Seismic Strengthening Of R.C Beam-Column Joint Using Post Installed Headed Anchors

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Abstract: Post Installation of Headed Anchors (PIHA) is an advanced technique proposed in this study for structural strengthening of R.C beam column joints (BCJ). Previous research work on seismic damage of joints are widely correlated with shear deformation and bond slip of anchored reinforcement in joint core. To mitigate complex issues of reinforcement congestion, anchorage, fabrication and placement of reinforcement in congested geometry of BCJ, this novel technique of “Post Installation by Headed Anchors” (PIHA) is proposed in this paper. It is an effective measure contributing to enhance implicit properties of shear, stiffness, confinement and ductility of joint core. This method gives viable solutions to conventional design practice of Precast and Cast-in place joints. Headed anchors provides good supplement to hooked anchorage system for improved shear, anchorage and ductile properties by delay the ultimate failure of joint. The state of headed-bars considered in this study is of bonded and un-bonded conditions with concrete. This paper focused on analytical aspects of proposed PIHA system so as to evaluate its strength and parametric influence against seismic shear strengthening of BCJ. Principle observations made in this study are “Theory behind post installation, Fastening techniques, Force transfer mechanism, Failure modes, Seismic suitability of anchors, and Implicit strengthening of joint core.

Index Terms: Beam-Column joint, Fastening Techniques, Headed Anchors, Implicit Strengthening, Post Installation, Seismic behavior.

1 INTRODUCTION

The current research on Seismic Beam-column joints (BCJ) are based on explicit strengthening techniques such as Section enhancement, Fiber-wrapping, Metal stripping etc. It is more significant that during seismic action, the implicit strengthening of joint enhance shear and ductile properties of joint core. Inspiteof this, the current seismic practice of BCJ believed to be more conservative and accordingly due considerations are assigned by design codes for discrete joint conditions of external BCJ as it possess more vulnerability of high seismic shear. In this process, joints are subjected to complex force transfer mechanism. Most of the critical failures in joints are happened by shear deformation and bond lose. In this context, the current seismic codes are unable to establish the real time behavior of joint failures. This is due to most of design codes are established on strength based system and is far away to establish joint on performance based system as it suggested to impeded good energy dissipation (MJN Priestly-1975). And most of the designers intended to validate strength based joint performance by displacement approach. This is quite contradictory approach and hindered the prospects of joint design. The constructability of joints is another important issue where the engineers often failed to establish correct detailing aspects of steel in joint core due to its confined geometry. In this context the effectiveness of conventional hooked anchorage system is unable to restrict the fracture mechanism of joint core. These flaws need to address by theoretical means and modeled for real time failures of joints. Park.R & Pauley.T [1975], recommend usage of mechanical headed anchors by mechanical (headed) anchorage system which associated with geometric configuration and detailing aspects of reinforcement.

1.2 Current Research

Eligehausen.R-2006 [9] conducted a wide range of pullout tests on headed anchorage system to study fracture failures of cast in-place R.C joints. He concluded that headed bars shows good convergence with Strut-Tie mechanism and prevent or delays the premature failure of joints. Since headed anchors possess good seismic energy dissipation and stable CCT (compression-compression tension) node conditions its strength is more than hooked anchors (Fig.4). Hence use of headed anchors are more vigilant at discrete joint conditions (External joints). ACI 374.1-05/15 suggested on substitution of hooked anchors by mechanical (headed) anchorage system gives an appropriate or better results of joint performance. Park and Pauley-1989 stated that the functionality of shear reinforcement is more crucial than confinement under pure shear conditions, of joint core. Walker- 2002 [10] expressed that during low deformation of BCJ (drift < 1.5%) the strength...
and stiffness degradation of joint is nominal, and shear strength of joint may consider as less than 10(fck)¹⁵ (Psi). Noguchi, Kashiwa Zaki -1992 [11] expressed that during large deformation of joint (drift > 2%) confinement is more significant. Fujii, Morita-1992 [12] noted that degradation of shear rigidity is accelerated when the shear strains of joint reaches 0.5%. Oka and Shiohara-1992 [13] stated that shear strength of joint does not possess linear relation with concrete compressive strength .Hayashi, Teraoka -1994 [4] expressed about post failure conditions of joint significantly influenced by amount of transverse reinforcement provided in joint core. Krishna. P & Ghimire -2019 [14],[15] proposed an expression for calculation of shear strength of joint by headed anchorage system .The results shows that anchorage strength of headed bars are proportional to [compressive strength of concrete]²⁴ and the contribution of confinement is proportional to area of confinement steel arranged parallel to headed reinforcement. Sung Chul Chun,-2019 [16] proposed a beam-column joint model for anchorage strength of headed bar. The results shows that contribution of head bearing is not related to embedment depth of headed bar. Experimental studies of Chutarat, Aboutaha-2003 [17] expressed the effect of cyclic loads on headed fasteners and concludes that headed bars are more effective than hooked anchors, and reduce the bond length as is possess both bearing resistance of head and bond resistance of bar both mechanisms helps to relocate potential plastic hinge formation away from joint core. Experimental studies by Vaibhav. R. Pawar -2017 [18] concludes that headed anchorage shows satisfactory seismic performance against shear deformation. Further the study observed that no brittle failure of concrete occurred in joints of headed bars , if the ratio of head size and bar diameter (A_{bry}/A_b) is at least 2.5 and the minimum embedment depth of bar is 11d_b (d_b: Bar diameter).Also large head size bars (A_{bry} /A_b > 4.2) exhibit higher anchorage strength than small heads(A_{bry}/A_b=2.6-2.9).

