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COMPREHENSIVE GUIDE TO THE PROCEDURES FOR ESTABLISHING REINFORCED CEMENT CONCRETE (RCC) STRUCTURES

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ABSTRACT
During this process, the primary flexural members are strengthened in the positive moments using conventional retrofitting techniques, which include replacing existing members, increasing cross sections with overlay and jacketing, adding new members such as columns and beams, external plates, fiber-reinforced polymer materials, adding supports, and introducing pre-stressing. Numerous studies have been conducted on strengthening and retrofitting concrete-framed buildings using various materials and methodologies. The results of the research trials were the incremental strength attained using certain materials and techniques that the researchers chose at random. Retrofitting structural members becomes necessary when it is proposed to alter the functional use of the existing structures. But, the techniques to strengthen the negative moment region are very little especially for an external column-beam junction in any mid floor of a multi storey structures. So this review is intended to study the principles & practicesand researches available to strengthen the negative moment region of the structural elements in a reinforced cement concrete framed structure. This paper provides a comprehensive review of methods of strengthening and outlines some suggestions in this area.

Key words: Column-Beam Junction, FRP Jacketing, Retrofitting, Plate Bonding.

INTRODUCTION

Subject Background
The functional demands in commercial buildings in cities like Chennai changes from user to user under the different perspective like customer convenience, statutory regulations, and occupational requirements. Repair, retrofitting and rehabilitation of buildings are gaining importance in order to enhance their usefulness instead of total replacement of the structure as a whole (retrofitting refers to addition of new technology or features to older systems and seismic retrofit refers to make thestructure earthquake resistant). Though the seismic retrofit is done using the principles of retrofitting, the purpose of seismic retrofit is exclusively to make the structure earthquake resistant by way of improving ductility. For example, when aground + 2 storied building has to be reconfigured as a stilt + 3 storey buildings, the major scope of retrofitting works involved are strengthening of columns, removal of required columnsin the ground floor to enable optimal usage of stilt floor for parking. The strengthening of columns is performed effectively by jacketing, and the required columns are removed. But forstrengthening of beams with increased span (due to removal of intermediate columns), the positive moment regions are strengthened by jacketing and/or by adding external member. Butthe same for negative moment region is a tedious task. This study is intended to review the methods to strengthen structural elements with key focus on the external column-beam junction.

Problem Statement

In a particular situation, a column has to be removed at stilt floor to ease theparking which involves demolition of the particular column at stilt floor, strengthening of columns on either side, strengthening of foundation of columns on either side and strengtheningof beam on positive moment region and negative moment region. Here strengthening of the beam at the negative moment region is a tedious task and rest of the scope are comparatively has hands on solutions like jacketing and increasing size of the member, and addition of externalmember like plate or rolled steel sections for the beam at positive moment region.

NEED FOR THE STUDY

Besides thecorner beam-column joints are also experimented rarely. The L-beams are less experimented which are often subjected to torsion and the isolated L-beams have skew neutral axis. The flangeof the edge beam is seldom considered in any researches. Researches on behaviour of external beam-column joints are not done much other than for theseismic strengthening which is intended to improve the ductility of the connection. So, the research on external beam-column joint, especially when there is a need tostrengthen the negative moment region in case of significant increase in span and the requirement of additional strength is in tune of 50% of the original design due to the change ofstructural configuration is felt necessary.

METHOD OF STUDY

The literatures collected are grouped on various classification like type of research (analyticalor experimental), type of structure (concrete or steel), method of strengthening techniques used (external addition of strengthening members, jacketing, overlaying, near surface mounted reinforcement and pre-stressing), behaviour of structural element considered (flexure, shear, axial, torsional, ductility, and durability), type of loading applied for experiment (fatigue, cyclic, static, dynamic, fire) and the materials used for strengthening (Carbon fibre, Glass fibre,Aramid fibre, Textile fibre, Polyethylene fibre, Steel fibre reinforced concrete, Ferro cement, and Steel plate) and bonding techniques adopted (through chemical bonding, mechanical anchors or both).

