Seismic Response of Post Tensioned Beam Strengthened with Fiber Reinforced Polymer

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Abstract - *The post-tensioning method is now a days increasing widely due to its most economic and safe design. Post tensioning is a method of strengthening concrete using high strength tendons. The main benefit over conventional reinforced concrete is its ability to span greater distances without resorting to thick slabs and beams and reduce deflection and cracking. Fiber reinforced polymer is one of the most commonly used composite material for strengthening in new construction or for rehabilitation of the existing structure. In this study, the effectiveness of Fiber reinforced polymer on post tensioned beam is investigated for seismic loading. The seismic performance of two frames with post tensioned beam models were analyzed and compared, one with FRP and other without FRP. The analysis was done using ETAB software. The FRP plates are provided at the tension zone of beam. The parameters studied are stiffness, storey shear, shear capacity and dissipated energy of the frame. The study concluded that frame with post tensioned beam strengthened with FRP have better seismic performance.*

Key Words: **Post tensioned, Fiber reinforced polymer, seismic response, strengthening.**

1. INTRODUCTION

Throughout the history earthquake have caused several losses both in human lives as well as economic values, hence in this study the seismic behaviour of post-tensioned beam strengthened with Fiber reinforced polymer (FRP) was studied. The use of FRP sheets to create composite structures has increased in recent years. There are two types of pre- stressing methods, pre-tensioning and post-tensioning. In this study, the post tensioning of beam is considered. Post tensioning is that the technique of reinforcing concrete or alternative materials with high strength steel strands known as tendons. In post tension, tension is applied on tendons after the concrete gets hardened. Strengthening using fiber reinforced polymer composite has become viable alternative to traditional strengthening methods. Post tensioning has several advantages such as less cost, reduced floor to floor height, high seismic performance, less steel and concrete consumptions. Post tensioning can be applied on slabs, bridges, water tanks etc. Fiber Reinforced Polymer (FRP) is composite material made of high strength fibers and a matrix for binding these fibers. The fibres are usually glass, carbon, or basalt. FRP composites are light weight and non-corrosive material which have high strength and high stiffness. Due to these advantages, it can be used as strengthening technique in new construction and also for the rehabilitation of the structures. It can be used as reinforcement in concrete, bridge decks, modular structures etc. and also as external reinforcement for strengthening and seismic upgrade. The main advantages of FRP are high strength / weight ratio, low thermal conductivity, long term durability, flexibility, design stability. The traditional technique of seismic retrofit of concrete structure is no longer a practical solution because repairing damaged structures with steel demands plenty of time, also steel is susceptible to corrosion and increases the stiffness of columns exposing a structure to higher transmitted seismic forces. While on other hand, FRP composites enable to repair structurally deficient structures in a time efficient manner and it improves seismic resistance. In this project the seismic response of post tensioned beam and post tensioned beam strengthened with FRP are to be studied using ETAB software.

2. LITERATURE REVIEW

A.Niroomandi A et.al (2010) studied the seismic performance of the ordinary reinforced concrete (RC) frame retrofitted with FRP and then compared with those of the original frame and the same frame retrofitted with steel bracings. The seismic performance level and R-factor components of the retrofitted frame were determined. The flexural behaviour of FRP retrofitted joints of the frame was first determined using nonlinear analysis of FE models of RC joints-FRP composites. The retrofitted joint stiffness is then implemented into FE model of frame in order to carry out nonlinear static analysis on FRP retrofitted frame. From this study, they concluded that the seismic behaviour of the FRP retrofitted RC frame enhanced compared with the original frame and using FRP can increase the ductility of the frame.

S.Cimilli Erkmen et.al (2014) conducted study on seismic behavior of FRP reinforced concrete frame building. Dynamic inelastic response history analyses of two CFRP reinforced concrete building were done following National Building code of Canada and the Canadian Standards Association (CSA) S806-02 (2002) for “Design and Construction of Building Components with Fiber-Reinforced Polymers. The buildings were analysed under NBCC compatible earthquake records to establish design force and deformation demands. In their study, the FRP reinforced concrete building does not show CFRP rupturing prior to the concrete crushing. Hence they concluded that FRP reinforcement can be used for building in seismically active regions. In elastic mode of deformation the FRP reinforced concrete building remain within the force and deformation demands indicated in building codes.