2 OBJECTIVES
Objectives are configured to verify the analytical aspects of headed anchorage system under Post installation of fastening techniques. The emphasis is based on physics related to (i) Force transfer mechanism, (ii) Failure conditions of joint, (iii) Seismic suitability of headed anchors, (iv)Implicit strengthening .

3 FORCE TRANSFER MECHANISM AND FAILURE MODES
During seismic action, headed anchorage system of Beam-column joints are subjected to lateral action of cyclic forces (tension or compression), transverse shear, or combination of both (Fig.1). Transfer of this explained by Strut-Tie Mechanism (STM) of discrete conditions shown in external beam-column joint.(Fig.4).

The participation of compression strut (by concrete) and tension tie (by steel) is more crucial in STM formation, as it significantly influence the strength and performance of joint core. It is further depends on load history ,boundary conditions, state of concrete (cracked or un-cracked) and detailing aspects of steel in joint core. The strength of compression strut, steel ties and node junction shows (Fig.4). During force transfer mechanism the detailing aspects of reinforcement should meet the strain compatibility of joint concrete within joint core. To meet external force action, headed anchors develop implicit shear resistance by head bearing and bond resistance of bar which depends on type of fastening and installation methods. It is comprised by (i) mechanical, (ii) friction, (iii) bonded anchorage system.

Mechanical anchorage (Fig.2a) of headed bars comprise significant role in force-transfer mechanism within joint core. The force transfer mechanism constituted by interlock action of bearing between the headed fastener and concrete in the anchorage system. This system is useful for both Cast-in-situ (headed studs, anchor bolts and anchor channels) and Precast concrete where the fastening system proceed by screw anchors or undercut anchors. Frictional anchorage (Fig.2b) results by generation of expansion forces, that gives frictional resistance at interface of anchor and concrete. During this process, expansion forces generate the frictional resistance between anchor and surface of hole. The generated frictional resistance forces are in equilibrium conditions with the applied tensile force. Chemical bonded anchorage (Fig.2c) is the most conventional method of Post-installed fastening system. It is also termed as bonded or adhesive anchoring which refers the anchorage system comprised by bond action between steel element (threaded or deformed bar) which was installed in drilled hole and developed bond between steel and concrete.
4 PARAMETRIC INFLUENCE ON HEADED ANCHORS

The performance evaluation of seismic joints is based on the development of interaction mechanism between inelastic behavior of beam and elastic behavior column at joint core. In this context, Park.R & Pauley.T concluded that unless significant axial load (P) act on column[P <(0.10-0.30)f_c.A_c] the design of seismic BCJ should based on assumptions that no shear force is resisted by concrete and shear the transfer through diagonal compression strut in joint core is obviated. Provision of steel reinforcement is considered in shear resistance mechanism. But this argument is deviated as the research studies of joint failures expressed on significant role by compression strut formation in concrete. During high seismic conditions, the behavior of headed anchors in beam-column joints are influenced by following parameters.