CRITERIA IN RESEARCHES IN STRENGTHENING OFSTRUCTURAL ELEMENTS

The researchers have worked on strengthening of RCC structural elements with varying set ofconstraints/ criteria which are based on individual perspectives of authors. The authors have setdifferent parameters like different materials with varying material specification like thickness,number of layers of wrap, different lengths of wrap, different adhesives having different bond strength, different type of application like U-wrap, two side wrap, at 90^0 & at an angle, surfacemounting, external addition, different combination of base materials, different substrate, effect of amount of reinforcement in original structure on strengthening result, influence of grade of concrete on strengthening, aspect ratio, L/d ratio, length of application of laminate, different exposure, loading pattern like two point loading, three point loading, real time loading,boundary condition and so on.

EXISTING RESEARCHES ON STRENGTHENING OFCONTINUOUS BEAMS

Ozgur Anil (2016) has studied the effectiveness of CFRP in strengthening the shear deficiencyin the RCC T beams subjecting to cyclic loads. He has experimented six RCC beams with a T section considering the width of CFRP straps, arrangements of straps along the shear span and anchorage technique as different parameters. He has considered inclined CFRP straps along theshear deficient section and found that the all types of CFRP arrangements improved the strengthand stiffness of the specimens including the ductility of the element and the failure mode has varied according to the different strengthening schemes and the failure was mainly by delaminating and not by conventional flexure failure.

Al-Mahaidi and Hii (2016) have focussed on the bond-behaviour of externally bonded CFRP in an overall investigation of torsional strengthening of solid and box-section reinforcedconcrete beams. Significant levels of debonding prior to failure by CFRP rupture weremeasured in experiments with photogrammetry. They have carryout numerical analysis using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist behaviour,steel and CFRP reinforcement responses, and crack patterns was achieved. The addition of a bond-slip model between the CFRP reinforcement and concrete meant that the debonding mechanisms prior to and unique failure modes of all the specimens were modelled correctly as well. Numerical work was carried out using non-linear finite element (FE) modelling. Good agreement in terms of torque-twist behaviour, steel and CFRP reinforcement responses, and crack patterns was achieved.

Aiello et al., (2022) compared the behaviour between continuous RC beams strengthened with of CFRP sheets at negative or positive moment regions and RC beams strengthened at both negative and positive moment regions. All the beams were strengthened with one CFRP sheet layer and with a constraint that the beams were not loaded at the middle of span. The control beams underwent a typical flexural and failure of the strengthened beams occurred by debonding of the CFRP sheets, together with concrete crushing. They concluded that when thestrengthening was applied to both hogging and sagging regions, the ultimate load capacity of the beams was the highest and about 20% of moment redistribution could be achieved by CFRPsheets externally glued in the sagging region.

Hii, A.K.Y., and Al-Mahadi, R. (2022) briefly recounted the experimental work in an overall investigation of torsional strengthening of solid and box-section reinforced concrete beams with externally bonded carbon fibre-reinforced polymer (CFRP).

Ameli and Ronagh (2022) experimentally investigated together with a numerical study on reinforced concrete beams subjected to torsion that are strengthened with FRP wraps in a varietyof configurations. Experimental results show that FRP wraps can increase the ultimate torque of fully wrapped beams considerably in addition to enhancing the ductility

Chalioris (2022) addressed an analytical method for the prediction of the entire torsional behaviour of reinforced concrete (RC) beams strengthened with externally bonded fibre- reinforced-polymers (FRP) materials combining two different theoretical models; a smeared crack analysis for plain concrete in torsion for the prediction of the elastic behaviour and the cracking torsional moment, and a properly modified softened truss theory for the description of the post-cracking torsional response and the calculation of the ultimate torque capacity. The contribution of the FRPs is implemented by the specially developed (a) equations in a well- known truss model and (b) stress - strain relationships of softened and FRP-confined concrete.In order to check the accuracy of the proposed methodology an experimental program of 12 rectangular beams under torsion was conducted. Tested beams were retrofitted using epoxy- bonded Carbon FRP continuous sheets and discrete strips as external reinforcement. Strengthened beams with continuous sheets performed improved torsional behaviour and higher capacity than the beams with strips, since failure occurred due to fibre rupture. Comparisons between analytically predicted results and experimental ones indicated that the proposed behavioural model provides rational torque curves and calculates the torsionalmoments at cracking and at ultimate with satisfactory accuracy.

