Review on Strengthening of Beam-Column Joint Retrofitted with FRP

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Abstract - The need for the study of beam-column joint is prominent due to the increase in the rate of seismic activity all over the world. Older buildings which are poor in reinforcement detailing are susceptible to damage under seismic events. Retrofitting those structures is one of the remedial measures. For any structure the behaviour of the beam- column joint is important determining the nature of behaviour of that particular structure. If the joint behaves as brittle, then that structure will undergo brittle failure, whereas if it is ductile, it will undergo ductile failure. Hence this study is concentrated on the behaviour of beam-column joint retrofitted with FRP under seismic conditions. Among different retrofitting schemes, FRP retrofitting technique is considered in this paper. This paper covers different FRP retrofitting techniques at beam-column joint, its numerical as well as experimental studies conducted so far. The scope of composite materials in retrofitting beam-column joint is also being evaluated. The present status of FRP composite materials its scope and testing facilities in India are also reviewed through this study.

Key Words: *Beam-column joint, FRP, Seismic Retrofitting*

1.INTRODUCTION

The present scenario of seismic activity all over the world is a wide threatening to major structures. Hence the need of retrofitting is much important in the present day. Different seismic retrofitting schemes such as providing external post tensioning, providing infill shear wall, providing additional brazing's, providing steel plates at tension zones of beams etc are available. Apart from all these retrofitting schemes FRP has a major advantage ie high strength to low weight ratio, this unique feature of FRP material made it as a common retrofitting material. There are a lot more studies needs to be carried out on beam-column joint retrofitted with FRP under seismic conditions. Some of the studies that were already been carried out over this field are discussed in this paper. Since the behaviour of structure under seismic events mainly depends on the behaviour of beam-column joint, this literature survey covers this area of study.

1.1 FRP STRENGTHENING SYSTEMS

Use of FRP confinement has proved effective in seismically active regions. Further scope of FRP confinement includes survivability of explosive attacks, required to increase the axial load capacity of a column under higher vertical loads etc. In India FRP material has taken shape in 1960s with a single resin manufacturer and a lone source of glass fibre. FRP materials were developed primarily for aerospace and defence industries in the 1940s but today it reaches in the field of civil, aeronautics, marine, automotive and electrical engineering etc. Large number of industries was emerged out all over India. Several research centres and institutions were emerged out as a result several advancements came in the field of composite materials.

Several researches were carried out under FRP material as strengthening system after 1990's. FRPs offer an excellent alternative to steel plates because of their high tensile capacity, non-corrosive nature and light weight. Commercially available FRP products are made of continuous fibres of Aramid (AFRP), Carbon (CFRP), or Glass (GFRP) impregnated in a resin matrix. The most impressive characteristic of FRPs in repair/strengthening applications is the speed and ease of installation. FRPs can be bonded to the tension side of concrete beams, girders and slabs to provide additional flexural strength. In order to get increase in shear strength ,FRP material may be bonded on the lateral side of beams and girders. For seismic zones, FRPs can also be used to wrap columns to enhance the ductility demand due to the induced confinement of the concrete. FRP material's selection should be based on strength, stiffness and durability required for a specific application. Resins are selected based on the environment to which the FRP will be exposed, as well as the method by which the FRP is manufactured. FRP materials are available in different forms such as FRP sheets, Laminates, rebar's, Cables etc. All these have specific mechanical properties; its use varies depending upon the functional requirement.

In view of the crucial need for developing indigenous capability in composites technology in India the following institutions play a major role. Structural Engineering Research Center (SERC) Chennai, FRP institute Chennai formed in 1999, Indian Society for Advancement of Materials & Process Engineering found in 1985 (headquarter-Bangalore), Research Designs and Standards Organisation (RDSO) in 1957, under Ministry of Railways at Lucknow, Technology Information Forecasting and Assessment Council (TIFAC) etc. A composite magazine entitled "FRP TODAY" is being published in India since today on monthly basis.

