International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

DESIGN IMPROVEMENTS OF NON-SEISMICALLY DETAILED R/C BEAM COLUMN JOINTS DURING SEISMIC TRANSFORMATION

[A study on Design essentialities of non-seismically detailed R/C joints during seismic transformation of India]

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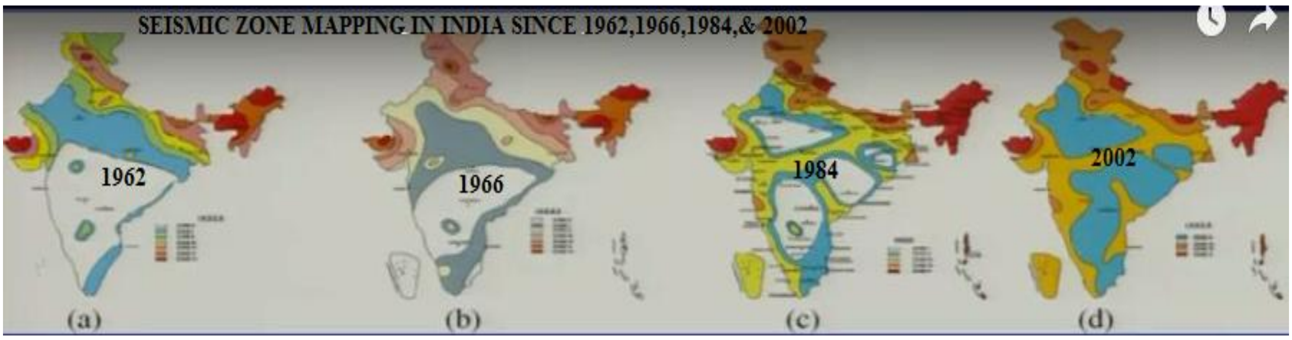
Abstract
During the current scenario, Indian subcontinent is conditioned as most active seismic region of the world. Seismicity of the country increased notably during the past few decades and transformed many geographical regions from non-seismic zones to seismic zones. In this context, the design codes are revised and upgrading seismic intensity in many parts of the country. Researchers demonstrated that the substandard and non-seismically detailed joints are explicitly responsible for most structural damages in R/C structures. A beam column joint is one such critical element that governs the integrity and performance of the structure during seismic action. But the current design codes are silent about the future aspects and design provisions of these critical elements and are unable to predict the influence of seismic transformations of the structural elements. In this context, this study is focused on design essentialities and retrofitting techniques of non engineered R/C beam column joints that may be featured under seismic action. The study also ensures bare minimum safety of non-seismically detailed R/C joints and critical components that may be influenced by future earthquakes.

Keywords: Seismic transformation, sub-standard joints, design essentialities, seismic improvements.

I. INTRODUCTION

The recent earthquake happenings in India (Assam, Gujarat, Sikkim) and Nepal demonstrated inadequate safety levels of R/C structures through poor design and construction practice. During the past few decades, seismic intensity improved in many parts of the country and results poor performance of non-engineered structures. As per the current geographical conditions more than 54% of Indian land exposed to moderate and severe earthquakes [7] .The National Disaster Management Authority (NDMA) of India, expressed serious concern about more than 38 cities of the country is vulnerable to moderate and severe earthquakes in near future. And more than 95% of existing buildings (prefabricated and cast in-situ constructions) are susceptible to moderate and severe earthquakes in their life cycle due to anticipated geological changes of earth.



In this context, the recent geographical transformation of seismic zones (changed from six to four) insists strengthening of the existing R/C structures and implementation of new design philosophy to accommodate future earthquakes. For example buildings designed in the past under gravity load conditions are now changed to lateral load conditions due to seismic transformations. Similarly strength based design philosophy under gravity conditions are changed to performance based approach under seismic conditions. These uncertainties significantly influence the load transfer mechanism of critical elements such as beam-column joints and influence beam column sub-assemblage. The seismic conditions impose nonlinear properties of joint and reduce the joint stiffness. This phenomenon is significant in load following conditions than non-following load conditions [6]. Based on seismic response of peak ground acceleration (PGA) zone II (PGA:0.10g) is considered under non-seismic conditions zone III onwards (PGA >0.10) to zone V (PGA: 0.36g) considered under seismic conditions.