Manuel A.G. Silva and Hugo Biscaia, (2008) have experimented the effects of cycles of saltfog, temperature, moisture and immersion in salt water on the bending responses of beams externally reinforced with GFRP or CFRP on bond between FRP reinforcement and concrete as debonding failure is the most common failure in using the FRP as strengthening materials and the environmental factors have the major role for the debonding failures. They have concluded that the temperature cycles of -10^0 C to +10^0C have incurred the most detrimental loss of 31% of the ultimate capacity of beams. The immersion in salt water results in a gain of21% due to the conjugated effect of increase in tensile strength of concrete and post-curing of the polymers. The failure type has been at the interface of FRP and substrate for the salt fog cycles, failure in the concrete substrate is associated with the temperature and moisture cycles,and the temperature cycles have caused significant loss of capacity of beams.

N. Pannirselvam et al., (2008) have developed a new computational model based on the General Regression Neural Network for predicting the yield load, ultimate load, yield deflection, ultimate deflection, deflection ductility and energy ductility of such beams analytically. They have validated the results through experimental investigations on nine RC beams with steel ratios of 0.419, 0.603 and 0.905% plated 0, 3 and 5 mm thick GFRP laminates.They have concluded that the predictions of the model closely agreed with experimental results.They have predicted that the yield strength of the GFRP plated beams were higher than the un-plated beams by 76% to 111% for 3mm and 5mm thick GFRP plating.

Chalioris (2008) has investigated the additional strength attained by strengthening the 14 no's reinforced cement concrete rectangular and T-beams with carbon fibre reinforced polymer(CFRP). The testing were conducted for pure torsion and found that based on the measured values of the torsional moment at cracking and at ultimate, the strengthened rectangular beamsexhibited enhanced torsional behaviour and higher capacity about 46% and the U jacketed flanged beams exhibited premature de-bonding failure and substantial reductions of the potential torsional capabilities. However, he has found the increment in strength of the flangedbeams under U wrap was in tune of about 35% and he has concluded that the CFRP could effectively be used as external torsional reinforcement in under reinforced concrete elements without steel transverse reinforcement.

Noorwirdawati Ali et al., (2009) have reviewed extensively the researches done on shear strengthening of reinforced concrete continuous beams using externally bonded FRP sheets andthe design approaches used to calculate the shear capacity of the FRP sheets that contribute to the shear capacity enhancement of the beams. They have reviewed the wrapping schemes, fibreorientation, spacing of strips and their significant impact & effectiveness on strengthening andhave reviewed the Triantafillou Model which adopts the classical truss analogy and is based onthe geometry of shear crack and the simplified stress distribution along the diagonal crack andthe Khalifa and Nanni model which was based on FRP rupture and delamination of the FRP from the concrete structure and the ACI Committee 440 model which suggest that the shear strength contribution of FRP shall be calculated by the determination of the force from the tensile stress in the FRP across the assumed crack. They have concluded that only limited studies have been done which are insufficient to confirm the applicability of existing models shear strengthening of negative moment region.

Deifalla A. and Ghobarah A (2010) developed an analytical model for the case of the RC beams strengthened in torsion. The model is based on the basics of the modified compression field theory, the hollow tube analogy, and the compatibility at the corner of the cross section. Several modifications were implemented to be able to take into account the effect of various parameters including various strengthening schemes where the FRP is not bonded to all beam faces, FRP contribution, and different failure modes. The model showed good agreement with the experimental results. The model predicted the strength more accurately than a previous model. The model predicted the FRP strain and the failure mode.

Mahmood and Mahmood (2021) have conducted several experiments to study the torsionalbehaviour of prestressed concrete beams strengthened with CFRP sheets. They have taken eightmedium-scale reinforced concrete beams (150mmx250mm) cross section and 2500mm long were constructed pure torsion test. All beams have four strands have no eccentricity (concentric)at neutral axis of section. There are classified into two group according uses of ordinary reinforcements. Where four beams with steel reinforcements, for representing partial prestressing beams, while other four beams have not steel reinforcements for representing full prestressing beams. The applied CFRP configurations are full wrap, U jacked, and stirrups withspacing equal to half the depth of beam along its entire length. The test results have shown thatthe performance of fully wrapped prestressed beams is superior to those with other form of sheet wrapping. All the strengthened beams have shown a significant increase in the torsional strength compared with the reference beams. Also, this study included the nonlinear finite element analysis of the tested beams to predict a model for analysing prestressed beams strengthening with CFRP sheets.

