Effect of Fibers and Detailing in Beam Column Joint Under Reverse Cyclic Loading

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Abstract - *Strength and ductility of structures depend mainly on proper detailing of the reinforcement in beam-column joints. The flow of forces within a beam-column joint may be interrupted if the shear strength of the joint is not adequately provided. Beam-column joints in a multistory reinforced concrete framed structure take an important role in the structural integrity of the building. Pertaining to these areas, a high percentage of transverse hoops in the core of joints are much needed to meet the requirement of strength, stiffness and ductility. A provision of high percentage of transverse hoops is certainly cause congestion of steel which results in construction difficulties. The usage of fiber reinforced concrete in beam-column joints can be an alternative solution for minimizing the congestion of transverse reinforcement. Main objective of this study is to identify the potential of fiber reinforced concrete (FRC) and as a ductile material which can be used for the construction of beam-column joints. The fiber content is varied by 0.5%, 1% and 1.5%. Different reinforcement detailing are also analyzed. Analytical study is performed using ANSYS 16.1 software. The specimens were subjected to reverse cyclic loading. Properties such as load carrying capacity, energy absorption capacity, energy dissipation capacity, stiffness degradation and joint shear strength are compared.*

Key Words: **Beam-column joints, Steel fibres, Reverse cyclic loading.**

1. INTRODUCTION

In RC buildings, portions of columns that are common to beams at their intersections are called beam column joints. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. As repairing damaged joints is difficult, and so damage must be avoided. Thus, beam-column joints must be designed to resist earthquake effects. Beam column joint is an important component of a reinforced concrete moment resisting frame and should be designed and detailed properly, especially when the frame is subjected to earthquake loading.

Beam-column joints in a multistory reinforced concrete framed structure take an important role in the structural integrity of the building. Pertaining to these areas, a high percentage of transverse hoops in the core of joints are much needed to meet the requirement of strength, stiffness and ductility. A provision of high percentage of transverse hoops is certainly cause congestion of steel which results in construction difficulties. The behavior of reinforced concrete which resists framed structures in recent earthquakes all over the world has alerts poor performance of beam column joints. Simple beam-column joints become less efficient structurally as a result of strong wind, earthquake, or explosion. Fiber Reinforced Concrete has potential application in building frames due to its high seismic energy absorption capability and relatively simple construction technique.

1.1 STEEL FIBER

Fiber is a small piece of reinforcing material possessing certain characteristics 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. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers. Within these different fibers that character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation and densities. Fiber-reinforcement is mainly used in shotcrete, but can also be used in normal concrete.

Concrete reinforced with steel fibers is less expensive than hand-tied rebar, while still increasing the tensile strength many times. Shape, dimension and length of fiber are important. Steel fibers are usually used in concrete to increase ductility and control cracking due to plastic shrinkage and to drying shrinkage. They also improve impact resistance, durability, energy absorption capacity and ductility of concrete.

1.2 ADVANTAGES OF FIBER REINFORCED CONCRETE

Fibers are usually used in concrete to control plastic shrinkage cracking and drying shrinkage cracking. They also lower the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion and shatter resistance in concrete. It increases the tensile strength of the concrete. It reduce the air voids and water voids the inherent porosity of gel. It increases the durability of the concrete. Fibers such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibers have a significant influence on the creep performance of rebars/tendons. Reinforced concrete itself is a composite material, where the reinforcement acts as the strengthening fiber and the concrete as the matrix. It is therefore imperative that the behavior under thermal stresses for the two materials be similar so that the differential deformations of concrete and the reinforcement are minimized. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

2. MODELING

Three different types of reinforcements are used in the analysis, namely convention, ductile and diagonally confined beam-column joint. All joints have both the column and the beam with an equal cross section of 150 mm x 200 mm while the overall column length is 1500 mm. Beam portion length was 1000 mm.

2.1 CONVENTIONAL BEAM-COLUMN JOINT

Reinforcement detailing of this specimen is designed as per (IS:456). The reinforcement pattern is shown in Fig 2.1.