The seismic transformation makes quantum jump of design philosophy (changed from non-seismic to seismic) and influencing the safety of substandard and non-seismically detailed R/C joints. The current seismic codes are unaware about these changes and silent on future design provisions in substandard joints when seismic transformation taken place. Most of damages in R/C framed structures are happened by failure of beam column joint, soft storey effect and short column failure. Apart from other failures, joint failures are critically reviewed in this paper since it significantly influencing the integrity , global performance and collapse mechanism of the R/C structure.
The current study of non-engineered joints express more susceptible seismic damages under cyclic load conditions [3]. During this conditions, the joints exhibit low ductility, stiffness shear and bond reduction, that results poor hysteresis behaviour [1]. The acceptable lateral load resistance system may provide in individual members through structural redundancy but the integrated effect of all members cannot establish unless beam column joint exhibit good strength and ductility [2]. Under moderate seismic conditions, the rigid joint assumptions may change to flexible joint conditions that result under performance and strength loss of both joint and connecting elements. Experimental studies identified that Inter storey drift of global structure significantly influenced by joint panel deformation [4]. Kaung J.S et al.,(1998) experimentally concluded that shear failure of non-seismically detailed joints occur before beam failure and suggested the provision of horizontal ties in joint will delay its failure [3]. The past studies endorsed the importance of how to implement new design philosophy and detailing aspects in non-seismically detailed joints during seismic transformations.

II. SIGNIFICANCE OF THE STUDY

The present study related to find suitable design modifications of non-seismically detailed R/C beam- column joints and its influential parameters during seismic transformation taken place. Further this study provides necessary design information and seismic mitigation of non-engineered beam column joints. This ultimately improves seismic viability of non-seismically designed R/C structures and to mitigate their failures .

III. LITERATURE REVIEW

Experimental studies of Kaung J.S et al.,(1998)[2] expressed that non-seismically detailed R/C joints are more vulnerable during seismic action. Ravi Kiran et al.,(2014)[10] observed the underperformance of beam column joints due to lack of shear reinforcement and poor construction practice. The R/C structures constructed in past are still in their service period and susceptible to seismic failures under geographic transformation taken place in India.

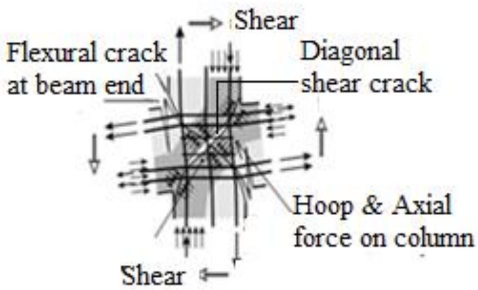
Research studies further concluded that the rigid joint assumptions of non-seismic joints are inappropriate under seismic action due to existence of stress reversal conditions. Jalil-Shafaei et al.,(2014)[13] expressed that the inelastic shear deformation in beam column joints shows significant influence on seismic response in terms of drift and damage. Sano et al., (2015) and Yamada et al, (2016) experimentally concluded that fibres could reduce the damage of joint panel system by increase shear force followed by bridging effect of fibres.

A general lack of information on experimental tests of seismic behaviour in non-engineered (designed under gravity loads) R/C framed structures and beam-column sub assembly observed in the literature review. Further studies are needed on behaviour of substandard existing structures under seismic loading conditions need to emphasize for satisfactory performance levels.[12]. Henceforth this study reveals that, there is a need to maintain minimum design essentialities of beam column joints in R/C structures when seismic transformation taken place. This is due to change in design philosophy from non-seismic conditions to seismic conditions.

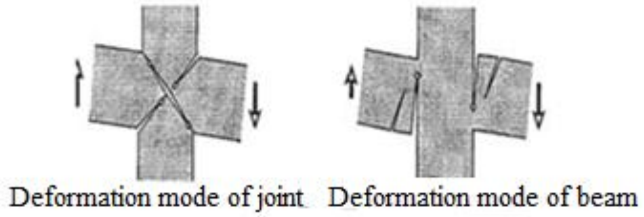
Further Indian government implemented significant measures on seismic risk assessment and its mitigation, such as establishing mapping of seismic zone based on vulnerability, micronized of urban cities, establish Tsunami warning centres etc. Hence there is a good feasibility to implement specific construction standards on non-engineered structures constructed in seismic transformed zones.

IV. INFLUENCE OF SEISMIC TRANSFORMATIONS

In India, R/C structures are categorised under low, moderate and high seismic intensity based on geography and seismic transformations taken place. During low seismic conditions, the principle structural elements are not influenced by strength and serviceability conditions. Hence the designer may proceed under elastic behaviour of structural elements. But in moderate and high seismic conditions, the elements has to show ductile performance with large inelastic deformations. In specific the critical elements such as beam column joints are subjected to inelastic deformations under dynamic loads that experience high shear and bond conditions through reverse cyclic loading conditions. In this process both and stiffness of joints are considerably reduced, that results joints are more susceptible to high shear and bond failures. Hence the design of joints are proceed under performance based design. In severe earthquake conditions, the intensity of stress developed in joint core is based on amount of base shear produced by the structure, stiffness of joint component, ductile property with connecting elements. Hence the transformations of seismic zones impart moderate and high seismic conditions on R/C structures during which joints are severely exposed to additional seismic forces in the lateral direction.