4.1 Strut-Tie mechanism

Based on STM approach headed anchorage system provides static equilibrium conditions at nodal points (Nodes) through appropriate force transfer mechanism. Typical compression-compression-tension (CCT) node formations are shown in Fig.4, where the presence of headed anchors classified by (i) External and (ii) Internal formation of CCT nodes. Since the discrete joint conditions of external beams are exclusively correlated with truss mechanism of force transfer system, formation of CCT node plays an important role in shear resistance mechanism of joint. The formation of Strut, Tie and Node junction decides the strength of joint. As described above, the formation of external nodes (Fig.4a&4b) gives more strength than internal nodes (Fig.4c&4d). In the conventional design system of joints, formation of sallow and deep strut conditions are developed upon the effective depth of beam and column width. Deep strut conditions are more vulnerable than shallow struts, as concrete exhibit crushing or buckling failure due to internal stresses. Hence deep strut conditions of joints should verified by tensile strength of concrete.

4.2 Anchorage Depth

The failure of anchors crucially depends on its embedment depth, and grade of concrete and confinement factor of joint core. Since the anchorage depth significantly influence the force transfer mechanism and strength of joint, its embedment depth is more crucial during failure assessment of a joint. In this context, studies conducted by De.Vries R.A [19] ,Thompson M.K [20] used a simple definition on shallow and deep embedment depth of headed anchorage system (Fig.6). Studies of Hung Jen Lee-2009 [21] mentioned another definition on embedment depth of anchors in BCJ. Accordingly deep anchorage system is one which possess embedment depth greater than five times the least cover dimension of anchored bar (Fig.5).

The shallow anchorage system is one in which the anchorage is less than five times of least cover of anchored bar. In the context of headed anchors, more bearing strength is provided by use of greater embedment depth due to good confinement effect produced by concrete during diagonal compressive strut formation. Similarly in the shallow anchorage system, less confinement effect was produced by concrete and results less strength of joint. Failures of headed anchorage system may classified under shallow and deep anchorage. In shallow anchorage system (anchor depth < 20 bar diameter) the failure is attributed to concrete cone breakout failure and in deep anchorage system (anchor depth > 20 bar diameter) the failure is due to side face blow out of concrete. Wallace, and Chun et al.,(2009) suggested that the minimum embedment of headed anchors should be more than 12ø and relative head are ratio (p) should between 3to4 .Experimental findings of Thompson et al[20] expressed that the optimum head bearing strength of effective concrete strength achieved by deep anchorage system when the anchor embedment reach 0.7L (Fig:6) Experimental studies of Sung chul chun -2009 [16] discussed on failure patterns of headed bars in shallow, moderate and deep anchorage system. In shallow anchorage system (Embedment depth Ld < 50% of column depth L) the concrete shaped concrete failures are generally happened. The bearing stress of head is not fully develop in this system and joint strut is not confined by head. In moderate depth of anchorage system (embedment depth Ld= 50%-70% of column depth L) the concrete break-out failures are generated by radiating of cracks from both sides of head. Here the head bearing is partially participated to bond conditions for shear resistance of anchored bar. The deep anchorage system (Ld > 0.70L) comprise the diagonal shear cracks initiated at head and propagated towards compression zone of beam. Both head bearing and bond stress are fully contributed to develop shear resistance mechanism of anchors. And the side face blowout of concrete is a susceptible failure in deep anchorage.
As per ACI 352R-02 code, any type of hooked or headed bars that may satisfy ASTM-A970 specifications can use for seismic anchorage of beam-column joint and the embedment depth is more than \(8d\) (\(d\): diameter of anchor). Research findings of Hung Jen lee-2009 [21] expressed the usage of multi headed anchors in joint core as it effectively enhance shear capacity of joint during cyclic loads producing high drift conditions.

### 4.3 Condition of joint concrete

In the design of headed anchorage system, the state of concrete should consider by un-cracked or cracked conditions. The un-cracked joint conditions is one which is no cracking of concrete occurs in the embedded length of bar during service life and the failure mode intends to only fracture failure of steel reinforcement in joint core. Studies pertaining to cracked concrete conditions are more significant in the seismic design of anchors as it exhibit the strength of pre and post damage conditions by connecting elements. It is a recommended practice that design of seismic joints must proceed under cracked conditions of concrete, since the bond strength influenced by development of tensile strains in joint concrete.

In this process, the seismic design considerations of joint must study the effect of concrete softening before crack formation and tension stiffening effect after crack formation of joints as to apply suitable confinement measures in joint core. Modeling of cracked concrete is quite essential to evaluate performance and strengthening measures of joint. In this context design of beam column joints proceed under a) Smear crack plastic model (Degraded stiffness model), b) Damage plasticity model. c) Bond slip model (by ABAQUS). Experimental results of previous studies on seismic joints expressed that the cracked concrete reduce its tensile strength considerably (approx 25%) of headed anchors (approximately compared with un-cracked conditions).

