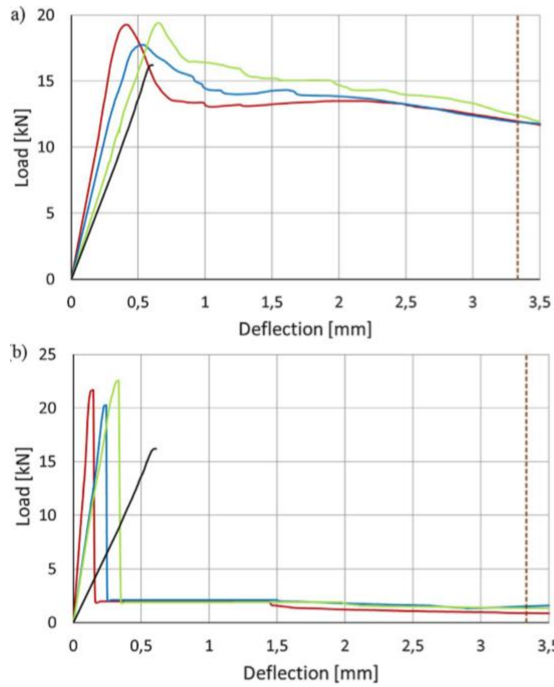

Fig.12.Load-deflection diagrams,(a) reference fibres (b) recycled fibres [14]

The first graph was plotted for fibre reinforced concrete with the fibres used and it was observed that after the quasi-static stage the structure can bear some load.The second graph was plotted for the fiber reinforced specimen with recylyed fibres and it was observed that after the quasi-static stage the specimen abruptly failed.

The equivalent flexural strength of the recycled fiber specimen is almost 5 times lower than that of normal fiber. The failure rate of FRC is lower than that of plain concrete. The specimens including FRC split easily into 2 halves when the split tensile test was done. Rate of deformation due to bending decreases in FRCs.

4. EFFECTIVENESS OF HORIZONTAL STIRRUPS IN JOINT CORE FOR EXTERIOR BEAM- COLUMN JOINTS WITH NON-SEISMIC DESIGN

Design provisions are available for seismic prone areas but they are rarely incorporated during the construction of a structure in a non- seismic region. The structure has to rely solely on the design and detailing that have been determined for non-seismic regions. According to Kuang and Wong [23] reinforced concrete beam-column joint assemblages with non-seismic designs proved to have poor hysteric behaviour, low ductility capacity and relatively low shear strength. Kuang and Wong [23] created a simulation of a reinforced concrete frame building with non-seismic design according to British standard BS8110. They undertook reverse cyclic-load tests for a full scale reinforced concrete exterior beam-column joint.

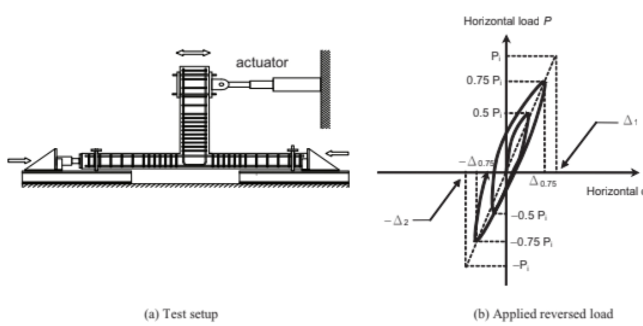

Fig.13.Experimental Set up [23]

Their work focuses on determining the seismic performance of structures with a non-seismic design detailing. It was found that horizontal stirrups which were provided in beam-column joints with non-seismic design improve the seismic effect and joint shear strength.

Experimental Research on T-shaped Beam-Column Joints at Top Floor with Mechanically Anchored Reinforcement

Mechanical anchorage is easy to install in congested connections during reinforced concrete constructions. Due to the advancement in RCC constructions, high-strength and large-diameter rebars are used. It has become a challenge to bend these rebars. Anchorage was developed to simplify this process in congested connections.

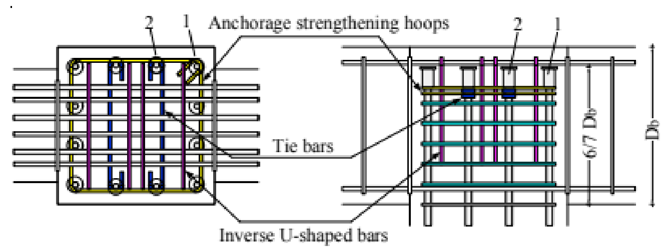

Fig.14.Reinforcement detailing [23]

The anchorage is placed beyond the beam core as the columns are generally greater in dimension. Therefore, critical failure can occur at the anchorage. Yeubing Li et.al [24] focused on the required amount of shear reinforcement in joints to prevent anchorage failure. They have narrowed it down to T-shaped beam-column joints which are tested under static and cyclic loads using three partial frame specimens including such beam-column joints. According to their results some anchorage- strengthening reinforcement yielded after resisting a high level of stress.