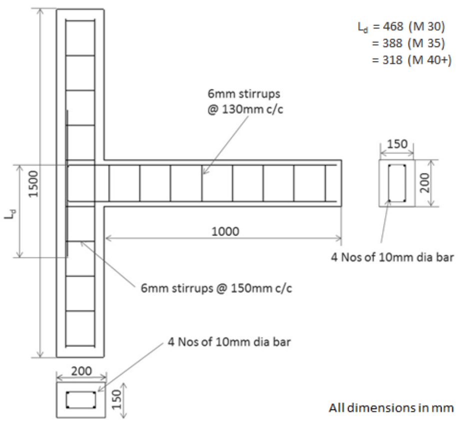

Fig -2.1: Conventional beam-column joint detailing

Four numbers of 10-mm diameter rods were used for the column main reinforcement. Four numbers of 10-mm diameter rods were used for the main reinforcement in the beam. Bars of diameter 6 mm with the spacing of 150 mm center to center are used as lateral ties in the column. Vertical stirrups of 6 mm diameter bar at 130 mm center to center were used in the beam. The development length L_d is provided according to codal provision of IS:456.

2.2 DUCTILE BEAM-COLUMN JOINT

Reinforcement detailing of this specimen is designed as per (IS:456 and I.S: 13920-1993). The reinforcement pattern is shown in Fig. 2.2

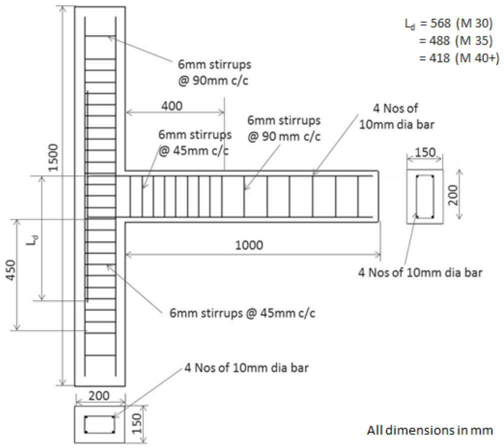

Fig -2.2: Ductile beam-column joint detailing

Main reinforcement is same as that used in conventional joint. Steel bars of 6 mm diameter with the spacing of 45 mm center to center are used as lateral ties in the column up to 400mm distance from the joint. For length after 450mm, 90mm center to center spacing is provided. Vertical stirrups of 6 mm diameter bar at 45 mm center to center were used in the beam up to 400mm distance from the joint. For length after 400mm, 90mm center to center spacing is provided.

2.3 DIAGONALLY CONFINED BEAM-COLUMN JOINT

Reinforcement detailing of this specimen is designed as per (IS:456).. The reinforcement pattern is shown in Fig. 2.3

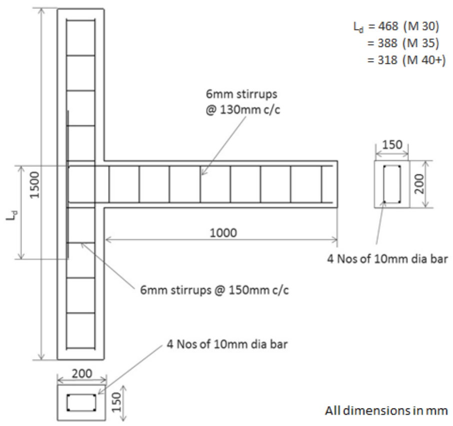

Fig -2.3: Diagonally confined beam-column joint detailing

The detailing for diagonally confined joint is same as that of the convention joint. An addition diagonal confinement is provided at the joint region.

2.4 GRADE OF THE CONCRETE

4 types of mixes are used in the analysis, namely M35, M65, and M85 and are denoted as M1, M2 and M3 respectively.

2.4 FIBER CONTENT

Hooked end steel fibers with aspect ratio 55 are added in different ratios 0.5%, 1% and 1.5% to find its effect on the beam-column joint.