### 4.3 Joint confinement

Two types of confinement effects are influencing the joint behavior of. They are (i) External confinement of joint by holistic action of members (ii) Internal confinement of joint by implicit strengthening process of joint core. The design codes address empirical solutions for external confinement of joint only. Internal confinement significantly influence anchorage mechanism of joint through Active and Passive Confinement process. Active confinement is one the stress field developed in the joint core due to action of superimposed loads (Dead load, Live load, Pre-stressing Load). The provision of unbounded headed anchorage system comes under Active confinement effect.(Ref Fig.9) Passive confinement is referred as stress field generated due to forces in the reinforcement detailed in anchorage zone (Stirrups, Headed studs, and Helical reinforcement). Since the confinement steel do not play any intermediate role against resistance of splitting tensile stresses of concrete until cracks appeared an intersect the confinement reinforcement, it is termed “Passive confinement” system. (Ref. Fig. 8). The splitting action resisted by confining reinforcement depends on width of splitting cracks, which is tapered through the length from anchored bar .The confinement reinforcement is more effective when it placed close to the surface of headed bar. Most of the previous experimental studies are based on passive confinement conditions and limited studies are conducted for active confinement conditions of joint core. During seismic action the behavior of post installed headed anchors are characterized under elastic un-cracked and elastic cracked sections of concrete. The stress distribution at various phases of joint concrete is shown in Fig.7

The mechanical property of concrete shows significant influence on bond development between concrete and reinforcement. Fig.7 explains different phases of concrete conditions and crack pattern against its condition of damage. Elastic-un cracked concrete (Fig.7a) is based on the principle that once joint concrete reached its tensile capacity, splitting cracks formed and bond failure mandatory. In this context the bond capacity is limited under pure elastic conditions of concrete. As shown in Fig.7b Elastic-Cracked section of joint core gives slightly higher bond capacity and allowing crack zone around the reinforcement of elastic behavior outside the zone. Tensile stress are not allowed in the cracked zone. The elastic-cracked concrete gives higher capacity than elastic concrete. It allows the regions of high tensile stress to get away from reinforcement surface up to distance where stresses act over large area. The elastic-cohesive concrete (Fig.7c) allows generation of tensile stresses within cracked zone. This formation is based on cohesive theory of material mentioned in fracture mechanics. In this model, the tensile behavior of concrete was derived by using principles of fracture mechanics. This model is based on tensile behavior of concrete which was derived from principles of fracture mechanics. Plastic concrete (Fig.7d) referred as optimum distribution of tensile stress in concrete and gives highest capacity of concrete. The splitting mode of failure is based on tensile strength of concrete. It is most economical process and produce uniform stresses distribution in concrete. Ultimate failure strength of concrete is higher than rest of the modeled concrete.

### 5 POST INSTALLATION TECHNIQUE OF HEADED ANCHOR

Use of headed anchor is considerably increased during the recent past as it possess quick and easy installation followed by economic viability. It is in the form of mechanical, friction and adhesive anchoring system for structural strengthening of concrete. The Headed fasteners are designed to exhibit sufficient load carry capacity and allowable deformation in joint. The anchorage system is defined by way of its installation, and is defined by (i) Direct installation, (ii) Drilled installation and (iii) Cast in- place installation system. For all these conditions, the detailing aspects of headed fasteners are more significant for shallow and deep strut conditions.
5.1 Post Installation process

Studies conducted by Higgins-1994, Klingner-1998, Cook, Konz-2001, Fujikake-2003 addressed on installation conditions of anchors (direction of installation, drilling of holes, cleaning, and moisture during installation), and loading conditions on anchor (i.e., short-term or long-term loading) at service conditions. The installation process of anchors are classified as follows. (Ref. Fig.8) (i) Pre-position installation, (ii) In-place installation (iii) Stand-off installation

