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Shear Strengthening of R.C Beam-Column Joint using Post Installation of Headed Anchors

K. Padmanabham [1], K. Rambabu[2]

[1]*Research Scholar (Ph.D), Department of Civil Engineering, Andhra University, India.*
[2] *Professor, Department of Civil Engineering, Andhra University, Visakhapatnam.. India*

Abstarct

Post Installation of Headed Anchor (PIHA) is an advanced technique proposed in this study for structural strengthening of R.C beam-column joints (BCJ). Previous research on seismic damages of R.C 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, a novel technique of "Post Installation by Headed Anchor" is proposed in this paper. It is an effective measure useful to enhance the implicit properties of joint core such as shear, stiffness, confinement and ductility. This method produce viable solution of conventional practice system of Precast , Cast in-situ beam column joints .Headed anchors provides good supplement to hooked anchorage system that improves shear, bond and ductile properties of joint which results delaying the ultimate failure .The state of fastening system considered in this study are bonded and un-bonded conditions anchors during mechanical and bonded fastening system in joint core. This paper focused on analytical aspects of proposed PIHA system so as to evaluate its strength and parametric influence against shear failure 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.

Keywords. *Beam-Column joint, Fastening Techniques, Headed Anchor, Implicit Strengthening. Post Installation.*

I. INTRODUCTION

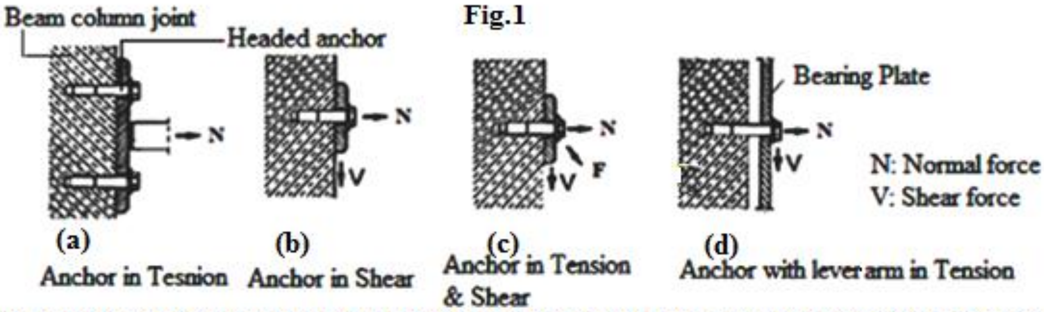
A. General

Current research studies on BCJ are based on explicit strengthening techniques of joints (Section enhancement, Fibre-wrapping, Metal stripping etc). Very few attempts are made to improve implicit strengthening of joints such as use of Fibre composites , Detailing of joint shear reinforcement, and Prestressing. It is quite evident that implicit strength of joint will contributed to shear and ductility enhancement of joint core. The current design practice of seismic BCJ are believed to be more conservative and safely adoptable. Accordingly due considerations are provided in the design codes for discrete external joint conditions as it exposed to high shear conditions. In this process joints are subjected to complex force transfer mechanism and critical failures by shear deformation and bond lose. In this context, the current seismic codes are unable to establish the real conditions of joint failures as the code provisions are established by strength based design system and far way to evaluate joint on performance based index. This process impeded good energy dissipation of joint (MJN Priestly-1975). But most of the designers intends to validate the performance of joints by displacement approach. This is quite contradictive approach and hinder the prospects of joint design. Constructability of BCJ is another important issue where the engineers often failed to establish correct detailing aspects of joint due to congested steel and confined geometry of joint. The effectiveness of conventional hooked anchorage system in joint is unable to restrict the fracture mechanism of joint core. These flaws need to address theoretically and modelled so as to meet the real time failures of seismic beam column joints.