2.6 SPECIMEN DESIGNATION FOR MODELS

Specimen designation used for models are given in Table 2.1

Table -2.1: Sample Table format

Designation	Detailing	Fiber Type	Fiber %	Mix Grade
J_1M_1	Conventional	-	0	35
$J_1SF_1M_1$	Conventional	Steel(hooked)	0.5	35
$J_1SF_2M_1$	Conventional	Steel(hooked)	1	35
$J_1SF_3M_1$	Conventional	Steel(hooked)	1.5	35
J_1M_2	Conventional	-	0	65
$J_1SF_1M_2$	Conventional	Steel(hooked)	0.5	65
$J_1SF_2M_2$	Conventional	Steel(hooked)	1	65
$J_1SF_3M_2$	Conventional	Steel(hooked)	1.5	65
J_1M_3	Conventional	-	0	85
$J_1SF_1M_3$	Conventional	Steel(hooked)	0.5	85
$J_1SF_2M_3$	Conventional	Steel(hooked)	1	85
$J_1SF_3M_3$	Conventional	Steel(hooked)	1.5	85
J_2M_1	Ductile	-	0	35
J_2M_3	Ductile	-	0	65
J_3M_1	Diagonally Confined	-	0	85
J_3M_2	Diagonally confined	-	0	35
J_3M_3	Diagonally confined	-	0	65

Beam column joint were modeled in ANSYS as shown in Fig. 2.4. The meshed view after Modeling is shown in Fig. 2.5

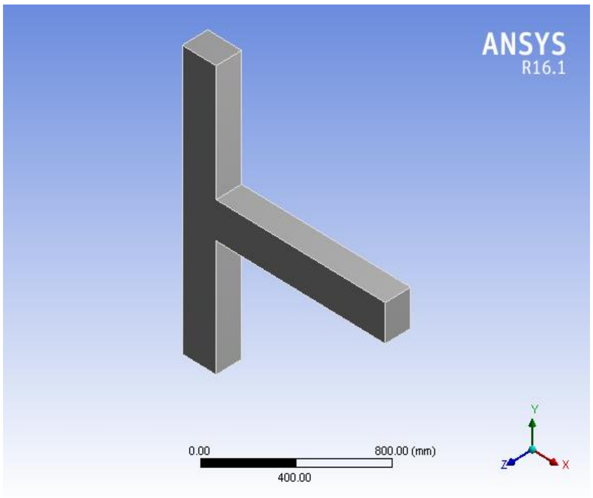

Fig -2.4: Beam column joint modeled in ANSYS

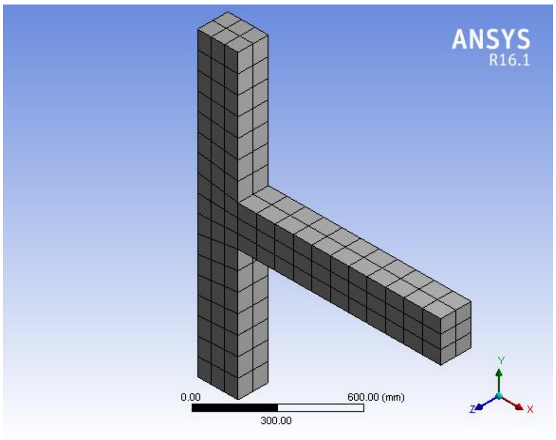

Fig -2.5: The meshed view after Modeling

3. ANALYSIS

In present study all models were subjected to reverse cyclic loading (Fig 3.1). Analysis was done using finite element program ANSYS WORKBENCH 16.1. The support of the column was kept fixed and reverse cyclic load was applied on the free end of the beam.

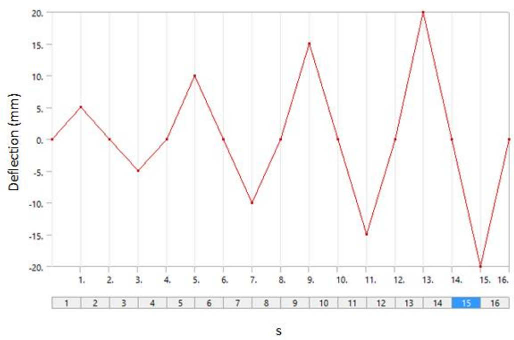

Fig. 3.1: Reverse Load cycle applied

4. RESULTS AND DISCUSSIONS

The beam-column joint was analyzed using finite element analysis in ANSYS workbench. Non-linear analysis was carried out for all the specimens.