As explained in Fig8, three types of anchor installation configurations are commonly used during fastenings of direct installation. It is mentioned by (i) Pre-position drilled installation (Grouted anchors) (ii) In-situ placed installation (iii) Stand-off installation. Pre-position drilled installation (Fig.8a) involves making a drilled hole with suitable clearance in hardened concrete and insert the fastened anchor and fix it with high strength epoxy grout. The size of drilled hole must be large enough to develop bond resistance between the anchor and constituent grouted material. Post installation of bonded anchors is an example of this method. In the In-place installation of anchor installation (Fig.8b) anchor is fixed in position and monolithically casted with concrete during joint construction. Hence the embedded anchor is in direct contact with concrete surface and produce shear resistance against bond.(Fig.8b). The stand-off installation is a post installation method, where the anchor is fastened through inserted made in hardened concrete through torque controlled mechanical anchorage system (using screws, bolts etc.)(Fig.8c) .The drilled anchor is able to take compression, tension through mechanical interlocking between steel threads and surrounding concrete. This type of installation further classified by (i) Torque controlled method (Fig.9) (ii) Displacement controlled method. (Fig.10)

In the Torque controlled expansion method, the transfer of external tensile force to base material through friction and mechanical interlocking with base material. It may generates pre-stressing force in bolt and clamps the fastened anchor against the surface of base material. This pre-stressing force diminished after installation of anchor due to relaxation of localized stresses in concrete .Torque controlled anchors may further classified under sleeved and bolted type. The sleeve type anchors consists of threaded bolt, nut and washer with expansion sleeve deformations that provided to prevent spinning of the anchor in the hole. The bolt type anchor typically consists of bolt, the end of which was swaged or machined into conical shape. Installation of Torque controlled mechanical anchors are generally carried out by inserting the anchor in drilled hole and apply specified torque on bolt or nut with torque wrench. Once the bolt or nut receive bearing against the base material , then the further application of torque draws the cone at the embedded end of the anchor up into the expasive sleeve ,thereby expanding the expansion elements against the sided of the drilled hole. To ensuring sufficient frictional resistance in torque controlled bolts should keeps the bolt in tension. If the torque controlled expansion anchor not set correctly, then it will rotate before achieve the prescribed torque. This type of anchors installed through use of drilling machine and specified tolerance allowed during preparation of hole size in concrete.

As shown in Fig.10, the displacement controlled expansion anchors (drop-in anchors) consist use of expansion sleeve and plug. The sleeve is internally threaded so as to accept threaded element. The displacement anchor transfer the tension load to base material by friction and in the localized deformation through mechanical interlocking. Magnitude of expansion force depends on sleeve size, expansion, deformation resistance against concrete, and gap between sides of drilled hole and anchor. The initial expansion force produced by anchor is more than torque controlled expansion anchor, but the high expansion stresses induced is reduced later stages by relaxing stress of concrete.
5.2 Post Installation process
The post installation of headed anchor in joint concrete is designated by two methods of fastening systems. Each method constitute has its own merits in strengthening process of joint core. The methods classified by (i) Bonded anchorage (ii) Un-bonded anchorage. Bonded anchorage system provides passive confinement effect in joint core through stress field generation and creating internal forces of reinforcement placed around anchorage. Provision of un-bounded anchorage system comes considered by active confinement mechanism as detailed below. Mechanism of both systems are shown in Fig.11 & Fig.12

5.2.1 Bonded or Adhesive anchorage system
As shown in Fig.11 the anchored reinforcement is in direct contact with joint concrete .Adhesive bonded anchors are sensitive against type of loading and direction of installation. During its installation hole is drilled across the joint with tolerance and produced to intercept required depth of connected beam. Later the drilled hole is filled with epoxy grouted material which interfaces both reinforcement and concrete. Another method of bonded anchorage is provided by inserting screwed anchors through joint concrete and later filled the drilled hole by grouted material. Hence the resistance is provided by head bearing and frictional bond resistance of stem through anchorage of reinforcement. Analysis of this method is proceed by pull-out tests. In this process, anchored bar is in direct contact with surface of concrete and contributed to develop stable CCT (Fig 4) node conditions during implicit strengthening process of joint core. The bond between headed anchor-grout and grout-concrete is more crucial during shear resistance mechanism. The bonded system is similar to cast-in place joint connection by headed anchors. This technique is suitable to meet seismic requirements of both undamaged and damaged state of concrete in joint core and preferred to use for moderate or high strength concrete. The bond force between anchor surface and drilled concrete hole produce adhesive bond resistance against applied tension and bond force in equilibrium conditions [Ref. Cook @al.-1998] [29]. If adhesive bond between anchor and concrete tends to brake, then force transfer is provided by friction action. Use of polymer modified cement concrete is one of the suggestive grouted material to develop bond between concrete and anchored steel of joint core. During seismic action the bond strength of headed anchor significantly influenced by Poisson's effect and larger bars intends to greater volume change (tensile force) and results high reduction of mechanical interlocking or frictional resistance.