Zojaji and Kabir (2021) developed a new computational procedure to predict the full torsional response of reinforced concrete beams strengthened with Fibre Reinforced Polymer (FRPs), based on the Softened Membrane Model for Torsion (SMMT). To validate theproposed analytical model, torque-twist curves obtained from the theoretical approaches are compared with experimental ones for both solid and hollow rectangular sections.

Majid Mohammed Ali Kadhim (2021) has studied the behaviour of the high strength concrete continuous beam strengthened with carbon fibre-reinforced polymer (CFRP) sheet with different CFRP sheet lengths. Three full-scale continuous beams are analysed under two points load, and the data of analysis are compared with the experimental data provided by otherresearchers. ANSYS program is used and the results obtained from analysis give good agreement with experimental data with respect to load–deflection curve, ultimate strength, andthe crack patterns. The length of CFRP sheet is changed in the negative and positive regions and the results showed that the ultimate strength of the beam was reached when the value of length of CFRP sheet/ Span length reaches 1.0, and when the value decreases, the ultimate strength of beam also decreases a little (1.4%), but when it decreases less than 0.6, the ultimatestrength also decreases a lot (15%).

Muhammad Mukhlesur Rahman and Jumaat Mohd Zamin (2023) have conducted a study on the effect of length of CFRP laminate in strengthening the tension zone of the reinforced concrete T-beam. They have experimented 1 no's control beam without stump and 2 no's specimen beam with stumps. The CFRP in compression zone of specimen beams were providedto the entire length whereas in the tension zone, it was 2500mm and full length (3000mm) andtested under three point loading and the failure loads were 69 KN for control beam, 104 KN &120 KN for the specimen beams. The failure mode for the control beam was by conventional flexure failure and for the specimen beams it was by end peeling. They have found the strengthincrease was 70% when the laminate was applied to full length of tension zone and 50% whenthe laminate was applied to a length where shear stress is to occur less than 0.80MPa (as per technical report 55).

EXISTING RESEARCHES ON STRENGTHENING OF COLUMN-BEAM JOINTS

Tarek and Youssef (2022) have formulated a computer program to predict the shear capacity ofthe joint and joint shear stress variations at various stages of loading and diagonal shear stress at the joints and found the analytical study is in agreement with the experimental investigations.The authors have found that the effectiveness of FRP strengthened joint could be increased through mechanical anchorage thereby suppressing the debonding failure. The increment in joint shear strength has been in tune of 48% and 65% in case of wrapping coupled with mechanical anchorage.

Alexander G. Sonos., (2008) has studied experimentally the performance of CFRP and RCCjackets in the post-earthquake and pre-earthquake retrofitting of beam-column sub assemblages.He has tested 4 no's identical control specimen with less transverse reinforcement and with notransverse reinforcement at joint. In the strengthened specimen, 1 specimen was strengthened by way of four sided cement grout jacketed with additional longitudinal and collar type transverse reinforcement in the joints and additional ties in the columns. The treatment given to another specimen was removal and replacement of all loose concrete with a premixed, non-shrink rheoplastic, flowable, and non-segregating mortar of high strength and high strength fibre jacketing of the joint and column region. Upon testing the control specimen resulted in premature shear failure during the early stages of seismic loadings and got damaged both in sub-assemblages and in the joint region. The failure of both the strengthened specimen were atthe beam by way of forming hinges at the beams indicating the transformation of brittle joint shear failure mode at junction to a more ductile failure mode at beams. Out of the two techniques adopted, the author claims that the reinforced concrete jacket has performed more effectively than the high strength fibre jacket.