After the analysis of the specimens, the load vs. deflection relation was plotted. Then, energy-dissipation capacity, energy-dissipation capacity, stiffness degradation and joint shear force are calculated.

4.1 LOAD DEFLECTION BEHAVIOUR

Maximum Load vs. Deflection for comparison and better representation the envelopes of the hysteresis of all the specimens were plotted in a single graph, as shown in Chart. 4.1 to Chart 4.3.

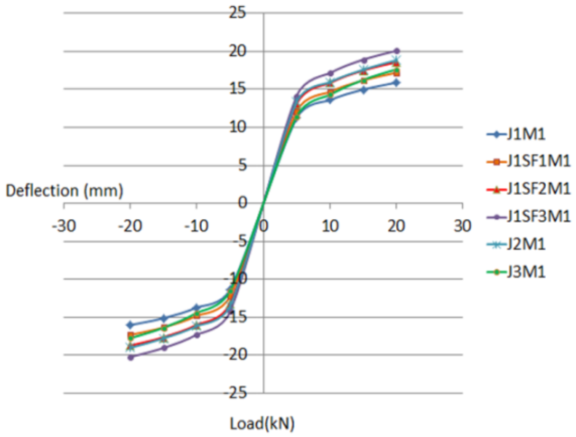

Chart -4.1: Comparison of maximum load vs. deflection for M1 mix

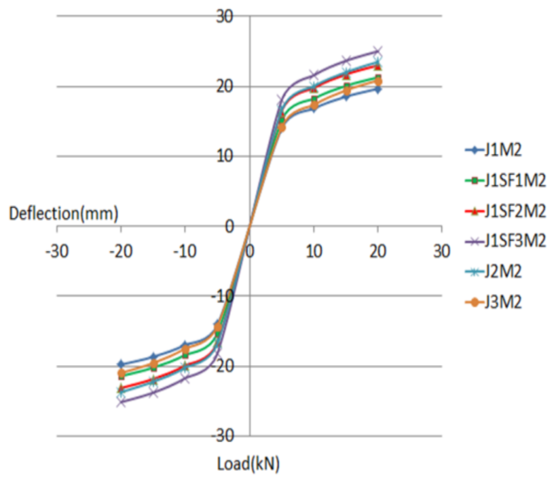

Chart -4.2: Comparison of maximum load vs. deflection for M2 mix

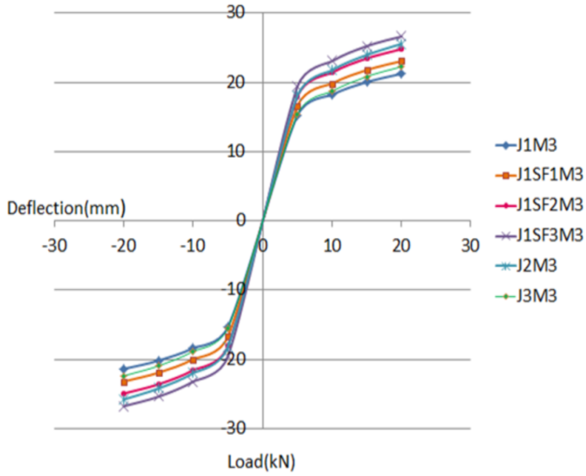

Chart -4.3: Comparison of maximum load vs. deflection for M3 mix

The load carrying capacity for ductile beam-column joint is 18-20% greater than conventional joint. Load carrying capacity for beam-column joint with 1.5% steel fiber increased 25%-27% than conventional joint and 3.7%-6.3% than the ductile joint. Load carrying capacity for beam-column joint with 1.5% steel fiber increased 3.7%-6.3% than ductile joint. Load carrying capacity for diagonal confined beam-column joint increased 4.6-10.8% higher than the conventional joint.

4.2 ENERGY DISSIPATION CAPACITY

It is an important indicator of the seismic properties of a structure. This energy dissipation calculated is shown in Chart. 4.4 to Chart 4.6.