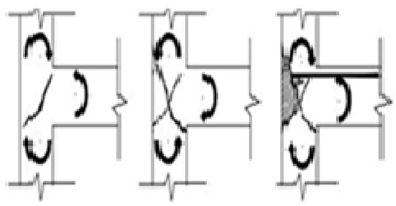


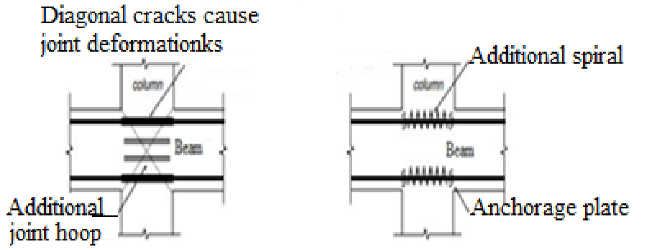
Joint failure & force transfer in Seismic Beam column joints



Ref: [Proposed by Shiohara et al-2001]
Roatation of joint & beam during seismic conditions

The non-seismically detailed joints are analysed under gravity loads with high compression stress and unbalanced moments. But the confined joint possess good flexural and axial strength and detailing aspects of joint reinforcement is not worthy unless joint deformation influenced by unbalanced moments. Hence specific geometric dimensions and reinforcement requirements are less influenced in joint design. Under this conditions the presumed rigid or partial rigid joint conditions may establish if the beam column joint possess enough anchorage length and joints are proceed under elastic conditions.
The seismic transformations induce non-linear stress conditions under which, the structural element shows inelastic behaviour (poor hysteretic performance, low energy dissipation under rigid or partial ductility). During transformation of seismic zones, it is not always possible and economical to ensure lateral load resistance system to the global structure as suggested by design codes. The joint plays an important role during transfer of seismic forces to the connecting element and for integrity of the elements. The designers may ensure safe performance of joint system and its integrity for improvement of load path and delay in collapse mechanism. During this conditions joint should exhibit medium or high ductility based on intensity of future seismic forces during seismic transformation taken place.
The degree of joint ductility is based on reinforcement detailing and redundancy of connecting joint elements. Partial ductility of joint allows moderate deformations and high ductility allows large ductile deformations before failure. The probabilistic loss model of seismic charts are helpful to estimate the average seismic intensity and return period .This type of measures useful to provide information as external measures, but the seismic vulnerability of existing buildings and deign improvements of non seismic buildings are less focused.
Retrofitting techniques and base isolation system are addressed for important structures but it is economically not viable and not suitable to adopt extensively [9].To avoid sudden failure of joint, a minimum ductility need to provide in joint irrespective of loading conditions. The phenomenon stressed about minimum shear reinforcement, detailing aspects and size requirements of beam column joints. Also the joint should ensure good fixity with connecting elements through bond and anchorage irrespective of seismic conditions.
Design codes ACI 318-2008 and I.S 1893-2016 specifically given the detailing aspects of TYPE-I (Non-seismic)and TYPE-II (Seismic) joints to ensure reliable performance and transformation of loads through joints [8]. The TYPE-I detailing based on flexural rigidity and compressive strength under gravity load static conditions, and TYPE-II joint detailing based on stiffness, shear modulus, tensile strength and flexural rigidity under lateral load reverse cyclic conditions. Both parameters influence the design requirements of joints of seismically transformed zones


Concrete wedge mechanism in Beam column joint



Detail to increase moment capacity Detailing to improve anchorage
(Ref: Hitoshi Shiohara)