T.Hari Prasad et.al (2018) in their study compared the seismic performance of three different RC frame models. The first model consists of a conventional RC frame with all beams and columns as RCC, the second model consist of RCC peripheral beams and interior post tensioned beams and the third model consist of all beams having PT tendons. The post tensioned members were analysed using ADAPT software and Static Nonlinear Pushover analysis was carried out for all the fifteen models generated using SAP2000 software. The seismic performance of the conventional RC beams on the periphery of the building and PT beams in the interior grids of the structure was the best for G+11 to G+15 storey structures. Also all PT beams with frames were performed quite well even without any separate lateral force resisting system.

Tong-Liang Xiao et.al (2018) conducted study on seismic behavior of Concrete beams reinforced with Steel-FRP Composite bars under Quasi-Static Loading. Initially the method and main result of experiment were briefly introduced. Further a simplified constitutive model of composite bar materials was designed. The main parameter includes FRP type, concrete strength, Basalt FRP content in SFCBs and shear span ratio. The load displacements-push over curves, seismic ultimate capacity and its corresponding drift ratio were evaluated. The result indicates that with the increase of the fiber bundle in the composite bar, the post-yield stiffness and ultimate capacity of the component increases and the ductility strengthens. The concrete strength of beam had little influence on seismic performance at the pre-yield stage. After yielding, the seismic ultimate capacity and post-yielding stiffness of the specimens increased slowly with the increase in concrete strength.

Giuseppe Santarsiero et.al (2018) studied FE modelling of seismic behavior of wide beam column joints strengthened with Carbon filer reinforced polymer (CFRP) system. On the basis of wide beam column joints previously tested without strengthening system, detailed nonlinear finite element models were calibrated. Then an FRP strengthening system intervention based on a new arrangement was modelled. The effectiveness of strengthening interventions was assessed by finding out strength and ductility. Two full-scale wide beam-column joints are tested under reversal cyclic quasi-static loading. Two externally bonded unidirectional U shaped CFRP fabrics are used. The seismic performance of the as-built joint specimen was increased with the significant increase in both positive and negative loads. It is worth noting that as the strength increase with the number of laminates' layers, the ductility decreases suggesting that the best solution are those with one or two layers depending on wanting more strength or ductility. The final crack patterns of the upgraded joint models were quite different from those ones of the as-built specimen resulting in a more diffuse damage but generally with a lower crack size.

Osman Hag-Elsafi et.al (2018) conducted study on seismic behavior of RC Square Columns strengthened with self-compacting concrete-filled CFRP-Steel Tubes. The lateral cyclic loads were applied to eleven columns. The test parameters included the number of CFRP layers, the thickness of the steel tube, and the axial load level. The study evaluated seismic behaviour based on the entire failure process, ultimate lateral load and deformation capacity. The experimental results shows that with the increase in number of CFRP layer , the ultimate bearing capacity, ductility and energy dissipation capacity of the CFCST-strengthened column increased slightly. Under higher axial load level, the CFCST-strengthened column exhibited better ultimate bearing capacity and energy dissipation capacity but low ductility. It is also concluded that the seismic performance improved with increase of the thickness of the steel tube.

Cumhur Cosgun et.al (2019) conducted study on seismic retrofit of joints of a Full-Scale 3D Reinforced Concrete Frame with FRP Composite. The effectiveness of carbon FRP composites for retrofitting beam column joints was demonstrated through testing of four full scale 3D reinforced concrete frames. Additionally analytical predictions on the seismic performance of reference and retrofitted frames were made using ASCE-41-13 and CNR 2013 documents. The continuous CFRP sheets of size 250mm wide and 3800mm long were bonded to the joint region. FRP retrofitting to the beam-column joints significantly enhanced the lateral load and displacement capacity.