B. Previous Research

Research community found the significance of beam reinforcement and its anchorage mechanism in seismic BCJ. The observations expressed that seismic joints with straight or hooked bars of stirrup confinement does not exhibit good seismic response and results large shear deformation by the application of cyclic loads. Experimental studies by Metwally E.L,1988 [1]. Allath,1995[2] expressed on shear deformation and reinforcement anchorage in BCJ are critical problems which associated with geometric configuration and detailing aspects of reinforcement. Studies conducted by Kaung J.S-2006[3] and Hayashi-1994 [4] expressed that anchorage of beam reinforcement significantly

Fig.1



SEISMIC FORCES ON DIFFERENT TYPES OF HEADED ANCHORAGE SYSTEM

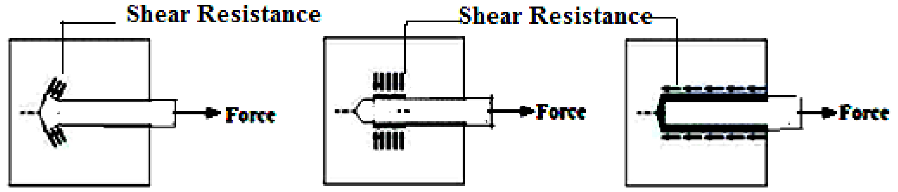
influencing the shear performance of joint. In this context, studies of Park and Millburn-1983 [5], Kitayama, Otani and Aoyamu-1987 [6], Park and Ruitong -1988[7] and
Joh-Goto- Shibata-1992 [8] discussed on size limitations of anchored reinforcement, for relocation of plastic hinge away from joint region .Wallance-1998 expressed that provision of headed bars in joint core is well supported by Strut and Tie mechanism (STM) as it facilitate ease of fabrication, concrete placement, and enhance the performance compared to hooked bars. But most of previous studies are unable to establish rigid joint conditions during high shear conditions as the design of joints are based on (Bernoulli) Flexural beam theory of inelastic approach. Park.R & Pauley.T, recommends the usage of mechanical anchors and its detailing aspects to mitigate design issues of seismic beam-column joints. In this context ductile detailing of hooked anchorage system gives deviated results of real form real happenings.

C. Current Research

Eligehausen.R -2006 [9] conducted a wide range of pullout tests of headed anchorage system to observe 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 posses good seismic energy dissipation and stable CCT (compression-compression tension) node conditions its strength is more than hooked anchors (Fig.4). Hence usage of headed anchors got more privileged at discrete joint conditions (External joints). ACI 352-02R and ACI 374.1-0515 suggested on substitution of hooked anchors by mechanical (headed) anchorage system gives an appropriate or better results of joint performance. The shear performance of seismic beam-column joint is influenced by wide range of parameters in joint core.

Park and Pauley-1989 stated that the functionality of shear reinforcement is more crucial of joint than confinement 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 is less than $10(fck)^{½}$ (Psi). Noguchi -1992 [11] expressed that during large deformation (drift $>$ 2%) joint 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 $[\text{compressive strength of concrete}]^{0.24}$ 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.

Fig.2



a) Mechanical Headed Anchor b) Frictional Anchor c) Chemical Bonded Anchor

RESISTANCE FORCE IN DIFFERENT ANCHORING SYSTEMS OF BEAM COLUMN JOINT

The study observed that no brittle failure of concrete occurred in joints of headed bars , if the ratio of head size and bar dia (A_{brg}/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_{brg} /A_b > 4.2) exhibit higher anchorage strengths than small heads (A_{brg}/A_b=2.6 to 2.9).

II. OBJECTIVES

Objectives are emphasized on the basis of theoretical studies and physics behind use of post installation of headed anchorage system in beam column joints. The study focused on (i) Force transfer mechanism, (ii) Failure conditions of joint, (iii)Seismic suitability of headed anchorage system, (iv) Implicit strengthening, and (v) Design improvements.