5.2.2 Un-Bonded or confined anchorage system
As referred in Fig.12 the Un-bounded headed anchorage system is produced active confinement effect on joint core. This method is similar to pre-tension effect through confinement of joint core and adoptable when the joint subjected to low or moderate shear strength. In this process headed bars are passing through an existing opening (sleeves or conduits) of joint and the tail end of anchor is embedded in beam concrete to develop sufficient bond strength against pull out failure of joint. This process is intended to produce tensile resistance of headed bar by head bearing system only and no bond stress of stem participated during force transfer mechanism. In this possess headed anchor in joint core is not in direct contact with concrete. This process contributed to induce implicit pre-tensioning force in anchored steel so as to produce confinement effect on joint core. The pre-tension forces applied by torque controlled screwed anchors arranged at tail of headed bar. The un-bonded anchoring system can also proceeded by using undercut expansion anchors. This system is very suitable for moderate seismic conditions, where the joints are inhibited by low shear conditions.

6 SEISMIC QUALIFICATION OF HEADED ANCHORS
Bonded expansion or undercut anchors are suitable to use in cracked concrete. In absence of steel rupture, bonded undercut anchors exhibit concrete cone breakout failure when the load in tension reaches its ultimate state. The bonded anchor constitute grouting materials such as polymer resins, cementitious material of epoxy grout or combination of the above. The bonded anchorage system is in the form of (i) Capsule anchorage system, (ii) Injection system. In the capsule anchoring , threaded rod equipped with 45° chisel or wedge shaped tip with hexagon nut and washer that was in conjunction with foil pouch filled with constituent bonding material. The required embedment is marked on the threaded bar and filled by polymer resin, hardener, and quartz aggregate at definite proportion .The capsule pouch placed in hole from which drilled dust has been removed. The threaded rod driven into the capsule until the embedment depth marked by percussion and rotary drilling method. When driving the rod into the hole, the glass capsule is broken and fragmented into pieces and the resin, hardener and fragmented pieces are mixed with sufficient energy input to induce rapid curing and the annular gap around the threaded rod filled with polymer matrix. In the injection anchorage system, the drilled hole is mechanically cleaned by stiff brush and compressed blow air. Due considerations are required in PIHA during nonlinear cyclic action of seismic forces. Most of the designs considered static load capacity of anchors with multiple factor while assessing seismic capacity of anchors. The seismic behavior of post installed headed anchors depends on prevailing conditions of concrete core, embedment depth, type and sequence of loads acting on joint. The seismic action of anchors may subjected to combination of tension, and shear loads while performing inelastic response cracked concrete conditions under varying crack width. Expansion anchors are intend to produce expansive force on concrete and preferred to locate at far distance from edge of concrete with sufficient spacing between the anchors. The distance between the anchors is a function of anchor diameter (ø) that is anchor with larger diameter must place far away from edge of concrete. Provision of multi headed anchors in joint core may effectively
transfer the compressive forces into the diagonal strut of joint core and establish good seismic absorption of joint during high seismic conditions. In the context of above observations, bonded anchorage system recommended in low drift conditions of joint (drift<1.5%) as the joint sustain with considerable strength and stiffness of seismic loads. Subsequently, the un-bonded anchorage system preferred in high drift conditions (drift>2%) conditions, where the joint subjected to considerable degradation of strength and stiffness. Hence post confinement effect is more significant during high drift conditions. Experimental findings of Hung-Jen Lee -2009 [21] addressed the usage of double headed anchors in joint core for enhance anchorage capacity and cyclic behavior of joint in high seismic conditions (drift >4%). The findings concluded that use of single headed anchors may limit to low drift conditions (drift <3.5%). The use of multi headed anchors may delay the reduction of shear strength in joint core.