3. SEISMIC ANALYSIS

3.1 Specimen details

In this study, two specimens were compared, one specimen was frame with post tensioned beam and the other one was frame with post tensioned beam strengthened with FRP. Response spectrum analysis was carried out using ETAB software. The frame was subjected to seismic load according to IS 1893-2002 and live load of 250kN. A three storeyed building with storey height of 3m was considered for the study. The building have beam with 250mm width and 500mm height and column cross section of 500*250mm. The slab thickness is 80mm. The M30 grade of concrete and Fe415 steel is considered.

3.2 Models

For seismic analysis two models were considered. Response spectrum analysis was done. The frame model is shown in Fig 1. The first model consist of frame with post tensioned beam alone as shown in Fig 2 and the second model consist of frame with post tensioned beam strengthened with FRP. The tension zones of the beam consist of FRP.

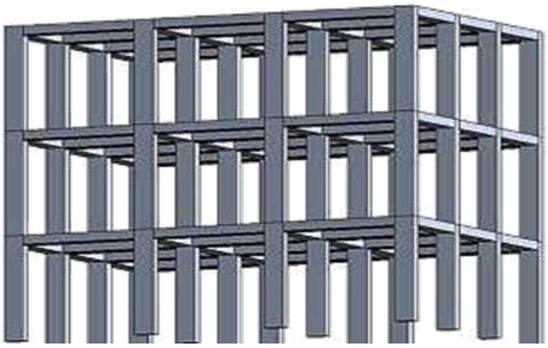

Fig 1- Frame model

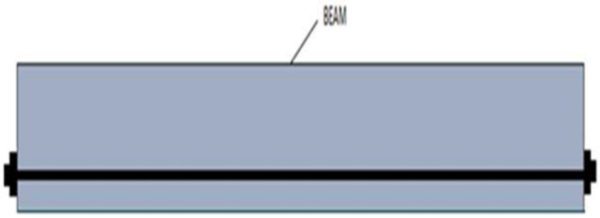

Fig 2 – Post tensioned beam

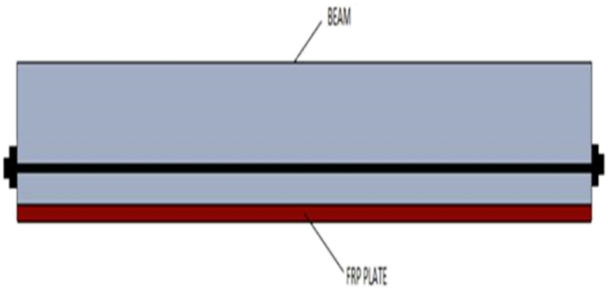

Fig 3 – Post tensioned beam with FRP

3.3 Loading

The three storey building was subjected to seismic load according to IS 1893-2002 and the live load of 250 kN. The loading diagrams of the frames are shown in Fig 5 and Fig 6.