V. SEISMIC VULNERABILITY OF NON-ENGINEERED JOINTS

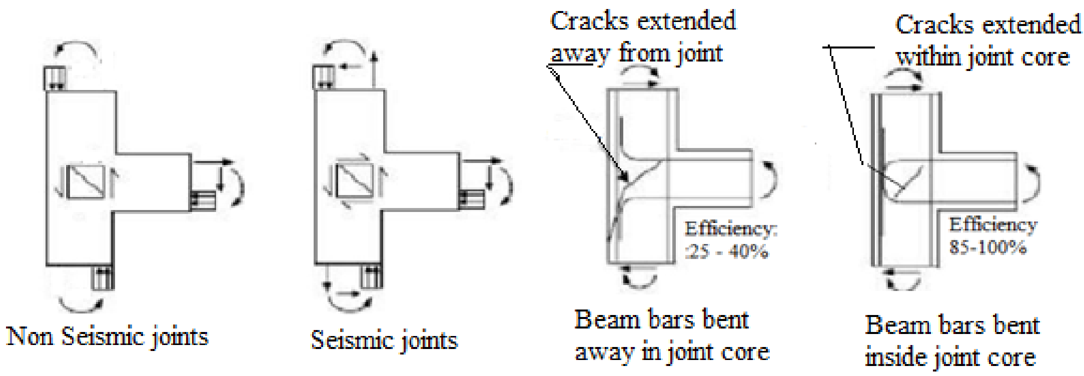
Seismic vulnerability of R/C joints influenced by damping ratio, flexural stiffness, and shear distribution in various floors .Researchers concluded that R/C frame members are more predominately resist the moderate seismic conditions when transformation of forces exist within the joint system core . But they are (TYPE-I joints) more susceptible when seismic action taken place by inelastic shear deformation. Also the influence of rigid joint assumption under seismic conditions is found to be inappropriate. During moderate seismic conditions, the elastic deformation of joint is more predominate than performance based. Under this conditions, beam-column joints must possess sufficient strength, and flexural rigidity rather than stiffness and ductility [17].The response of joint material under seismic loading conditions is a complex and multiple, which include cracks developed in concrete, crushing of confined and unconfined concrete, closing of concrete cracks under load-reversal, shearing across concrete crack surfaces, yielding of reinforcing steel and damage to bond-zone concrete. Beam column joints are severely influenced during redistribution of seismic forces within joint core. The seismic vulnerability of joints depends on joint eccentricity, cross section area, influence of external loads, distribution of shear reinforcement, and its boundary conditions. The probabilistic loss model of seismic charts helps to estimate the average seismic intensity and return period. This type of measures useful to provide information as external measures but the seismic vulnerability of existing buildings and deign improvements of non seismic buildings are less focused. However retrofitting techniques and base isolation system are addressed for important structures but it is economically not viable and not suitable to use extensively [9].

During the design of joints, both implicit and explicit conditions need to verify against seismic vulnerability. The implicit joint conditions are associated with the influence of relative strength ratios of connecting beam and column elements and related stiffness and strength loss of joint damage. The flexural strength ratio (ρ) of column and beam substantially influence the performance of joint and shear capacity. Experimental observations by Hitoshi et al., concluded that shear capacity of a joint substantially reduced (5% to 30%) when flexural strength ratio (ρ) is unity, and column to beam depth ratio (d_c/d_b) is greater than unity. Hence the current seismic provisions of R/C joints are deficient and more vulnerable than we expect [15]. Most of the implicit joint models exhibit higher shear deformations. This ultimately influence column yield conditions (non-sway or sway conditions) and contribute large shear deformation of joint panel.

(i) Parametric influence:

Parametric influence on non-seismically detailed beam column joints are characterised under externally applied loads, and internal response of joint (based on materials). The externally applied loads are due to base shear, column compression, and unbalanced flexural moments on joint. The internal response of joint is in the form of compression and tensile strength of joint, confinement of joint core, bond strength; stiffness and ductility .The dynamic action of seismic force induce high shear conditions on joint core .The shear force on joint transformed to develop principle compression and tensile stresses along major and minor planes of joint through Strut and Tie mechanism. As per research observations, most of joint failures happened due to limiting principle tensile stress of R/C joint core [10]. Due to inadequacy of transverse shear reinforcement and lack of detailing aspects, the non-seismically detailed joints are more susceptible to tensile failure.

Joint aspect ratio plays an important role for efficient force distribution within joint and sub-assemblage. During seismic action joint exhibit complex interaction between bond and shear. Formation of plastic hinge in beam imparts when longitudinal beam bars at joint face stressed beyond the yield strength. As a result splitting cracks are initiated along the reinforcement called yield penetration which reduce the stiffness and strength of joint .To avoid yield penetration, adequate anchorage of bars are necessary to transfer the tensile stresses in joint core



Force transfer & Reinforcement detailing of External Beam column joint

(ii) Failure mechanism

Joint behaviour exhibit complex interaction between bond and shear strength. The horizontal shear produced due to seismic action is four to five times larger than the column shear and located above and below the column region in joint core(Ref: Park.R& Paulay). This action produce failure mechanism that was entirely different from lateral confinement of concrete. Hence there is a need for provision of transverse reinforcement in effective column section, to provide shear resistance, confinement and to prevent premature reinforcement buckling of column bars. The pattern of forces acting on joint depends on the configuration of joint and type of loads acting on it. The bond performance of anchored beam bars significantly influence the shear resistance mechanism. The anchorage hook is responsible for the formation of the compression strut in joint core and the tail extension is necessary to prevent pull out the bars during tension forces. Non-seismically designed joints significantly influenced by limiting bond stress against slippage of longitudinal beam bars. As per the past research, it was observed that bond deterioration does not occur if development length of longitudinal bar should extended 28φ (φ:diameter of longitudinal bar). Hence minimum column depth 28φ need to provide to develop sufficient bond strength.