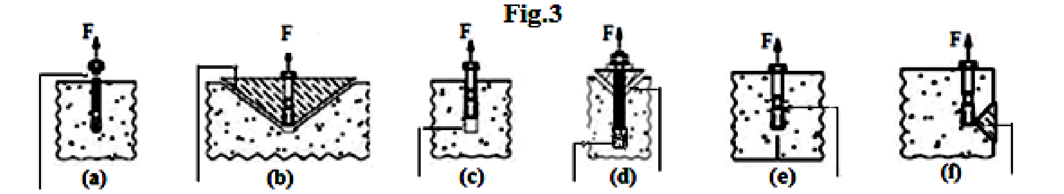
III. FORCE TRANSFER MECHANISM & FAILURE CODITIONS OF HEADED ANCHOR

During seismic action headed anchors of beam column joints are subjected to lateral forces (tension or compression) , transverse shear, or combination of both (Fig.1).Transfer of this forces in joint core was explained STM during discrete joint conditions. The participation of Compression strut (by concrete) and Tension tie (by steel) is very crucial in STM mechanism, since STM formation significantly influence the strength and performance of joint core. Further STM formation 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 during external and internal CCT node formations are shown in Fig.4. During force transfer mechanism the detailing aspects of reinforcement should meet the strain compatibility of joint concrete within joint core.To meet the external force action, headed anchors develops Implicit shear resistance mechanism by head bearing and bond resistance that depends on type of fastening system used and its installation. It was comprised by (i) Mechanical, (ii) Frictional resistance ,(iii) Bonded anchorage of headed Mechanical anchors (Fig.2a) t possess significant role on force-transfer mechanism through head bearing resistance. 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. Bonded anchorage (Fig.2c) is a conventional type of Post-installed anchoring system. This system was often used in practice. 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 development of bond between steel and concrete.

IV. PARAMETRIC INFLUENCE AND FAILURE MODES OF HEADED ANCHORAGE SYSTEM

The performance evaluation of seismic joints is based on the development of interaction mechanism between inelastic behaviour of beam and elastic behaviour column at joint core. In this context, Park.R & Pauley.T concluded that unless a significant axial load (P) acts on column [P < (0.10 - 0.30) x f_{ck} (concrete strength) x A_c (area)] the design of seismic BCJ should be 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 lateral reinforcement in joint core may consider during shear resistance mechanism. But this argument is deviated by successive researchers as they express most of joint failures shows significant role of compression strut formation in joint concrete. During high seismic conditions, the behaviour of headed anchors in BCJ are justified by following important parameters mentioned below.

Fig.3



DIFFERENT TYPES OF FAILURE MODES IN HEADED ANCHORS UNDER DIRECT TENSION

A. Strut and 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 as (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 most of the conventional design system of joints, the 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 the concrete exhibit crushing or buckling failure due to internal stresses. Hence the deep strut conditions of joints should potentially verified by tensile strength of concrete.

B. Anchorage depth*.*

The failure of anchors crucially depends on embedment depth of anchors , 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 in failure assessment of joint. In this context, studies conducted by De.Vries R.A[19] ,Thompson M.K [20] used a simplified definition on shallow and deep embedment depth of headed anchorage system (Fig.6). Studies conducted by by Hung Jen Lee-2009 [21] mentioned substitutive definition that deep anchorage system is one that definition on embedment depth of anchors of BCJ. Accordingly possess embedment depth is greater than five times the least cover dimension of anchored bar.(Fig5&Fig6). The shallow anchorage system is one which possess anchorage is less than five times the least cover of anchored bar. In the context of headed bars, more bearing strength is provided by use of greater embedment depth as it provides good confinement effect of concrete by 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 is 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 intended to side face blow out of concrete. Wallace (2009) suggested that minimum embedment of headed anchors should be more than 12ø and relative head area ratio (ρ) should between 3-to-4 .Experimental findings of Thompson et al [20] expressed that the optimum head bearing strength of effective concrete strength achieved by deep anchorage system when anchor embedment depth (Ld) reach to 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 is less than 50% of column depth) the cone shaped concrete failures are generally happened. The head bearing stress was not developed fully and the joint strut not confined by head. The moderate depth of anchorage system (embedment depth Ld < 50% column depth L) intends the concrete break out failures by radiating the cracks from both faces of the head. Here the head bearing is partially participated along with bond conditions of anchored bar during shear resistance. During deep anchorage system, the diagonal shear cracks initiated at head and propagated towards compression zone of beam. Both head bearing and bond stress are fully contributed in producing the resistance mechanism of anchorage failure. Side face blowout failure of concrete is most susceptible failure mode in deep anchorage of headed bar. ACI 352R-02 suggested that any hooked or headed bars that satisfy ASTM-A970 specifications can be used for seismic anchorage of beam-column joint if the embedment depth is more than 8φ (φ: diameter of anchored bar). Research findings of Hung Jen lee-2009 [21] expressed on usage of multi headed anchors in joint core as it effectively enhance shear capacity of joint during cyclic loads of high drift conditions .

