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Study of Behavior & Strengthening of Beam-Column Joint

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***Abstract*—** The beam column joint is the crucial zone in a reinforced concrete moment resisting frame. It is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. One of the most important factors affecting the successful strengthening technique of structures is the selection of the strengthening material. The need to lower the cost of maintenance, repair and strengthening techniques, while extending the service life of the structures, has resulted in new systems, processes, or products to save money and time. The objective of this paper is to study and gathering information about the beam-column joint, its structural behavior under seismic conditions, forces acting, types, factors those influences the designing criteria, bond and transverse reinforcement requirements and effective rehabilitation schemes for reinforced concrete beam-column joints thus providing a contribution to a more reliable evaluation of the seismic vulnerability of Reinforced Concrete buildings. Different fiber-wrap rehabilitation schemes are apply to the joint panel with the objective of upgrading the shear strength of the joint. In order to obtain local and global ductility, a series of structural details are required in the seismic design, generally absent or inadequate in the existing RC buildings designed without seismic rules. A reliable evaluation of the seismic performance is particularly needed on these buildings, as a fundamental tool in order to select type, technique, extent and urgency of the strengthening intervention. Many are the factors influencing the structural performances of RC buildings, among them an important role is carried on by the ultimate capacity of the beam-column joints. Some authors performed experimental investigations both on reduced and real scale beam-column sub assemblages to better understand their behavior, also for the development and calibration of software models to be used in non-linear analysis of framed RC structures.

Keywords- *Beam column joint; seismic behavior ;beam column joint rehabilitation; ground shaking*

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I. INTRODUCTION

The beam–column joint is considered as the most critical zone in a reinforced concrete moment resisting frame. It is subjected to large forces during earthquake excitation and its behavior has a significant influence on the response of the entire structure. As a result, a great attention has to be paid for good detailing of such joint. The absence of transverse reinforcement in the joint, insufficient development length for the beam reinforcement and the inadequately spliced reinforcement for the column just above the joint can be considered as the most important causes for the failure of the beam–column joint under any unexpected transverse loading on the building. The recent earthquakes revealed the importance of the design of reinforced concrete (RC) structures with ductile behavior. Ductility can be described as the ability of reinforced concrete cross sections, elements and structures to absorb the large energy released during earthquakes without losing their strength under large amplitude and reversible deformations.

Generally, the beam-column joints of a RC frame structure subjected to cyclic loads such as earthquakes experience large internal forces. Consequently, the ductile behavior of RC structures dominantly depends on the reinforcement detailing of the beam-column joints.

The observation of the damage caused by strong earthquakes has highlighted the typical collapse mechanisms affecting Reinforced Concrete (RC) buildings designed for gravity loads only, such as formation of plastic hinges on columns driving to soft storey, shear failure in beams, bar slip, and shear failure of beam-column joints. The assumption of joint being rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions. Shear failure of beam-column joints is identified as the principal cause of collapse of many moment-resisting frame buildings during recent earthquakes. Effective and economical rehabilitation techniques for the upgrade of the joint shear-resistance capacity in existing structures are needed.

In the analysis of reinforced concrete moment resisting frames the joints are generally assumed as rigid. There have been many catastrophic failures reported in the past earthquakes, in particular with Turkey and Taiwan earthquakes occurred in 1999, which have been attributed to beam-column joints. The poor design practice of beam column joints is compounded by the high demand imposed by the adjoining flexural members (beams and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. Since past three decades extensive research has been carried out on studying the behavior of joints under seismic conditions through experimental and analytical studies. Various international codes of practices have been undergoing periodic revisions to incorporate the research findings into practice. The paper is aimed at making designers aware of the theoretical background on the design of beam column joints highlighting important parameters affecting seismic behavior of joints.

Numerous investigations have been reported about the behaviour and reinforcement detailing of beam-column joints under reverse cyclic loading. In these researches, factors affecting the behaviour of RC beam-column joints were studied. In brief, the results of these investigations showed that the shear strength and ductility of RC beam-column joints increased as the compressive strength of concrete and the amount of transverse reinforcement increased. Moreover, for adequate ductility of beam-column joints, the use of closely spaced hoops as transverse reinforcement was recommended in various earthquake codes for RC structures. Previous experimental investigations have identified the steel fiber reinforced concrete as having a potential solution. By introducing the steel fibers as secondary reinforcement in the beam column joints, ductility can be achieved at a lower cost and the fibrous concept can offer saving in material and labour costs.

II. OBJECTIVES

The objective of the paper is to review and discuss the well postulated theories of joints in reinforced concrete moment resisting frames.

III. THEOROTICAL CONTENTS

A. *Beam Column Joint*

In RCC buildings the portion of column that are common to the beam at their intersection are called beam-column joints. The constituent materials of joints have limited force carrying capacity and limited strength. When the forces that applied during earthquake are larger than the resisting capacity of joints, joints are severely damaged. Beam-Column joints are the weakest link in RC moment resisting frame. The prime reason behind it failure is the inadequate shear strength of the joints, and this is occurred due to the insufficient and inadequate detailed reinforcement in the joint region. Damage must be avoided by using different techniques during construction stages because repairing of damaged joints is very difficult after it appears. Generally in earthquake resisting frame the column should be stronger then beam.