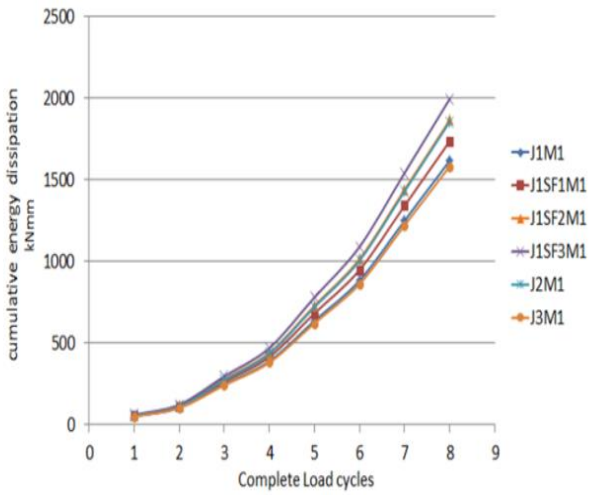

Chart -4.4: Comparison of cumulative energy dissipation for M1 mix

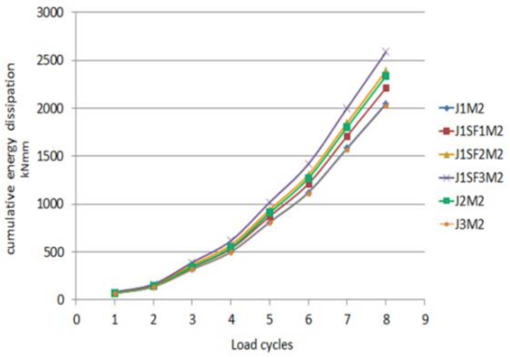

Chart -4.5: Comparison of cumulative energy dissipation for M2 mix

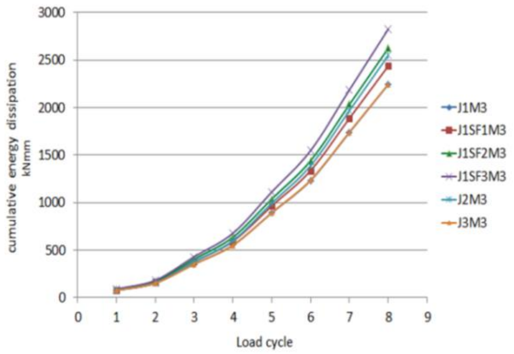

Chart -4.6: Comparison of cumulative energy dissipation for M3 mix

Cumulative Energy Dissipation for beam-column joint with 1.5% steel fiber increased 23-26% than conventional joint and 7.5-10.8% than ductile joint. Cumulative Energy Dissipation for diagonal confinement increases at a slow rate with grade increase.

4.3 ENERGY ABSORPTION CAPACITY

The area under the load deflection curve indicates the energy absorption capacity. Energy absorption capacity comparison is shown Table 4.1

Table 4.1 Energy absorption capacity comparison

Designation of specimen	**Energy Absorption capacity (kNmm)**	
	Forward cycle	**Reverse cycle**
J_1M_1	238.74	240.82
J_2M_1	281.42	284.49
J_3M_1	254.03	255.93
$J_1SF_1M_1$	257.83	259.98
$J_1SF_2M_1$	278.69	280.84
$J_1SF_3M_1$	301.27	303.49
J_1M_2	295.585	297.94
J_2M_2	351.635	355.31
J_3M_2	306.68	308.86
$J_1SF_1M_2$	320.44	322.93
$J_1SF_2M_2$	346.91	349.45
$J_1SF_3M_2$	378.57	381.25
J_1M_3	320.19	322.72
J_2M_3	382.43	386.38
J_3M_3	332.36	329.99
$J_1SF_1M_3$	348.38	351.05
$J_1SF_2M_3$	375.74	378.47
$J_1SF_3M_3$	404.77	407.66

Energy absorption for beam-column joint with 1.5% steel fiber increased 26-28% than conventional joint and 6.1-7.7% than the ductile joint. Energy absorption for diagonal confinement is 2.2-6.2% higher than conventional joint.

4.4 STIFFNESS DEGRADATION

Application of cyclic or repeated loading on the RCC beam–column joint causes reduction in the stiffness of the joint. The stiffness degradation is shown in Fig. 4.7 to Fig 4.9.