Some of the prestigious advancement of composite materials in different fields are listed below. In Indian Railways, 11 projects were launched which include gear-cases for diesel & electric locomotives, axial-flow fans for diesel locomotives, sleepers for railway girder bridges, modular toilets for passenger coaches, FRP doors for passenger, composite interiors for railway coaches and composite interiors for diesel loco driver's cabin etc. The composite coach for Sky Bus was developed for Konkan Railway under the programme. This is the first indigenous technology for MRTS(Chennai Mass Rapid Transit System).Composite houseboat developed for the backwaters of Kerala consumed about 19.20 tonnes of composites for its components such as the hull, deck and the superstructure- making the houseboat one of the largest composite products in the country. India's first filament wound composite road tanker for horizontal mounting on truck was developed under the program. Another milestone has been receiving of the prestigious certificate from American Petroleum Institute (API) for filament wound composite pipes and pipe-fittings. The industry partner in the project has been the first in South Asia and 17th in the world to have API certificate for glass reinforced epoxy pipes for critical applications (offshore & onshore) for oil & gas sector. FRP materials can also be used as retrofitting materials such as flexural strengthening of RC slabs, flexural strengthening of beams, shear strengthening and confinement of column, wrapping of concrete tank, shear strengthening of beam-column joint etc.

2. REVIEW OF LITERATURE

Beam column joint retrofitting technique using FRP for seismic strengthening of structures is a wide advancing area. There were several studies which are already been carried out for the effectiveness of FRP materials. Still there are a lot of limitations in this area. The suitability of FRP material at seismic cases needs to be evaluated. The advancement in technology leads to the application of hybrid FRP panels which includes the combinations of FRP materials such as FRP sheers, laminates and FRP bars. This literature review concentrates on beam-column joint retrofitted with FRP systems.

Tarek Kamal Hassan Mohamed (2002) conducted detailed studies on the bonding as well as the flexural performance of FRP retrofitted RC structures. In the study RC beams strengthened with carbon fibre reinforced polymers (CFRP) sheets at different values of negative and positive moment regions and traditional RC beams strengthened at both negative and positive moment regions. All beams were strengthened with a single CFRP layer. It has been observed that when strengthening was performed at both hogging and sagging regions, the ultimate load carrying capacity of the beam is increased by about 22%. The deflection of RC beam retrofitted with FRP sheets shows much lower deflection value as compared to control beam. Debonding failure was observed. Several results were point out in the suitability of FRP materials for flexural strengthening of beams. The area of study also includes FRP bars, strips/Laminates and sheets. In general the beams strengthened with FRP materials have adequate ductility as well as strength after being retrofitted.

Raafat EI-Hacha and Sami H.Rizkalla (2004) conducted study on Near Surface Mounted (NSM) FRP reinforcements for flexural strengthening of concrete structures. They conducted experimental tests over RC T-beam strengthened with different configurations of Fibre Reinforced Polymer materials of FRP bars, Laminates or strips. They have considered both CFRP and GFRP material. It is found that NSM FRP reinforcing bars and strips are practically significant in improving the stiffness and increases the flexural capacity of RC beam. It has one major advantage over externally bonded FRP material ie strengthening using NSM technique provides higher strength capacity as compared to externally bonded one; also there is significant increase in the ductility of beam.

M. Ekenel etal (2005) investigated on the effect of fatigue loading on flexural performance of RC beams retrofitted with FRP and pre-cured laminate systems. Special anchorage system of GFRP material for anchoring the FRP laminates is also considered. They have considered five RC beams of which two are retrofitted with CFRP and two are retrofitted with GFRP fabrics. Cyclic loading of 2-million cycles is applied and all the beams have survived except un-strengthened control beam. Results also prove the efficiency of FRP anchorage system such as wedge and spikes over FRP epoxy bonded binding system. The use of anchor spikes resulted in a significant increase of about 42% in the ultimate capacity of the beam as compared to CFRP strengthened beam without anchor spikes. Hence conclude the effectiveness of mechanical anchorages over the conventional bonding technique using epoxy.

Alper Ilki etal, (2008), investigated on the seismic retrofit of beam-column joints with FRP Sheets. They have tested four full-scale beam-column joints under reversed cyclic loads. All specimens were cast using low quality of concrete and plain reinforcing bars with inadequate detailing to represent old reinforced concrete structures. It is found that the retrofitted beams have significant increase in strength, while non-retrofitted beams fail due to shear at much lower load.