Non- Seismically detailed Beam-column joint by Shear & Anchorage failure

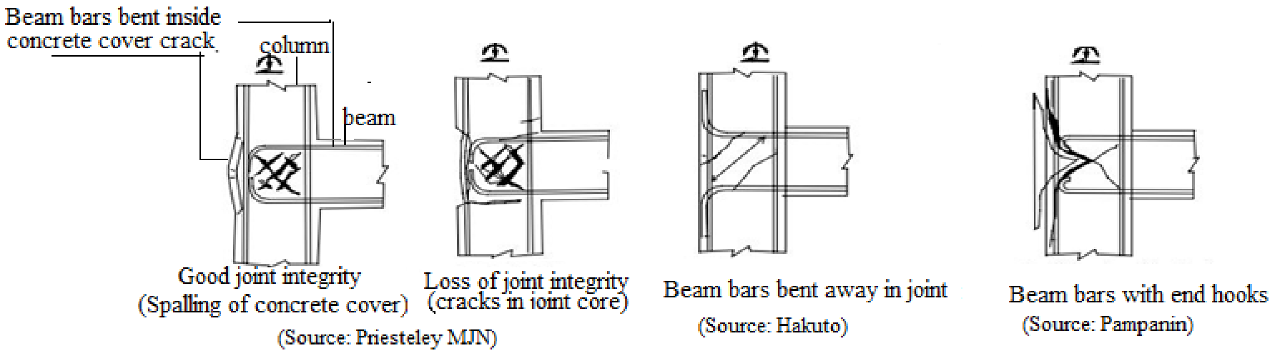
The pull out failure of longitudinal bars results complete loss of flexural strength of connecting beam.
As per design codes, joint shear strength Vjh= Vch + Vsh
(Vch: shear contribution by strut mechanism, Vsh: shear contribution by truss mechanism).
Analysis of discrete joint elements are followed by strut and tie mechanism (STM) for transfer of loads. The efficiency of STM influenced by enhanced bond conditions between steel and concrete within the joint core. The deterioration of bond conditions cause local compression failure of concrete near the joint. Hence compressive strength of concrete is taken as reliable source to support strut mechanism during which strut failure initiated by developing tensile strains in the joint core. But increase of compressive strength of concrete decrease the ductility. During uni-axial compressive stress level of concrete (Less than 30% of cylindrical strength) the concrete behaves as linear elastic element and the pre-existing micro cracks are stable and do not propagate. When concrete loaded to maximum, the micro cracks are localized under narrow bands and form macro cracks that results strength loss of joint. The truss action in joint initiated only after development of initial crack in concrete. Under this conditions, transverse reinforcement in joint core, dowel action of column bars and anchorage reinforcement of beam bars contributed in truss mechanism. As per the experimental studies maximum transverse reinforcement in joint core is limited to 4% of cross section of joint core, over which shear capacity of joint core substantially not improved. Joh et al.,(1991), Oka and Shohara (1992) suggested that increase of shear reinforcement in joint core improve the tendency of beam yielding before joint failure.
The shear strength of joint is little influenced by column axial loads. Kitayama et al.,(1987) suggested that axial load improves shear strength of joint by confining effect for both seismically and non seismically designed joints. Axial loads contribute part of inclined strut loads during joint shear conditions (Paulay et al.,1978).Kurose et al.,(1987) and Morita (1991) concluded that axial load influence the deformation of joint panel but not to its strength. In substandard joints, the column axial load improves confinement and ductility which improves load carrying capacity. During seismic action, the period of time is so limited during which maximum strain reached in joint material. In most of the failures, the brittle response associated with joint failure prior to beam yielding and ductile response of joint associated beam yielding prior to joint failure [17]. Ignoring the design considerations, beam column joint may lead to potential damage of R/C framed buildings during moderate seismic conditions [18]

(iii) Shear resistance mechanism

The beam column joint region is idealized as two dimensional plane, subjected to internal forces from connecting beam and the column acting on joint face. The forces primarily consist of compressive, tensile and shear forces. The shear forces in the joint region develop diagonal compressive and tensile forces within the joint core, resulting the formation of a principle failure planes. The shear resisting mechanism consists of a diagonal concrete strut action and a truss action .The diagonal concrete strut mechanism is formed by major diagonal concrete compression force of joint. This force is produced by vertical and horizontal compression stresses and the shear stresses on concrete at the beam and column critical sections. The truss mechanism is formed by a combination of the bond stress transfer along the beam and column longitudinal reinforcement.