Lakshmi.G.A, (2008) has analytically and experimentally studied the behaviour of beam- column joint under cyclic excitation. The specimen were designed to fail in three different modes like flexural failure of beam, shear failure of beam and shear failure of columns when cyclic load is applied. The author has strengthened all the three type of specimen using FRP materials in such a way that the eventual failure of the system is due to flexural failure of the beam which is a most acceptable failure mode. The author has obtained the result that the strengthening of column-beam joint with FRP composite has resulted the transformation of failure mode of column to the beam and the strength increase has been found to be 45% to 55%and the analytical study carried by using finite element analysis have in good agreements withthe experimental study.

K.R. Bindhu et al., (2009) have experimented different model specimens of beam column joints designed for different codal provisions (IS: 456, SP-34 and IS: 13920) and compared theresult and concluded that in all methods of detailing, the joints fail by developing tensile cracksat the interface between beam and column which satisfies the condition of strong column-weakbeam condition, and the joints had adequate shear resisting capacity and the specimen having confined reinforcement as per IS: 13920 had an improved energy absorption capacity than the lateral reinforcement detailing.

Lee W.T et al., (2010) have conducted a study on RCC beam-column joint designed basedon pre-seismic code guidelines which will not have transverse reinforcement strengthened withCFRP and tested for the structural stiffness, strength and energy dissipation capacity. They havefound the result that the rehabilitation strategy has been

effective to increase the ductility of thejoint and transform the failure mode to beam or delay the shear failure mode.
Polies W et al., (2010) have experimented the flat slab column interior joint duly strengthened with CFRP sheets subjected to monotonic shear and unbalanced moment keepingthe effect of eccentricity as key design parameter. The control specimen was loaded up to failureand in the strengthened specimen the load has been applied in two stages of 70% of ultimate load creating flexure cracks in the tension zone and in the second stage of applying load, the cracked specimen is reinforced using CFRP sheets bonded on the tension cracked surface. On testing, they have concluded that the CFRP sheets have enhanced and restores the ultimate loading capacity and stiffness of all cracked specimen and the increment in strength was in therange of 43% to 51% and also observed that the more the load eccentricity lesser the strength increment in the rehabilitated specimen.
Kien Le-Trung et al., (2010) have found from the experimental investigation of 14 no's exterior RCC beam column joint specimen strengthened with different configurations of CFRPsheets that addition of CFRP composites to non-seismic specimen significantly improve the lateral strength as well as the ductility of the joint. They have adopted different configuration of wrapping such as T-shape, L-shape, X-shape and strip combinations. Out of the tested configuration, the X shaped configuration of wrapping was found to be resulted in a better performance in terms of ductility and strength.
K. Balasubramanian et al., (2012) have experimented the performance of beam-column joint by strengthening in four different ways, by providing CFRP laminates in the top face of the beam, providing CFRP laminates in the top face of the beam and confining the junction with CFRP sheets, providing MS flat section in the top face of the beam, anchored with MS bolts on both faces and by providing additional reinforcement in the top face by cutting a groove and filling the groove with non-shrink cementitious material and confining the joint with CFRP sheets. For analytical predictions the model suggested by Ibarra et al. (2005) was applied, and the performances of the specimen were evaluated under cyclic loading. To predict the failure the hysteresis model of deformation vs. the total cumulative energy dissipation was used and inexperiment it was found that having equal initial stiffness in all specimen, the yield load takencorresponding to a deflection of 5mm has varied, the specimen strengthened only providing CFRP laminates on the top face of the beam has taken comparatively 25% lesser load (32 Kilonewton against 39 KN) than the other specimen. The authors have concluded that the strengthening by confining the junction with mild steel flat on top faces of the beam with MS bolts including additional reinforcement has resulted well in cyclic reversal loading.
H.Y. Choi & J.Y. Lee (2012) have tested the strength of beam-column joints as per the design guidelines recommended by the three countries (America, Japan and New Zealand). They have conducted the experiments by designing the joints both by arch and truss mechanism and by both incorporating the features of both the arch and truss mechanism and derived a newequation and concluded that the new equation could be used to evaluate the strength and ductility of the joint and also recommends that this new equation will take care of the bond strength of the joint and observed that the co-efficient of variance is 20 to 25% with the, ACI and AIJ guidelines.
Arul Gnanapragasam et al., (2016) have investigated the effectiveness of strengthening beam-column joints using natural and artificial fibres. They have used basalt fibres as monolithic composite (BFRP) and as hybrid composite along with glass fibres. They have tested6 specimen, 2 no's control specimen, 2 no's monolithic basalt fibre and 2 no's with hybrid wrapping and tested for the initial and ultimate cracking loads, energy absorption, deflection ductility and stiffness at ultimate. The authors have found that for hybrid composites, an increase of 125% in initial cracking load, 60% increase in ultimate load, 208% increase in energy absorption, 131% increase in deflection ductility and for monolithic basalt fibrepolymer, 100% increase in initial cracking load, 20% increase in ultimate load, 71% increase in energy absorption, 43% increase in deflection ductility were obtained and observed that the stiffness has reduced by 24% when hybrid composite were used. One important behaviour of joint observed by them was the control specimen failed by crushing of column whereas the strengthened specimen failed in peeling of the FRP composites in the beam which indicates thestrengthened joint show the strong column-weak beam concept.

