Short Review on Reinforced Concrete Beam - Column Joint: Earthquake Response and Rehabilitation Techniques

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Abstract. It is highly recognized throughout the entire literature that there are many serious attempts to investigate the structural behavior of Reinforced concrete (RC) beam column joint. These studies tried to cover many key elements that usually govern the intended behavior of such structural element. It can be also from any simple survey during that literature that the reported failures in the past confirm the fact that the used design methods did not play the required role in providing good safe design. The most classic trend in strengthening the reinforced concrete joints was the addition of transversal bars. However, there are agreements throughout the recent contributions that increasing the level of reinforcement illustrated and optimum value and the extra addition may give negative results. In contrast, many alternative rehabilitation techniques were examined in the past such as Slurry Infiltrated Fiber Reinforced Concrete (SIFCON) blocks and Fiber Reinforced Polymer (FRP) sheets which gave good results regarding mechanical strength, stiffness and ductility behavior. The current study tries to present an overview with respect to past research programs that deals with such concern of science.

Keywords: Beam Column Joints, Shear reinforcement , SIFCON , steel Fiber Reinforcement

1. Introduction

Grossly, it is known from the current practice that many big cities buildings now days need to be rehabilitated to be ready for any unexpected load limits that such buildings may subjected to earthquakes. This need is dictated by the expected errors in construction, low level of maintenance, adequate design limits and the possible change in the use nature. In this way, there is a continuous need to propose / upgrade new procedures to attain the common trends that used recently.

The common techniques that recently proved a good improvement role were the steel jacketing method, removal and casting, concrete jacketing and FRP wrapping. The problem behind the use of traditional concrete within the field of construction is the brittleness and the relevant loss in tensile resistance and cracking formation. However, the scientific field had witnessed considerable attempts to overcome the post cracking behavior lack in performance by proposing the addition of steel fibers which proved good enhancement role. Such addition have many sacksful effects in increasing the energy absorption and ductility behavior.

A special type of fiber reinforced concrete is the slurry infiltrated fiber concrete (SIFCON). It can be defined as a type of self -compacted concrete with high strength of material’s performance with...
volume fraction of fibers (5-20) percent. This type of concrete is usually distinguished by the high amount of steel fibers and can give good performance regarding ultimate capacity and ductility behavior. The production of this concrete includes the infiltration of cement slurry inside the pre-established steel fibers to get a homogenous matrix able to withstand mechanical loads. However, the good structural potential of this concrete motivates the research fields to develop its related key elements.

2. The ACI requirements for beam and column connections

- Relatively resistant to permeability and leakage
- Able to absorb the deformation caused by the movement of the joint members
- Has a holding capacity between the column and the beam, to prevent rupture
- Restore the properties and original shape after the periodic deformations
- Do not relent to unacceptable symmetry on high Service temperatures
- It does not stiffen or become unacceptably brittle at low Service temperatures
- It is not adversely affected by aging, prevailing weather factors, or other aspects of service life in the temperature range and others environmental conditions.
- Be replaceable at the end of a reasonable service life
- The spacing between joints is more rational and more consistent for expansion and contraction joint

[1]

3. Force Transmission and The Relevant Cracks Formation

The recent studies have included the matter of force transmission and the consequent possible cracks formation [2]. Figure (1.a) shows beam column joint core that assumed to be subjected to earthquakes loads and a plastic hinge was developed.

The tension forced during the current assumption are denoted as T, T’ and T” while C_s, C_s’, C_s” are the compression forces. Fig(2) mention joint damage, Fig(3) refers to plastic hinge in frames.