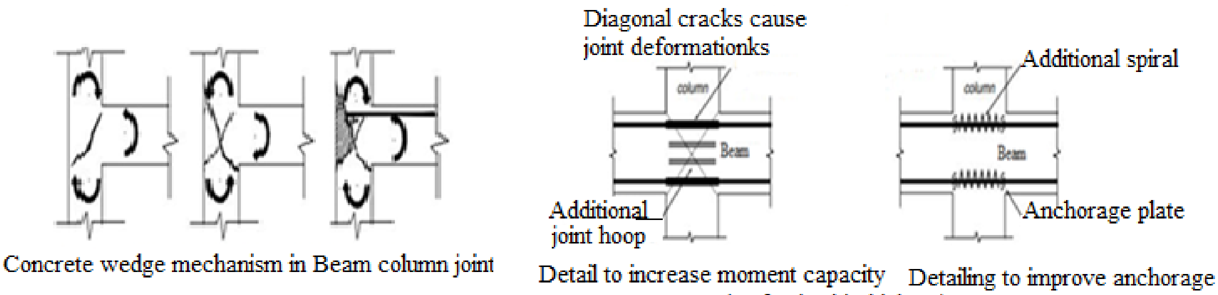
The strength of the strut mechanism depends on the compressive strength of concrete and that of the truss mechanism depends on tensile yield strength of the lateral reinforcement crossing the failure plane. In resisting the joint shear, the diagonal strut mechanism can exist without any bond stress transfer along the beam and column reinforcement within the joint, while the truss mechanism can develop only when a good bond transfer is maintained along the beam and column reinforcement. Under seismic loading conditions, the bond along the beam reinforcement inevitably deteriorates especially after beam flexural yielding takes place unless the strength and size of the reinforcement is strictly restricted. With the outset of bond deterioration, the truss mechanism starts to diminish and the diagonal strut mechanism must resist the most dominant part of the joint shear. Under this conditions, the tension force in beam reinforcement not transferred to the joint concrete by bond and resisted by the concrete at the compression face of the joint, thus increasing the compression stress in the main strut. The concrete strut is progressively weakened by reverse cyclic loading. At the same time, the compressive strength of concrete is reduced by the increasing tensile strain perpendicular to the direction of main strut. The combination of these two phenomenon results failure of concrete strut in shear compression. The principal role of the lateral reinforcement in this case is to confine the cracked core concrete.

(iv) Response of non-seismic joints



The structural response of R/C framed buildings are strongly influenced by flexibility of beam column joints. The non seismic and rigid joint condition of substandard joint system shows poor response under high lateral loads due to its non flexibility .Design of non seismic joints are based on provision of sufficient anchorage length to accommodate tensile stresses produced by moments on joint system. But the seismic vulnerability of joint panel under high shear conditions produce slippage of reinforcement by inadequate anchorage. Concrete wedge brittle failure mechanism is more obvious in hooked anchorage system due to high shear and stress concentration exists in beam column joints.

Joint flexibility is a key parameter to assess magnitude of lateral loads acting on the structure. This condition is more acceptable when joint failure happened in shear before beam yielding. Joint flexibility is essential for simulating beam-column subassemblies and older-type RC buildings containing unreinforced joints. The seismic design require additional anchorage in joint panel to accommodate the tensile force produced by unbalanced moments. During diagonal cracking, the shear transfer of joint attributed to compression strut formation and its efficiency related to anchorage of beam .Most of the seismic codes followed this mechanism to evaluate shear capacity of joint.

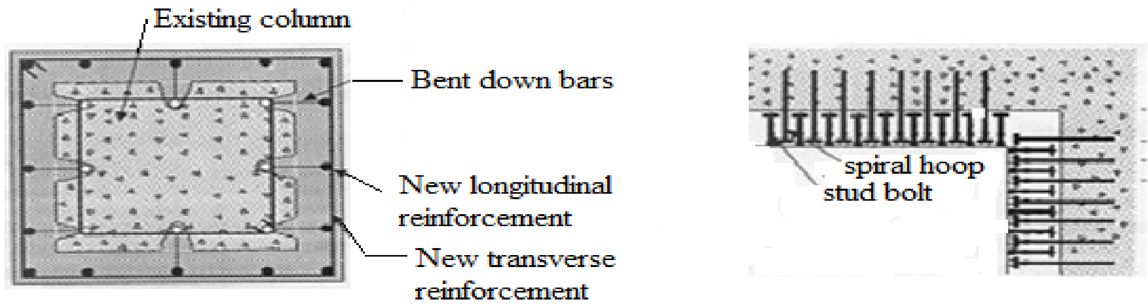


(Ref: Hitoshi Shiohara)

V. STRENGTHENING MEASURES OF NON SEISMIC STRUCTURES

The current non-seismically detailed buildings not possess enough lateral resistance against seismic forces and the requirement of large ductility demands of members is difficult to be meet for the existing structure. Provision of supplementary strength in form of additional lateral force-resisting elements such as shear walls, braced or moment frames help to reduce inelastic demands of existing gravity designed structures. But the implementation is difficult as the implementation of above retrofitting techniques is needs feasibility and economic aspects.