FINDINGS

Upon review, it is observed that the experimental studies are conducted more on models constitute 77% and on the prototype constitutes 1%, analytical studies constitutes 27%,and 2% of the studies are on the review of different studies. It is interpreted from the analysis that most of the studies are carried out on beams which constitutes about 43% and the least is on slab-column junction which is 1 in the researches the flexur%. And al behaviour is analysed at most in tune of 37% and the torsional behaviour is studied least whichis 0.50%. When looking at the type of materials used the carbon fibre reinforced polymer composite (CFRP) is the most preferred strengthening material which takes about 55% and the textile fibre used is the lease which is 0.30%.As far as the methods of strengthening concerned, the external addition dominates than any other method. Pre-stressing and Near Surface Mounted technique has significant technological values but researches done are comparatively little.

CONCLUDING REMARKS

The researches done earlier were to strengthen the beam-column joints in order to increasethe overall performance under reversal loading and to enhance the energy absorption capacity of the joint under seismic loading and to increase the strength of weak joints which were originally not designed for seismic compliance and to strengthen the damages joints with different materials & techniques and in all the researches, only the incremental strength were focused, and no notable work on the required additional strength at a negative moment region required for the actual ground condition were analyzed.While strengthening the beams or any structural elements using FRP composites, it has been proved that it gives an increase in strength but the % of increase varies from 15% to 70% whichdepends on parameters considered by authors like width of wrap, length of wrap, size of substrate, available reinforcement, size of specimen considered for testing, grade of concrete, grade of reinforcement steel used in the structural member. But in reality, the results obtained from the laboratory experiment will vary based on parameters like exposure condition, life of the structure, residual life of the structure, the strain already undergone, actual loading condition, workmanship in implementing the strengthening scheme, probable difference prototype and model, aspect ratio. Especially the practical errors are not taken care in laboratoryresearches especially in using FRP composites, the reliability of performance of FRP compositesolely depends on gluing properly. Even in laboratory condition, the de-bonding failure is the primary failure encountered. So, a straight approach or model on strengthening scheme on structural members on real scenario varies from case to case.

This review shows that still no comprehensive research has been done to strengthen the negative moment region at external column-beam junction under a demanding situation.

The parameters like existing design strength, available reinforcement, change in curtailmentpattern (upon removal of an existing intermediate column), stiffness variation at the beam-beamjunction, increase in span, available head room, architectural requirement, foundation adequacy, are extensively need to be studied.

The FRP composites and the size of specimen were chosen arbitrarily to fit into the laboratory condition which will not suit to the field condition.

Few researches carried out on internal beam-column joints have not taken care of the reaction from the upper columns and the strengthening schemes were worked on the slab area (the wrap were applied not exactly over the negative moment region).

No notable researches were carried out on the corner beam-column joints (“L" junction in plan) to strengthen the negative moment region.

There has been no scientific or empirical model has been established incorporating all relevant parameters like thickness or external strengthening materials, length to be glued, various modulus of material, exposure, property of substrate, existing strength of substrate, strain already attained, existing stress, etc.

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