![Figure 1](image)

Figure 1. (a) Force acting in the joint core [3] (b) crack development in the joint core [3] (c) Concrete strut mechanism (d)
Figure (2): The expected modes of failure in joint zone [4]

Figure (3): Plastic hinge in frame of structure [5]
3.1 Truss Mechanism

In addition to the above assumptions, the boundary shear forces are the beam shear \( V_b \) and column shear which are denoted as \( V_{col} \) and \( V'_{col} \). So, the total force of shear \( (V_{jh}) \):

\[
V_{jh} = T - V_{col} \quad (1)
\]

Excessive diagonal tensile stresses in the concrete core are commonly caused by such identical vertical joint shear forces, resulting in diagonal strain cracks as seen in Figure (1 b). The joint core's diagonally cracked concrete can effectively pass diagonal compressive forces, which are roughly parallel to the cracks while Bond stresses and as well as “bearing stresses” usually deliver the stresses from beam and column reinforcement to the core of joint including anchorage mechanism of the beam upper bars as shown in Figures (1 b) and (1 c).

More precisely, “strut mechanism” can be introduced when the diagonal strut force \( Dc \) can be an equivalent to the existing compressive components of the defined forced within its direction and no need to include the components of shear rebar of joint as shown in Figure (1 d). at the same context, \( Ds_i \) can be introduced as the compressive diagonally aligned components whereas the horizontal component \( Ti \) is the tension one which intended to carried out by rebar. However, such description is also known as “truss mechanism”. It is important to state that high levels of steel strains are expected to be reported in this approach due to the extensive path of tension forces.

3.2 Transvers Joint Rebar of Shear

Broadly, most the proposed details that practiced to resist earthquake in reinforced concrete joints including the addition of extra amounts of transversal reinforcement. Many design codes and specifications proposed such detailing throughout the literature (GB 50010 2010 [6], ACI 318-11 [7], NZS 3101 2006 [8], EC8 2003 [9])

Figure 4. Typical Layout of transversal joint Shear Reinforcement [2,10]
Due to above, the recent contributions dealt the matter of transverse reinforcement seriously, however, in the earliest contributions, most of the research programs included examining the role of transversal rebar as declared by Park and Paulay (1981) [10] and shown in Figure (4 a). However, during the results of that research, it is proved that the added transversal rebar may not be adequate according to ACI 318-71 and no dependence can be obtained for the cracked joint to resist shear if the member was subjected to cyclic load.

Some additional studies conducted by Paulay and Scarpas [2] had taken the role of transversal rebar numbers as illustrated in Figure (4 b). However, such study established half the amount recommended by DZ3101 2nd Draft New Zealand Standard. The results of that study that the added reinforcement is adequate in enhancing the deflection response.

Some studies like Kaung and Wong [11] to investigate the role stirrups ratio and the ultimate moment capacity of the beam and the results showed that the added stirrups proved good enhancement with respect to seismic behavior and ultimate shear capacity. However, that study recommended that the maximum level of shear rebar against low to moderate seismic load should not exceed 0.4%.

It is highly recognized that the proposed design codes / specifications had introduced different trends in design and detailing. In this way, some of recent contributions included such comparison like Sasmal [12] which compare the Eurocode and Indian Standard. However it is stated that the Indian standards illustrated low transversal shear rebar ratio but accompanied with high moment capacity.

Another research efforts were devoted to investigate the role of the amount of shear rebar in reinforced concrete joints but including the different levels of axil load of columns as indicated by Masi [13]. The experimental results of that studied revealed clearly the role of axial load in damage propagation and collapsing modes in reinforced concrete joints. It is observed that when the axial load low levels may cause low shear strength and a consequent diagonal cracking which interpreted by the relevant loss in bond. However, a study that done by Asthiani [14] proved the same fact in high strength self compacted concrete specimens.
4. Slurry Infiltrated Fiber Concrete “SIFCON”

3.1 Unit Weigh of SIFCON

Actually, the heavy content of steel fibers within SIFCON dictates that it unit weight is higher than normal and other fibrous concrete. It is reported that increasing the steel fiber amount from 5% to 20% increases the consequent density of slurry from 12.5% to 63%. However, the relation between the fiber content and the relevant density is almost linear [15].