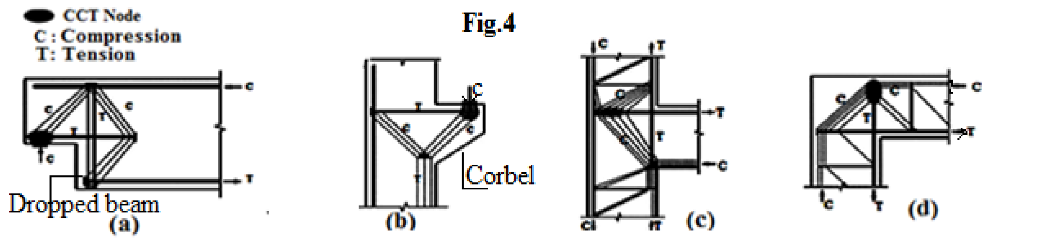


Fig. 4a & 4b: Formation of External CCT nodes   Fig.4c & 4d: Formation of Internal CCT nodes

CCT NODE CONDITIONS IN EXTERNAL BEAM COLUMN JOINT

C. State of Concrete

In the design of headed anchorage system, the state of concrete is defined 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 is intends to fracture failure of steel reinforcement in joint core. Studies pertaining to cracked concrete conditions are more significant in design of anchors as it exhibit the strength of un-damage and post damage conditions of connecting elements. It is a recommended practice that design of seismic joints must proceed under cracked conditions of concrete, as the bond strength influenced by development of tensile strains in concrete. In this process, joint must studied by the induced effect of concrete softening before crack formation and tension stiffening effect after crack formation so as to apply suitable confinement measures in joint core. 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. Modelling of cracked concrete is quite essential to evaluate performance and strengthening measures of joint.

The design of BCJ are proceed by

a).Smeared crack plastic model (Degraded stiffness),

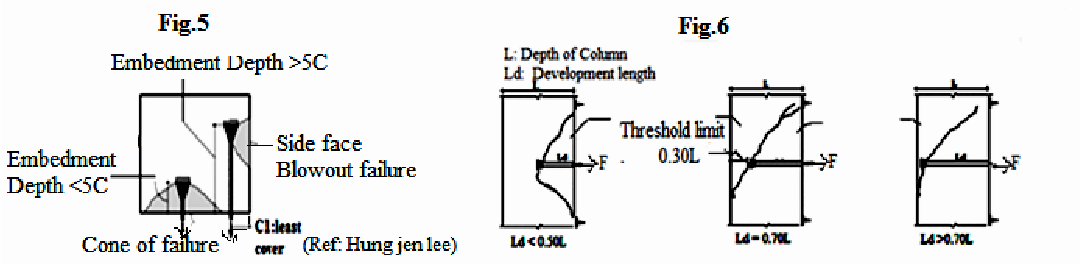
b).Damage plasticity model.

c). Bond slip model (ABAQUS).

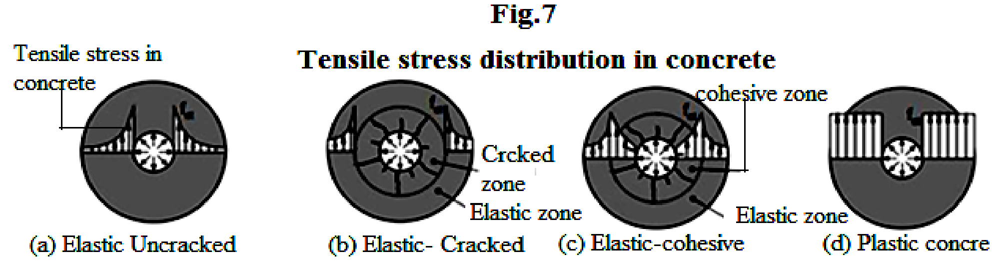
D. Joint Confinement

Two types of confinement effects are influencing the joint behaviour 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 the anchorage mechanism of joint through Active and Passive Confinement process. Active confinement is one which 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 addressed by Active confinement system. (Fig.9). Passive confinement is referred to be stress field generated by the forces of 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.(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 behaviour of post installed headed anchors are characterised under elastic un-cracked section and elastic cracked sections of concrete. The stress distribution at various phases of joint concrete is shown in Fig.7. The mechanical properties of concrete shows significant influence on bond development between concrete and reinforcement. Fig.7 explains different phases of concrete conditions and crack pattern against the plastic properties. 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 behaviour 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 behaviour of concrete was derived by using principles of fracture mechanics. This model is based on tensile behaviour 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. The ultimate failure strength of concrete is higher than rest of the modelled concrete.