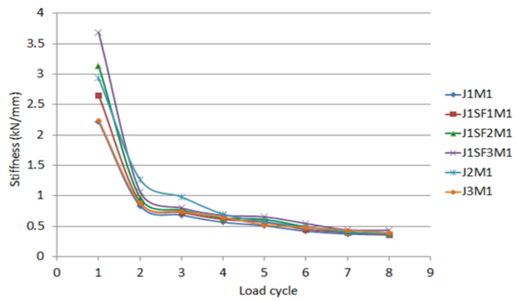

Chart -4.7: Comparison of stiffness degradation for M1 mix

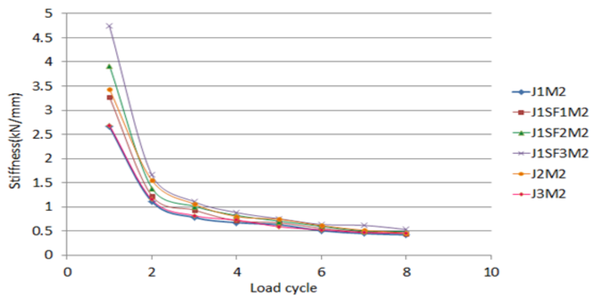

Chart -4.8: Comparison of stiffness degradation for M2 mix

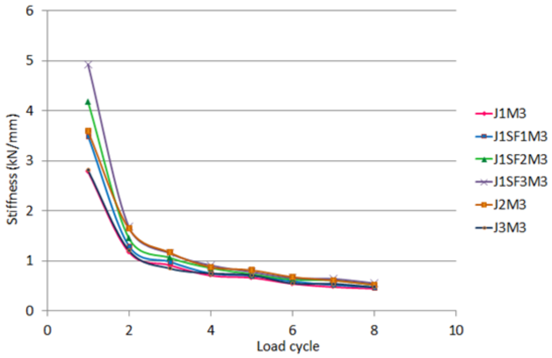

Chart -4.9: Comparison of stiffness degradation for M3 mix

Initial Stiffness for ductile joint is 32-29% higher than conventional joint. Initial Stiffness for beam-column joint with 1.5% steel fiber increased 65.9-77% than conventional joint and 25.6-38% higher than ductile joint. Initial Stiffness for diagonal confinement is 0.9-1.2% higher than conventional joint.

4.2 JOINT SHEAR FORCE

Joint shear force acting on the beam column joint decreases as the fiber content in the mix increases. The comparison of joint shear forces of fibers is given below as shown in Chart. 4.10

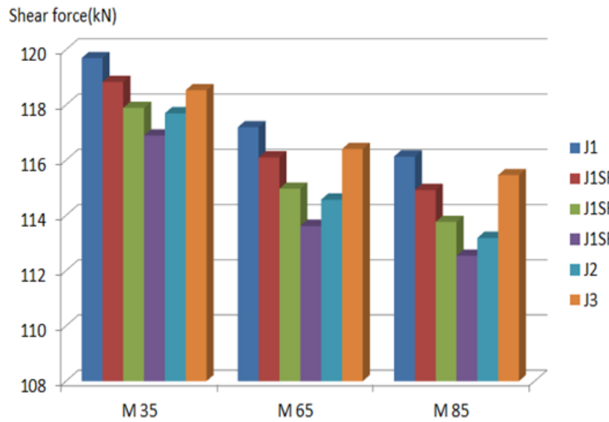

Chart -4.10: Joint shear force comparison for steel fibers

Shear force acting on ductile joint is 1.6-2.5% less than the conventional joint. Shear force acting on beam-column joint with 1.5% steel fiber decreased 2-3% than conventional joint and 0.57-0.82% than ductile joint. Shear force acting on diagonal confinement is 0.5-0.96% less than the conventional joint.

5. CONCLUSIONS

After comparing the results, it is concluded that, with the addition of steel fiber, seismic force resisting properties of the beam-column joint increases. Joints with 1.5% steel fiber and 1% steel fiber can be used to replace the ductile joint. This allows in eliminating the congestion in the ductile joint by replacing ductile steel fiber reinforced joint. Diagonally confined joint has higher seismic resistance than conventional joint but cannot replace the ductile joint in terms of seismic resistance.

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