(i) Strengthening of R/C framed Structures



Retrofitting of column by section enhancement technique

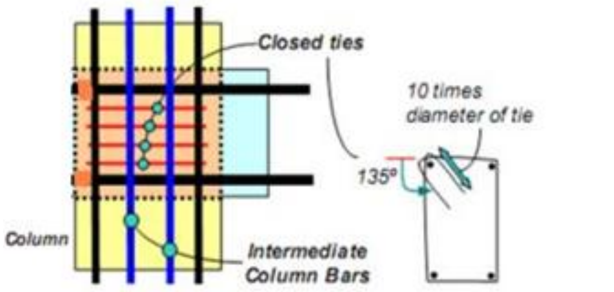
The, seismically deficient frame members and joints are identified during detailed evaluation of R/C building. Members requiring strengthening or enhanced ductility can be jacketed by reinforced concrete jacketing, steel profile jacketing, steel encasement or wrapping with FRPs. Where possible, the deficient members should first be stress-relieved by propping.. RC jacketing involves placement of new longitudinal reinforcement and transverse reinforcement bars in the new concrete overlay around existing member. Steel profile jacketing can be done through steel angle profiles placed at each corner of the existing reinforced concrete member and connected together as a skeleton with transverse steel straps.

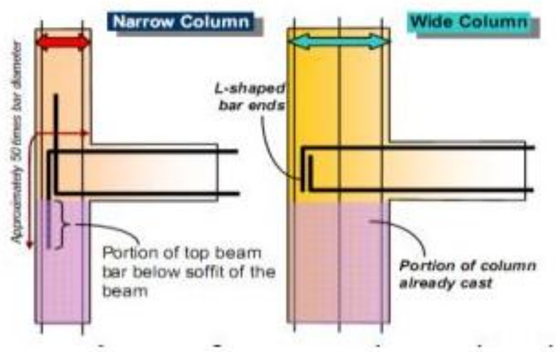
Another way is by providing steel encasement. Steel encasement is the complete covering of the existing member with thin plates.

(ii) Retrofitting techniques of beam column joint

Addition of fibres in beam-column joint core will decreased the rate of stiffness degradation considerably when compared to the joints without fibres [19]. Section enhancement of joint is new technique where the joint section enhanced its strength by reinforcement caging and concreting .Fibre wrapping technique is considerably used to enhance joint stiffness and strength but the joint is still considered under elastic condition. In view of well employed techniques,it is always advisable to maintain good dimensional proportionality of joint core and reinforcement detailing in the initial design stage itself for safely transfer the loads under seismic conditions.

VII. RECOMENDED PRACTICE OF NON-ENGINEERED R/C STRUCTURES



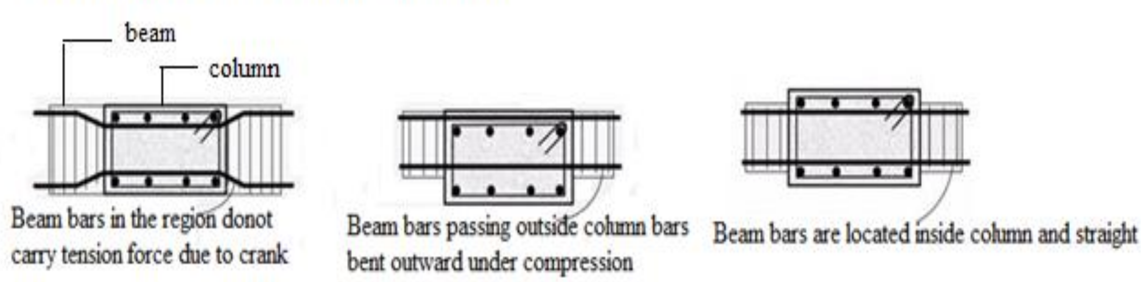


The joint must posses sufficient number of closed ties
Splicing of column bars should not allowed in joints

(i) Design improvements of joint core

a) The rigid joint assumption of joint is obviated unless the joint posses sufficient anchorage and shear strength during lateral loads.
b) Beam column joints must possess adequate size and shape to ensure strut mechanism and anchorage requirements. Judicious detailing of reinforcement to ensure full strength of reinforcement. Joint aspect ratio precisely controls the shear stress distribution across the joint panel. This will provide increase of load carrying capacity of strut mechanism and to enhance bond properties.
c) Small size bars possess good performance than large size bars for anchorage. The anchorage bars should locate inside the joint to avoid diagonal cracking. Splicing of column or beam reinforcement in joint core should not be allowed.
d) The non-seismic joints should be designed under strong column and weak beam conditions. To fulfil this conditions the design codes Mc/Mb>1.00 [Mc, Mb: Sum of Moment capacity of column, and Sum of moment capacity of beam respectively
e) A good detailing practice of joint ensures the properties of confinement, ductility, energy dissipation and shear strength. As per the experimental studies, maximum 0.4% shear reinforcement allowed in joints for moderate seismic conditions