B. *Types of beam column Joints*

In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint (Fig.1). 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.

1. *Interior joint :*

In an interior joint, the force in a bar passing continuously through the joint changes from compression to tension. This causes a push-pull effect which imposes severe demand on bond strength and necessitates adequate development length within the joint. The development length has to satisfy the requirements for compression and for tension forces in the same bar. Insufficient development length and the spread of splitting cracks into the joint core may result in slippage of bars in the joint. Slippage of bar occurs when the limiting bond stress is exceeded within the available development length. In the case of interior joints, the column depth is the available development length for the straight longitudinal bars passing through the joint. Hence, for a given limiting bond stress, the ratio of development length to the bar diameter becomes a constant value.

2. *Exterior Joint*

In exterior joints the beam longitudinal reinforcement that frames into the column terminates within the joint core. After a few cycles of inelastic loading, the bond deterioration initiated at the column face due to yield penetration and splitting cracks, progresses towards the joint core. Repeated loading will aggravate the situation and a complete loss of bond up to the beginning of the bent portion of the bar may take place. The longitudinal reinforcement bar, if terminating straight, will get pulled out due to progressive loss of bond. The pull out failure of the longitudinal bars of the beam results in complete loss of flexural strength. This kind of failure is unacceptable at any stage. Hence, proper anchorage of the beam longitudinal reinforcement bars in the joint core is of utmost importance.

3. *Corner Joint*

In a corner joint with column continuing above and in knee type joints, the bond requirements of longitudinal bars of beams will be similar to that in an exterior joint though there are no specific code requirements related to bond for knee joints. However, the performance of these joints is significantly influenced by shear diagonal cracks.

C. *Behavior of Beam Column Joint During Earthquake*

During earthquake shaking, the beams adjoining a joint are subjected to moments in the same direction either in clockwise or anti-clockwise. Under these moments, the top bars in the beam-column joints are pulled in one direction and the bottom one in the opposite direction. These forces are balanced by bond stress developed between concrete and steel in the joint region. If the column is not wide enough or if the strength of the concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such condition the bar slips inside the joint region and beam lose their capacity to carry load. Under these pull and push forces at top and bottom ends joints undergo geometric distortion, one diagonal length of the joint elongate and the other compresses and if the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks. These pull-push forces on joint cause two problems i.e. Loss of grip on beam bars in joint region and distortion of joints causing diagonal cracks and crushing of concrete.

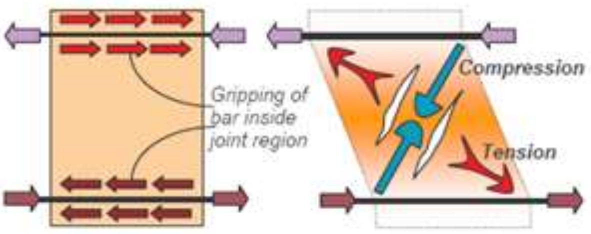

Fig.1

D. Forces acting on Beam Column Joint

The pattern of forces acting on a joint depends upon the configuration of the joint and the type of loads acting on it. The effects of loads on the three types of joints are discussed with reference to stresses and the associated crack patterns developed in them. The tension and compression from the beam ends and axial loads from the columns can be transmitted directly through the joint. In the case of lateral (or seismic) loading, the equilibrating forces from beams and columns, develop diagonal tensile and compressive stresses within the joint. Concrete being weak in tension, transverse reinforcements are provided in such a way that they cross the plane of failure to resist the diagonal tensile forces. The shear force in the joint gives rise to diagonal cracks thus requiring reinforcement of the joint.

E. Bond requirements

The flexural forces from the beams and columns cause tension or compression forces in the longitudinal reinforcements passing through the joint. During plastic hinge formation, relatively large tensile forces are transferred through bond. When the longitudinal bars at the joint face are stressed beyond yield splitting cracks are initiated along the bar at the joint face which is referred to as 'yield penetration'. Adequate development length for the longitudinal bar is to be ensured within the joint taking yield penetration into consideration. Therefore, the bond requirement has a direct implication on the sizes of the beams and columns framing into the joint.

F. Shear requirements of joint

The external forces acting on the face of the joint develop high shear stresses within the joint. The shear stresses give rise to diagonal stresses causing diagonal cracks when tensile stresses exceed the tensile strength of concrete. Extensive cracking occur within the joint under load reversals, affecting its strength and stiffness and hence the joint becomes flexible enough to undergo substantial shear deformation (distortion). Before discussing the shear behavior in detail, it is imperative to arrive at the shear force demand on joints. The determination of shear force in the vertical and horizontal direction is usually essential. However, since well established code procedures aim at the beam hinging mechanism, it is generally sufficient to discuss the shear force demand in the horizontal direction only.