INFLUENCE OF EMBEDMENT DEPTH SHALLOW & DEEP ANCHORAGE OF HEADED BARS



CRACK PATTERN & STRESS DISTRIBUTION IN DIFFERENT CONDITIONS OF CONCRETE

V. POST INSTALLATION TECHNIQUE

Use of headed anchors are considerably increased in the recent past due to quick and easy installation with economic viability. The mechanical, friction and adhesive anchors are extensively used for structural strengthening of concrete. Fasteners should be designed to exhibit sufficient load carry capacity and allowable deformation. The anchorage system is defined by the way of anchor installation process which is in the form of (i)Direct installation, (ii) Drilled installation (iii) Cast in- place installation system. In this process the detailing aspects of headed fasteners are more significant for shallow and deep strut conditions prevailed in joint core.

TABLE .1
SEQUENCE OF POST INSTALLATION BY HEADED ANCHORAGE SYSTEM

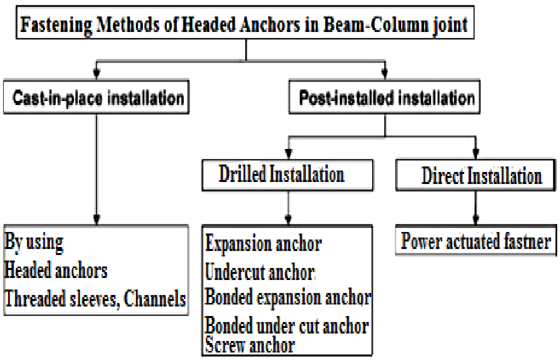
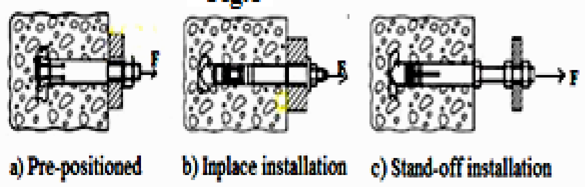
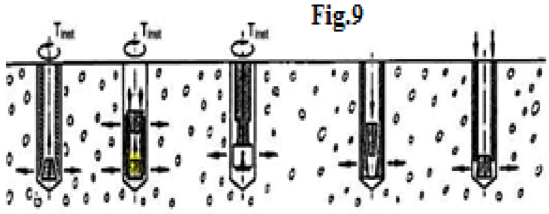


Fig.8



DIFFERENT PHASES OF ANCHOR INSTALLATION

Fig.9



TORQUE CONTROLLED EXPANSION ANCHORING

A. 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. Accordingly the installation process of anchors are classified as (i) Pre-position installation of anchor, (ii) In-place installation (iii) Stand-off installation (Fig.10)

As explained in Fig8, three types of installation configurations commonly used for anchor fastenings by direct installation method. It is classified as (i) Pre-position drilled installation (Grouted anchors) (ii) In-situ placed installation (iii) Stand-off installation.

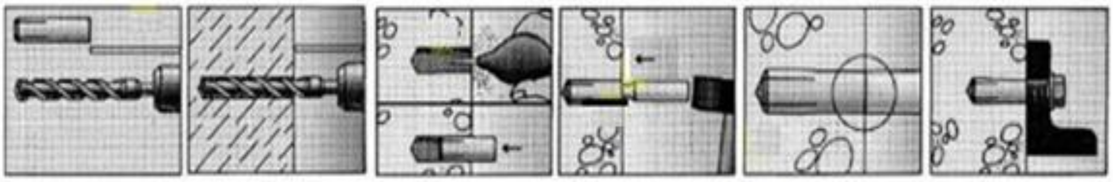
Pre-position drilled installation (Fig.8a) involves making a drilled hole with suitable clearance in hardened concrete and insert the fastened anchor and fix it with high strength epoxy grout. The size of drilled hole must be large enough to develop bond resistance between the anchor and constituent 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