Construction practice of Beam column joint



Poor Construction Practice of Beam column joint

Good Construction practice of R/C Beam column joint

(ii) Design improvements of beam and column

a) Beam bars should not allowed to place outside the column bars. Localised stress distribution is essential to consider in joint core. Provision of transverse reinforcement in joint should serve the purpose of both confinement and lateral shear. When local bearing or bond failure expected, the lower of the two values should uses in joint design.

b) Column orientation is significantly influence the performance of joints. All non seismic beam column joints should fulfil minimum geometric dimensions for safe transfer of stresses between the joint and associated members. The non-seismic beam column joints should satisfy medium ductility as minimum requirement to ensure safety and integrity of structural damage in joint system. To satisfy this condition, good detailing provisions are mandatory. Beam-column joints shall have ties spaced at or less than 150 mm. The beam stirrups and column ties shall preferably be anchored into the member cores with hooks of 135° and 6times bar diameter extension.

c) Research studies also suggested that under seismic conditions the non seismic joints are exhibit 30% reduction in strength and ductility which results 60% loss of energy dissipation when compared with seismic joint. The non-seismic joints predominantly influenced by unbalance bending moments whereas seismic joints influenced by lateral shear force. Hence the transformed joints should satisfy both anchorage and shear requirements in joint panel.

d) Flexibility of joint panel shows significant influence on unreinforced joints. The joint panel must design for flexibility to avoid overestimation of frame stiffness and under estimation of drift. Most of shear deformation in joints is due to diagonal tensile component of joint panel. Diagonal compressions of join contribute 20% of shear deformation

(iii) Design provision of reinforcement detailing

At least two longitudinal top and two longitudinal bottom bars of beam reinforcement shall be extend continuously through the length of each frame beam. At least 25% of the longitudinal bars located at the joints for either positive or negative moment shall be continuous throughout the length of the members. Lap splices of beam bars shall be located only in the central half of the member length and proportioned as a tension splice. Hoops shall be located over the entire splice length at spacing not exceeding 150 mm centre to centre and not more than 50 percent of the bars shall preferably be spliced at one section. If more than 50 percent of the bars are spliced at one section, the lap length shall be 1.3 Ld **(**Ld: Development length of bar in tension (IS 456: 2000)

The lap length shall not be less than the bar development length in tension. Lap splices shall not be located (a) within a joint, (b) within a distance of 2d (d: effective depth of beam) from joint face, and (c) within a quarter length of the member where flexural yielding may occur under the effect of earthquake forces.

The parallel legs of rectangular hoop shall be spaced not more than 300 mm centre to centre. If the length of any side of the hoop exceeds 300 mm, the provision of a crosstie should be provide. Ultimately pair of overlapping hoops may be located within the column. The hooks shall engage peripheral longitudinal bar. The spacing of stirrups over a length of 2times depth of beam (d) at either end of a beam shall not exceed (i) d/4, or (b) 8 times the diameter of the smallest longitudinal bar; however, it need not be less than 100 mm. The first hoop shall be at a distance not exceeding 50 mm from the joint face. In case of beams vertical hoops at the same spacing as above shall also be located over a length equal to 2d on either side of a section where flexural yielding may occur under the effect of earthquake forces.

VIII. CONCLUSIONS

- The recommended practice of R/C structures under seismic transformations need to satisfy minimum design essentialities against lateral load resisting system. External retrofitting techniques of joints may improve elastic performance of joint but shows poor and inefficient force transfer mechanism in joint core. This results poor ductile performance of joint.
- The design of critical R/C joint elements must proceed with performance based design and the important joints must be posses minimum ductility irrespective of loading conditions.
- The seismically transformed joint should possess minimum stiffness implicitly, and flexible enough externally so as to dissipate the energy. A good detailing of reinforcement in joint core ensure ductile behaviour and efficient force transfer mechanism.
- The anchorage configuration has significant influence on load carrying capacity and failure mode of non seismic joints. Shear failure of joint core and slippage of flexural reinforcement are found to be the critical modes of failure in substandard EBC joints
- Constructability and detailing aspects are more significant in R/C structures that are exposed to seismic transformation that will influence the collapse mechanism of global structure. The designer must ensure strong column and week beam in framed structure to avoid soft storey effect..
- The design of principle elements such as R/C columns and beams must satisfy basic dimensional requirements with respect to joint core. The strength of joint concrete has significant influence on shear resistance. In this context seismic provisions mentioned in design codes must be ensured in the design.

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