G. Performance Criteria

The moment resisting frame is expected to obtain ductility and energy dissipating capacity from flexural yield mechanism at the plastic hinges. Beam-column joint behavior is controlled by bond and shear failure mechanisms, which are weak sources for energy dissipation. The performance criteria for joints under seismic actions may be summarized as follows:

- The joint should have sufficient strength to enable the maximum capacities to be mobilized in the adjoining flexural members.
- The degradation of joints should be so limited such that the capacity of the column is not affected in carrying its design loads.
- The joint deformation should not result in increased storey drift.

H. Joint Mechanisms

In the strong column-weak beam design, beams are expected to form plastic hinges at their ends and develop flexural over strength beyond the design strength. The high internal forces developed at plastic hinges cause critical bond conditions in the longitudinal reinforcing bars passing through the joint and also impose high shear demand in the joint core. The joint behavior exhibits a complex interaction between bond and shear. The bond performance of the bars anchored in a joint affects the shear resisting mechanism to a significant extent.

I. Strengthening of Beam Column Joint

1. *Using Fiber Reinforced Polymer*

The fiber-reinforced polymer (FRP) systems are recently used in the field of strengthening and restoration of the buildings. The most commonly utilized fiber-reinforced polymers (FRPs) are fibers made of carbon (C) or glass (G). These materials can be designed and used in the form of laminates, rods, dry fibers (sheets) adhesively bonded to the concrete, wet lay-up sheets mounted on the surface, or near surface mounted bars or laminate strips in the concrete cover. Fiber reinforced polymer, FRP, can be used in order to replace the missing steel or compensate the low concrete strength or structural faults in design. That is because FRP in the form of plates or fabric sheet has its strength in the direction of the fibers only and can be engineered to place the strengthening in the needed direction only. It addition, it can provide an improved load carrying capacity and a higher rate of stiffness than that of un-strengthened specimens. FRP systems may have thermal expansion properties that are different from those of concrete. FRP composites have become more popular in the last two decades due to the reduction in their cost, combined with newer understanding of the versatility and benefits of the material properties.

2. *Using Carbon Fiber Reinforced Polymer*

Carbon-fiber-reinforced polymer or carbon-fiber-reinforced plastic is a very strong and light fiber-reinforced polymer which contains carbon fibers. Carbon fibres are

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created when polyacrylonitrile fibres (PAN), Pitch resins, or Rayon are carbonized (through oxidation and thermal pyrolysis) at high temperatures. It is expensive but commonly used wherever high strength and rigidity is required. The carbon fiber-reinforced polymer (CFRP) materials have a high potential for manufacturing effective strengthening systems to increase the flexural or shear strength of RC beams. The CFRP materials have a very low weight to volume ratio, are immune to corrosion, and possess high tensile strength. In the fiber direction, CFRP systems have a coefficient of thermal expansion near zero, however previous research work has indicated that the thermal expansion differences do not affect the bonding for small ranges of temperature change (+/−50 °C). Also, due to their electrical conductivity, Ghali et al. concluded that carbon based FRP materials should not come in direct contact with steel to avoid potential galvanic corrosion of steel reinforcement and, a minimum concrete cover of about 10 mm was recommended.

3. *Use of Fiber Cocktails*

Cocktail fiber consists of constant % (1.5) of steel fiber and 0 to 0.6% polypropylene fiber. This cocktail fiber reinforced concrete in the joint region has more energy absorption capacity, more stiffness and more ductility. In the research carried out by Dr.P.Perumal1**,** B. Thanukumari the properties of ultimate strength, ductility, energy dissipation capacity and joint stiffness were compared. It was determined that the cocktail fibre combinations of 1.5% of steel fibre and 0.2% of polypropylene fibre have shown the best performance considering the energy dissipation capacity and ductility factor. Research results indicate that the use of cocktail reinforced concrete leads to an increase in energy dissipating capacity, displacement capacity, stiffness and outstanding damage tolerance, which make the joints attractive for reducing the need for costly post-earthquake repairs.

J. Factors affecting bond strength

The significant parameters that influence the bond performance of the reinforcing bar are confinement, clear distance between the bars and nature of the surface of the bar. Confinement of the embedded bar is very essential to improving the bond performance in order to transfer the tensile forces. The relevant confinement is obtained from axial compression due to the column and with reinforcement that helps in arresting the splitting cracks. Joint horizontal shear reinforcement improves anchorage of beam bars. But, there is an upper bound to the beneficial effects of confinement. At this limit, maximum bond strength is attained beyond which the crushing of concrete in front of the rib portion of the deformed bar occurs. Research indicates better bond performance when the clear distance between the longitudinal bars is less than times the diameter of the bar . As expected, the deformed bars give better performance in bond. The behavior of the reinforcing bar in bond also depends on the quality of concrete around the bar.

IV. Conclusion

From this paper we studied structural behavior of beam column joint under seismic conditions, various types of forces acting, types , factors those influences the designing criteria, bond and transverse reinforcement requirements and effective rehabilitation schemes for reinforced concrete beam-column joints. Study indicate that beam column joint is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. The fibres are effective in resisting deformation, CRPF sheets are very effective in improving shear resistance and deformation capacity of the exterior and interior beam-column joints and delaying their stiffness degradation during earthquake.

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