7 IMPLICIT SHEAR STRENGTHENING OF JOINT CORE

Implicit shear strengthening of joint core is a mechanism achieved by induced confinement effect implicitly so as to reduction the tensile stresses in joint core. In the headed anchorage system, the active confinement effect of unbonded anchorage system and passive confinement effect of bonded anchorage system within joint core are significantly influence the efficient stress transfer mechanism by Strut and Tie method. The contribution of concrete strength under strut action is accompanied by head bearing and bond resistance of headed anchor. The pure shear conditions of joint inhibit development of principal stresses in joint core. In this process, concrete failure is attributed to development of excess compressive stresses or tensile strain in major principal planes. Fig.12 shows the state of stress conditions in hooked and headed anchorage system of external beam column joint. The anchorage capacity of hooked bar is same as regardless the direction of bent of hooked bar and the hook extension is placed towards joint and the hook possess poor shear resistance mechanism when it bent outward direction as the minimum steel contributed in concrete strength. Hence joint core with hooked anchorage shows poor cyclic response

The formation of single strut mechanism (Fig.13a, Fig.13b) results unbalanced equilibrium conditions of forces and results poor performance of joint. During cyclic conditions the headed anchorage system provided efficient stress flow since the direction of concrete strut (hatched area) and local bearing stress at anchor plate coincide with each other. As a result the capacity of mechanical anchor increased by bearing plate located within the concrete strut area. Use of supplementary shear reinforcement is used to enhance tensile capacity of concrete and to avoid cone of fracture. Subsequently it provides good confinement in joint core. (Fig.13c & Fig.13d)

8 SUGGESTIVE MEASURES

Design codes of ACI 349-01,352-02R, NZS3101, and FIB-2000 are presented confined discussion on PIHA technique during mechanical anchorage of R.C foundations. But no specific guidelines addressed for its adoptability in seismic BCJ except few design limitations. Most of the codes follows seismic compliance of joints as per strength of concrete rather than shear reinforcement provisions. Codes are widely contradicted on parametric influence of joint against shear resistance mechanism, which include detailing aspects of shear reinforcement. Strength reduction factors of cracked concrete are normalized in concrete under cone of failure (0.65), side face blowout failure (0.55), and pull out or pry out failure (0.45) which are defined in post installation of anchors by direct tension (absence of supplementary reinforcement). For cracked concrete section the strength reduction factor (0.70) during face blowout failure is need to consider during post installation of anchor. The concrete mode of failure is not acceptable in the design of headed anchorage system. The failure of steel is acceptable due to possessing ductility. Use of supplementary reinforcement in with headed bars will improve the ductility of joint during failure. To meet this requirement, supplementary steel should satisfy displacement compatibility such as developing appropriate tensile force prior to peak failure of concrete.

9 CONCLUSIONS

This paper reports the analytical aspects of Post Installed Headed Anchorage (PIHA) system used for strengthening of R.C external beam-column joints. PIHA system is based on the principle of “Developing Implicit Strengthening Mechanism” of joint core. A wide range of advantages are featured in this system against seismic strengthening and constructability. It is most adoptive technique for precast and cast–in place joints and useful to strengthen BCJ at moderate, high seismic conditions. and rehabilitation of damaged joints. The headed bars used in this system are verified at bonded or un-bonded conditions of concrete. Salient features are follows.

- Post-Installed Headed Anchorage (PIHA) system provides implicit enhancement of shear resistance in beam-column joint by confinement and bond resistance. PIHA restricts brittle failure and shear deformation of joints and enhance elastic stiffness and ductility of joint core.
- Use of headed bars in PIHA is an added advantage of strengthening and delay the fracture failure of joint. It is good means to provide stable CCT node conditions and improves joint shear resistance.
- Provision of headed bars at bonded phase of PIHA is recommended when good concrete conditions exists in joint core (undamaged conditions). During this process PIHA provides shear resistance mechanism through passive confinement effect and establish a bond between steel and concrete through friction and bearing resistance of head.
• Provision of headed bars in un-bonded conditions of PIHA is suitable during poor conditions of joint concrete (preferably damaged). This system gives shear resistance mechanism by active confinement effect of joint by induce pretension forces by confined anchorage system. Anchor heads pays key role in shear resistance mechanism.

• PIHA restricts the entry of heavy reinforcement from beams to joint core. The additional requirements for anchorage and bond strength of beam can be substituted by PIHA technique.

10 RECOMMENDATIONS
This study recommends usage of Post Installed Headed Anchorage (PIHA) system during seismic strengthening of external R.C beam-column joints. Analytical studies explain the implicit strengthening mechanism of joint by PIHA. It provides rapid and assured process to mitigate the construction problems and rehabilitate the joints in beam-column joints such as reinforcement congestion, anchorage , fabrication , and rehabilitation etc This method has good adoptability for precast and cast in-situ R.C joints.

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