B. Classification of anchorage methods

A drilled anchor is able to take both compression, and tension through mechanical interlocking between steel threads and surrounding concrete. This type of installation is further classified as (i) Torque controlled method (Fig.9) (ii) Displacement controlled method. (Fig.10). During Torque controlled expansion method, the transfer of tensile force to base material is followed by surface friction and mechanical interlocking with base material. It may generate pre-stressing force in bolt and clamps of fastened anchor against the surface of the base material. This pre-stressing force diminished after installation of anchor due to relaxation of localised stresses in concrete .Torque controlled anchors may further classified under sleeved and bolted type. The sleeve type anchors consists threaded bolt, nut and washer with expansion sleeve deformations 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 ,the further application of torque draws the cone at embedded end of the anchor up into the expansive sleeve ,thereby expanding the expansion elements against the sided of the drilled hole. To ensuing 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. The displacement controlled expansion anchoring (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 localised 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 high expansion stresses induced are reduced in later stages by relaxing stress of concrete.

Fig. 10



INSTALLATION OF DISPLACEMENT CONTROLLED EXPANSION ANCHOR

VI. IMPLICIT STRENGTHENING MECHANSIM OF JOINT CORE

Implicit shear strengthening of joint core is a mechanism applied to induce confinement effect on joint core implicitly so as to reduce the tensile stresses in joint core is possible. In the headed anchorage system, the active confinement effect of unbounded anchorage system and passive confinement effect of bonded anchorage system are significantly influence the efficient stress transfer mechanism and can be well defined by STM method. The contribution of concrete strength under strut action is accompanied by head bearing and bond resistance of headed anchor. Pure shear conditions of joint inhibit the 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[22]. Fig.12 shows 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 (Fig.13a & Fig.13b). 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. Hence it provides stable CCT node conditions[23]. As a result the capacity of mechanical anchor increased by bearing plate located within the concrete strut area .The use of supplementary shear reinforcement applicable to enhance tensile capacity of concrete in joint against cone of fracture. Headed anchors provides good confinement by stable strut formation. (Fig.13c,13d)

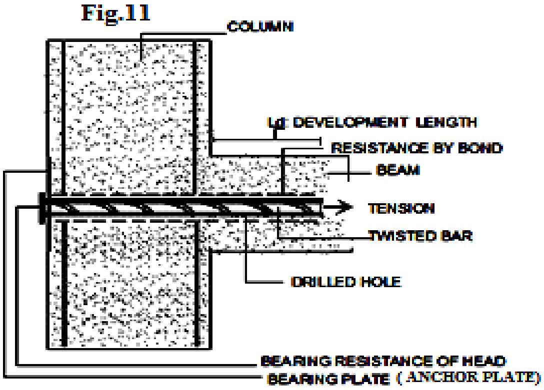
VII. BOND CONDITIONS OF ANCHORS

The post installation of headed anchor with concrete is designated by two methods of fastening system associated with concrete. Each method constitute its own merits in the strengthening process of joint core .They are (i) Bonded anchorage (ii) Un-bonded anchorage. Bonded anchorage system provides passive confinement effect in joint core through stress field generation by 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 given inFig.11&12

A. Adhesively Bonded Anchorage

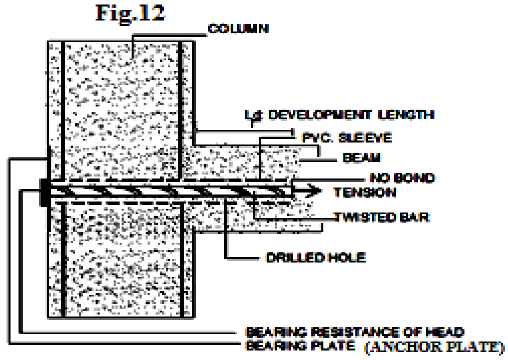
As shown in Fig.11 of Adhesive anchorage system, the anchored reinforcement is in direct contact with joint concrete. Adhesively bonded anchors are sensitive about type of loading and direction of installation. During the installation a hole is drilled across the joint with tolerance and produced to intercept required depth of connected beam. Later the drilled hole is filled with epoxy grouted material that interface both anchor 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 core and preferred to use in moderate or high concrete strength conditions. 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] . 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.