Akanshu Sharma, G. Genesio etal., (2010) conducted experimental investigations on seismic retrofitting of reinforced concrete beam column joints. Since beam-column joint is the critical and vulnerable zone under seismic load; they conducted investigation at beam-column joint using different retrofitting techniques. The techniques include Concrete jacketing, FRP wrapping and Haunch retrofit system. In case of concrete jacketing it increase the strength. However, it leads to an increase in size, significant change in stiffness. It needs a lot of care to make sure that the old and new concrete work together, requires lot of time and labour and is quite invasive. In case of FRP wrapping it is very light as compared to concrete jacketing. It is able to increase the strength; but the drawback is the cost effectiveness. In case of Haunch retrofit solution, it is very practical, easy to apply in practice, cheap and efficient system for retrofitting the joints by the concept of redistribution of forces and moments. However the system may not be totally suitable for retrofitting the pre-damaged joints and extra care in design is needed to strengthen weak column strong beam configuration.

Consuelo Beschi, Alberto Meda and Paolo Riva (2012) investigated on beam-column joint retrofitting with high performance fiber reinforced concrete jacketing. They made the test specimen and the beam-column joint is subjected to static load followed by cyclic loading. The column is encased with FRP sheets which were bent at 90°. Eventually, they were encased in the HPFRC. The strengthening jacket, having a thickness of 40 mm, was eventually cast adopting a self-compacting HPFRC. During the test horizontal load was applied with cycles characterized by increasing amplitude up to failure. It is found that application of HPFRC jacketing increases the bearing capacity as well as the ductility of the column and overall performance of the beam column joint.

N.H.Hamid etal (2013) conducted study on retrofitting of beam-column joint using CFRP and steel plates. They have tested the specimen until failure by providing 1% drift, later it is then retrofitted with CFRP sheets and steel plates. Applying a drift of about 1.75% it is found that the overall performance of retrofitted beam is increased in comparison with non-retrofitted one. The ductility and shears strength also increased as a result of retrofitting.

A.Ilki, C. Demir and M. Comert (2013) conducted study on the retrofit of RC joints with FRP composites. This paper explains about typical failure modes of RC beam-column joints. The most common FRP retrofitting schemes and contribution of the FRP retrofitting to behaviour of exterior beam column joint is examined. For the study large scale structural tests on retrofitting beam column joints built with low strength concrete and plain bars by FRP sheets is done. It is found that FRPs can contribute significantly to the performance of RC joints against various deficiencies. The need for standard code of practise in the field of FRP retrofitting is pointed out from this study.

Mr.M.Vinodkumar and Dr.M.Muthukannan (2014) conducted a literature review on CFRP/GFRP composites used for Strengthening of Reinforced Concrete Beams". In this study a brief review on flexural and shear strengthening of rectangular RC beams using CFRP/GFRP laminate of different thickness and scheme reviewed in this paper. It is concluded that the CFRP and GFRP laminate can increase both flexural and shear strength of a beam. There is no design standards regarding the thickness of FRP material and the orientation required for retrofitting it.

W. M. Hassan and A. A. Bilal (2014) conducted study on the seismic retrofit of shear critical beam-column joints in existing concrete buildings. Since conventional retrofitting schemes are expensive in order to overcome this, new simpler retrofitting method are tried for existing exterior beam-column joints that aims to transfer the mode of failure from joint shear failure to a weak-beam-strong column one with no shear degradation in the joint. The retrofit solution is validated through an experimental program that consists of testing four exterior beam-column joint sub-assemblages. It is found that inserting U-shape bars at beam-column joint did not improve joint cyclic response due to practical constrains of limited available spacing between beam bar hooks, which led to hindering the confinement effect of the joint retrofit bars.

A. Eslamil and H. R. Ronagh (2015) conducted a numerical investigation on the seismic retrofitting of RC beam–column connections using Flange-Bonded CFRP Composites. In this study nonlinear FE modelling approach is used to predict the seismic performance of RC code-compliant beam-column connections retrofitted using flange bonded CFRP scheme. The suitability of FE approach for numerical analysis is validated through this study. It is found that FE models can reliably predict the performance of the original and retrofitted test specimens under both monotonic and cyclic loadings. In addition, the numerical analysis could precisely predict the failure mechanism and location of plastic hinges observed during the experimental tests. However, the accuracy of any retrofitting scheme should be initially confirmed through experimental testing.