5. SEISMIC BEHAVIOUR OF INTERIOR R-C BEAM-COLUMN JOINTS WITH ADDITIONAL BARS UNDER CYCLIC LOADING

Most failures of RCC structures occur because of a lack of efficiency in joint detailing. The poor design of an R-C beam column joint does not effectively dissipate seismic energy when the flexural members are immobilized. Xilin Lu et.al [25] have constructed ten full-scale interior beam-column specimens with various additional reinforcements details and configurations.

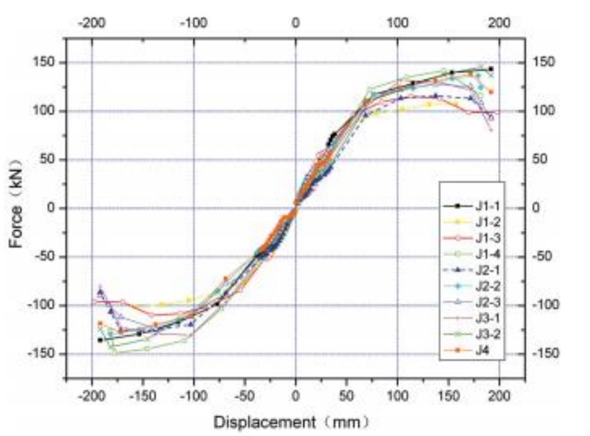

Fig.15.Force-Displacement curve [25]

The parameters studied by Xilin Lu et.al [25] were the joint critical principal strength, ductility, joint behaviour and energy dissipation capacity. They found that the specimens with additional bars did have sufficient strength after or close to their maximum shear strength. It was also found that these additional diagonal bars prevented cracks at the edges of joint interface between column and beam.

Behaviour of Corner Beam Column Joint with Rectangular Spiral Reinforcement and Longitudinal FRP Bars

Stirrups are common shear reinforcements in a RC rectangular element. The advancement in improving this reinforcement has led to spiral shear force reinforcement. Continuous spiral reinforcements incorporated in circular cross-sections could improve the strength, ductility and energy dissipation capacity. Athira p et.al [26] have used Finite Element Model (FEM) formulation to investigate the behaviour of RC beam column connections using rectangular spiral and conventional shear reinforcement system under cyclic loading.

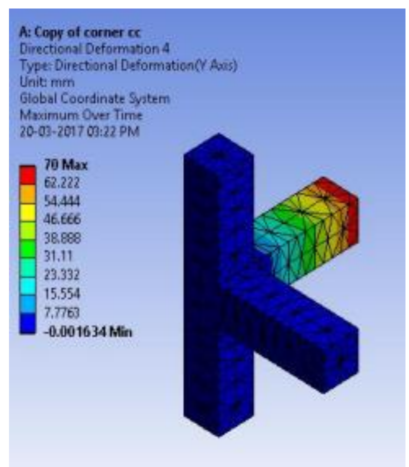

Fig.16.FEM for Beam=column joint [26]

They have also investigated the influence of FRP bars with spiral reinforcement on ductility at beam column joint under cyclic and reverse cyclic loading and have conducted a study on FRP bars with hybridization at beam column joint. It was found that spiral reinforcements reduces deformation, increases stiffness, increases the energy absorption capacity and improves the seismic performance of a beam column joint. The FRP bars that are hybridized show improved ductility and lesser deformation when compared to conventional steel bars.

6. CYCLIC LOADING TEST FOR EXTERIOR BEAM – COLUMN JOINTS OF CEFT COLUMNS

In the concrete –encased –and –filed tubular columns the cross ties are replaced with steel tubes that acts as a structural element that resists member forces. The concrete encasement is separated from the core concrete layers to defy monolithic properties. For this very reason, the structural performance of CEFT columns and the beam-column joints should be verified under cyclic loading. Ho- Jun Lee et al [27] performed a cyclic loading test to investigate the seismic performance of exterior beam – column joints of concrete-encased- and –filled steel tubular (CEFT) columns.

Fig.17.Cracks pattern of tested specimens [27]

They tested two specimens with steel beams and two specimens with precast concrete under cyclic loading. It was found that brittle failure occurred in the continuity plate-to-column tube connection in the steel beams. The precast beams showed good deformation capacity, developing the full moment capacity in the beam plastic zone. It was also observed that the bottom part of the precast beam was vulnerable to early spalling due to lack of concrete integrity in the beam-column tube connection.

7. CONCLUSIONS:

From the Literature study it is evident that adopting the techniques of SMA reinforcement, super-elastic SMA rebars in the joints, utilization of fibre-reinforced concrete, horizontal stiruups and Concrete-encased-and–filled tubular members increases Load carrying capacity, Energy Dissipation capacity of the members and Fatigue Resistance of the members. On usage of SMAs, the residual strain in the joints has been reduced. The addition of fibers helps in plastic deformations. Providing additional diagonal bars prevented cracks at the edges of joint interface between column and beam. spiral reinforcements reduces deformation and increases the stiffness.

8. SCOPE OF FUTURE WORK:

a. Experimental investigation shall be carried out study the influence of an innovative reinforcement pattern on the seismic performance of the Beam-column joints under cyclic loading

b. A software model shall be developed to study the role of the different reinforcement patterns in enhancement of the behavior of beam-coulmn joints

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