Fig.11



BONDED ANCHORS OF POST INSTALLATION

Fig.12



UN-BONDED ANCHORS OF POST INSTALLATION

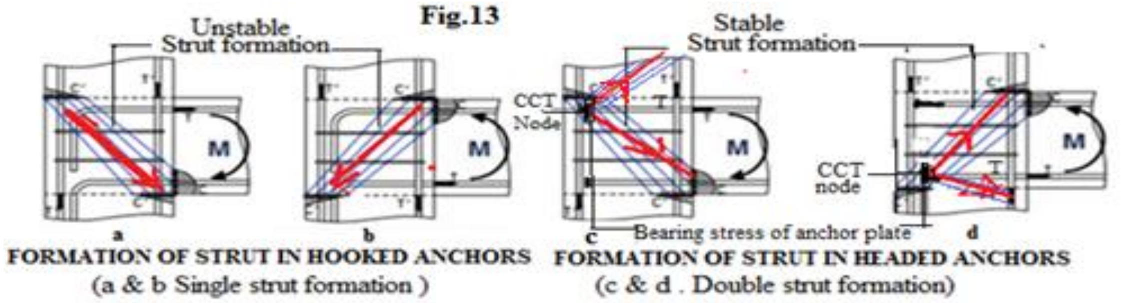
B. Un-Bonded or Confined Anchorage

Fig.12 refers the Un-bounded conditions of headed anchorage system as it produce active confinement effect on joint core. This method is similar to develop pre-tension effect through confinement on joint core and adoptable during low or moderate shear condition of joint. In this process headed bars are passing through an existing opening (sleeves or conduits) of joint and the tail end of bar is embedded in beam 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 resistance of bar only and no bond stress by stem during force transfer mechanism. In this possess headed anchor in joint core is not in direct contact with concrete. This process shall contribute to induce implicit pre-tensioning force in anchored steel there by confinement effect produce on joint core .One method of applying pre-tension forces on joint is by torque controlled screwed anchors arranged in joint core. Another method of un-bonded anchoring system is produced by use of undercut expansion anchors. This system is very suitable for moderate seismic conditions, where the joints are inhibited by low shear conditions.

VIII. SEISMIC INFLUENCE ON ANCHORS

A. Anchorage conditions

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, cementecious 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 behaviour of post installed headed anchors depends on prevailing conditions of concrete core, embedment depth, type and sequence of loads acting on joint. During seismic action , 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 behaviour 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.



STRUT FORMATION IN HOOKED AND HEADED ANCHORAGE SYSTEM

B. 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 normalised 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.

IX. CONCLUSIONS

This paper discussed about the theoretical aspects of Post Installed Headed Anchorage (PIHA) system used to strengthen R.C External beam-column joints. PIHA system is based on the principle of “Developing Implicit Strengthening Mechanism” of joint core. It is an adoptive technique for precast and cast–in place joints and useful to strengthening of BCJ at moderate and high seismic conditions. It provides implicit strengthening of damaged joints by use of headed anchors. This PIHA system is verified at bonded or un-bonded conditions of concrete. Salient features this study are as follows.

1.PIHA provides implicit enhancement of shear resistance in beam-column joint through confinement and bond resistance mechanism.

PIHA restricts brittle failure and shear deformation of joints. It enhance the elastic stiffness and ductility of joint core.

2.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.

3.Provision of headed bars at **bonded** conditions of PIHA is suitably recommended when good concrete conditions exists in joint core (undamaged conditions). In this process PIHA provides shear resistance through passive confinement effect and establish bond between steel and concrete by friction and bearing resistance of headed bar.

4.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.

5. PIHA restricts the entry of heavy reinforcement in joint core (from beams to joint core). The additional steel requirement of anchorage and bond strength can be substituted by PIHA technique in joint core.

X. STUDY RECOMENDATIONS

This study recommends usage of Post Installed Headed Anchorage system during seismic strengthening of R.C beam-column joints. The study explains about Implicit strengthening mechanism of joint by PIHA. It is a rapid and assured technique useful to mitigate most of the constructability issues in BCJ. The PIHA technique mitigates reinforcement congestion, fabrication issues and provides viable method during rehabilitation beam-column joint. It is an adoptive system for precast and cast in-situ joints.

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