T.Subramani and J.Jayalakshmi (2015) conducted analytical investigation of bonded glass fibre reinforced polymer sheets with reinforced concrete beam using Ansys. They have conducted analytical and experimental study to investigate the behaviour of concrete beams bonded with Glass Fibre Reinforced Polymer (GFRP) sheets on all sides with different thickness of the plate under loading. The behaviour of concrete beams strengthened with GFRP unidirectional composite laminates have been studied. It is found that the analytical and experimental results are coinciding with each other and can be concluded that FEM software ANSYS can be used to conduct numerical studies.

Mr. Rajendra P. Deshpande and Prof. Dr. Kiran B. Ladhane (2015) conducted study on the analysis of RC Frame Strengthened by FRP Laminates using ANSYS Software. RC framed building is modelled and the laminates are attached at different configurations. It is found that there is decrease in deflections as we attached more no. of sides with laminates except in case of 2 side attached laminates case. The reason for the increase in deflection in the 2side attached laminate case is the decrease in flexural strength of about 52.4% because of not attaching laminates to the bottom side.

Jafar Ali M and Gayathri S (2017) investigated on the behaviour of RC beam column joint retrofitted with various thicknesses of CFRP and GFRP Sheets. Beam column joint of a G+3 story building is considered. CFRP and GFRP sheets of varying thickness are considered. Analytical study for the model is done using ANSYS software and the results are discussed. Result shows that retrofitting using CFRP will give 50% more strength (Von-Mises stress) as compared to GFRP. Also increasing the thickness of FRP sheets doesn't provide much increment in strength. Hence there is optimum value of thickness of FRP sheet to be provided at beam column junction.

Ramin Azarm, Mahmoud R. Maheri and Ashkan Torabi (2017) conducted study on the retrofitting RC joints using Flange-Bonded FRP Sheets. The ability of CFRP overlays is assessed to improve the seismic capacity of RC joints. Two, full-scale RC exterior joints of a moderate ductility moment resisting frame are designed, fabricated and tested under monotonic pushover loads before and after retrofitting. In a parametric study, the optimal thickness of FRP sheets needed for relocation of the plastic hinge away from the column face is then determined. Results of the experimental and numerical analysis show that the retrofitting method improves the capacity and performance of the overall RC beam–column joint.

3. SUMMARY

From literature review, a clear idea has been obtained regarding the suitability of FRP materials for retrofitting of column-beam joint. It is found that FRP material such as FRP sheets and FRP strips can be used for retrofitting of Column-Beam joint. FRP material can increase the shear resistance at the section. Similarly FRP materials can be used for flexural strengthening of beams, slabs etc. The mechanical properties of FRP materials enable its use as retrofitting material. Different FRP materials such as FRP bars, FRP Sheets, FRP bars are available now a days in the market. In India FRP materials have not gained much acceptance due to non-availability of materials locally. One major problem is the non-availability of Indian standard codes of practise for FRP and its design criteria. Even though ACI 440.2R-02 gives the "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures" still there are a lot of limitations in this field. Standardisation is the only one remedy for gaining the acceptance of FRP as a retrofitting scheme. For the advancements in the field of FRP composites several researches are being carried out and still needs to be carried out for the well acceptance of FRP material in India.

It is found that flexural strengthening of RC structures using FRP enhances the ultimate load carrying capacity. The deflection of members can be minimized as a means of retrofitting. Apart from conventional retrofitting technique where the FRP materials were bonded at the exterior portion of structure, NSM technique has more beneficial qualities such as increase in strength, stiffness and ductility of member as compared to externally bonded system. Application of mechanical anchorages of GFRP material over the FRP laminates leads to an increase in the load bearing capacity as compared to laminates without anchorages. Suitability of NSM technique and the use of mechanical anchorages for retrofitting at the beam-column joint needs to be explored. The thickness and type of FRP material such as CFRP, GFRP and AFRP also plays major role in the strengthening technique. Under cyclic conditions also FRP materials will impart good performance. The suitability of FRP under seismic loading at beam-column joint needs to be explored in detail. The performance of FRP at beam-column joint is also affected by the mode of wrapping the FRP material. The most appropriate mode of wrapping or placing of FRP material at the beam-column joint needs to be found out. Numerical models can be made use for the analysis of beam-column joint retrofitted systems and numerical studies are economical compared to experimental investigations. Cost effectiveness of FRP composite material for retrofitting purpose needs to be evaluated to make these materials globally acceptable.

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