4.2 SIFCON Design Principles

The production of SIFCON can be made by any type of the available steel fibers and additional strength can also gained by incorporating high strength mortar. It also known that some admixtures can be used in addition to the existing cement and the common representative term is “water-cement plus admixtures” in addition to “admixtures to cement”. All that parameters can be considered as the basic variables of the SIFCON relevant strength.
4.3 Behavior of Exterior Beam Column Joints using SIFCON

A comparison study done by Thamilselvi [16] compared the structural behavior of traditional, SIFCON and fibrous reinforced concrete joints subjected to lateral cyclic loads. During that study, it is reported that the cracks width was highly reduced in SIFCON specimens. In addition, the SIFCON specimens illustrated the optimum results with respect to ultimate load capacity.

5. FRP Reinforced concrete beam joint

Costas [17] conducted an experimental research program for exterior shear - critical RC joints that already strengthened by fiber reinforced polymer (FRP) subjected to seismic load. Throughout that study, the structural response were characterized by the load – deflection curves. The results of that study showed the importance of the mechanical anchorages in inhibiting the expected defocusing. The specimens and the flowed strengthening fashions are shown in Figure (6).

![Figure (6) Specimens and strengthening fashions of Costas [17]](image)

Nassereddine [18] conducted an experimental program to investigate the role of different FRP materials in the structural response of rehabolitated reinforced concrete joints subjected to reversed cyclic loads accompanied with axil column loads. The included FRP materials were glass fiber reinforced polymer “GFRP”, carbon fiber reinforced polymer “CFRP” as well as hybrid type of them as shown in Figure (7). The results of that study showed that the GFRP and CFRP improves the structural response with somewhat convergence while the hybrid form improves the ductility by to a serious concern.
Figure 7. Specimens and strengthening fashions of Nassereddine [18]

6. Ductility Behaviour of External steel fiber Beam Column Joint
It was highly noticed throughout the recent reconnaissance that the reinforced concrete old joints are illustrated high level of structural response with respect to seismicity. Since the structural integrity of the reinforced concrete building systems are highly dependent upon such elements, it should be ensured that such elements should have good mechanical properties. For doing this action, it is common to increase the percent’s of transversal hoops accompanied with using self-compacted concrete to overcome the jam shortcoming.

Comingstarful and Shembiang [19] conducted and experimental program to investigate the structural behavior of joints made of reinforced concrete included steel fibers and 0.5 % hand cut Polyethylene terephthalate (PET) under cyclic load. The results of that study illustrated that the presence of such material enhances the ultimate load capacity, stiffness, damage tolerance as well as the absorbed energy.

7. Conclusion
Combining many styles of strengthening techniques can not produce the desired results. Four distinct strengthening applications were investigated in this review. The findings suggest that although local structural techniques do not increase capacity, they may increase ductility. Depending on the previous researcher the following conclusions can be pointed:

1. The cracking behavior may be enhanced seriously with the presence of steel fibers within reinforced concrete joints due to the post cracking behavior.
2. The ductility and energy dissipation behavior of SIFCON core joints are higher than of fibrous concrete joints.
3. SIFCON beam column joints illustrate lower damage tolerance than reinforced concrete joints.
4. Flexible sheets are more efficient than strips for the same reinforcement area fraction.
5. The number of FRP layers increases both the intensity and the amount of energy dissipated.
6. Strips and sheets are more efficient when mechanical anchorages are used.
7. The use of transverse layers to wrap longitudinal FRP sheets proved to be a highly effective anchorage method.
8. Glass fiber sheets outperformed carbon fiber sheets by a small margin.
9. The RC beam-column joint demonstrated brittle shear failure due to insufficient anchorage of steel bars in the bottom part of the beam.
10. For repairs on RC beam-column joints, the effectiveness of a GFRP composite reinforcement on an external joint was verified.
11. The addition of steel fibers to the SCC improved the strength and ductility of the joints.

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