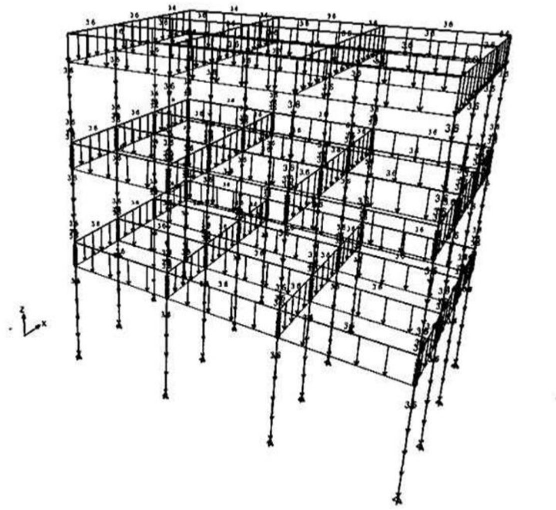

Fig -4: Loading diagram

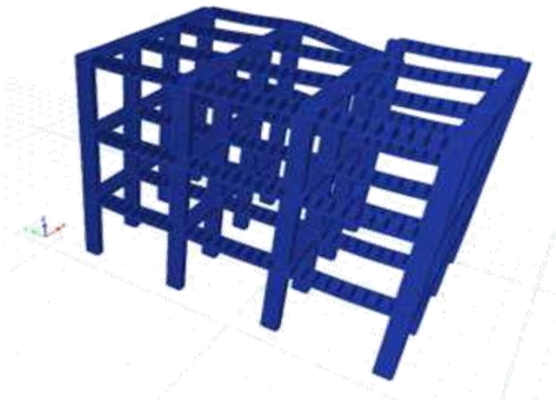

Fig -5: Loading diagram of frame with post tensioned beam

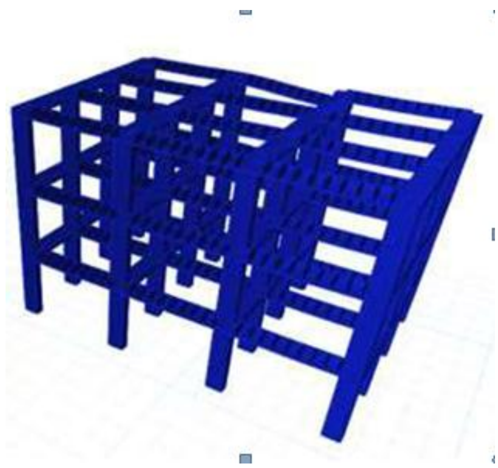

Fig -6: Loading diagram of frame with post tensioned beam strengthened with FRP

4. RESULTS AND DISCUSSIONS

4.1 Stiffness Graph

The Fig 7 shows the stiffness v/s loading step graph of frame with post tensioned beam and frame with post tensioned beam strengthened with FRP. Here for each 20% increment of load, stiffness decreases. The reason behind decrease in stiffness can be due to cracking. From the below graph it is clear that frame with post tensioned beam strengthened with FRP shows less decrease in stiffness. Hence it has the best seismic performance. The maximum value of stiffness for frame with post tensioned beam is 8000KN/m and for frame with FRP plates on Post tensioned beam is 11500KN/m.

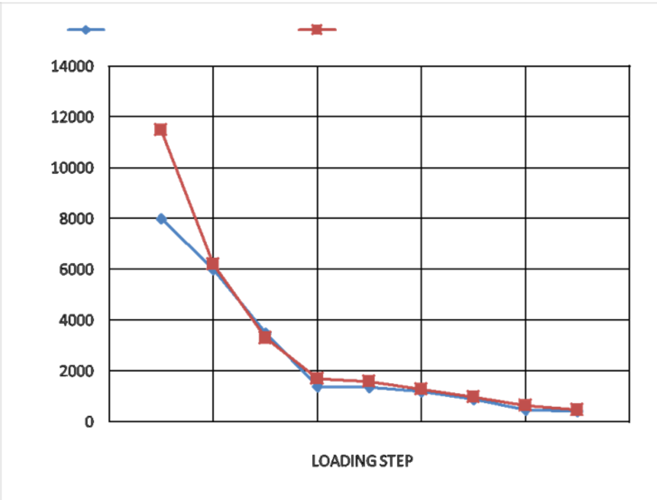

Fig-7: Stiffness Graph

Table- 1 Stiffness value for each loading steps

Loading steps	Stiffness (KN/m)	
	Frame with PT beams	Frame with FRP plates on PT beams
1	8000	11500
2	6000	6200
3	3500	3300
4	1400	1700
5	1380	1600

4.2 Storey shear versus Storey height

The Fig 8 shows the storey shear corresponding to each storey height. It is clear that storey shear decreases with increase in height. The frame with post tensioned beam strengthened with FRP causes less storey shear with increase in height. At maximum height of 9m, the value of storey shear is 3.3KN for frame with Post tensioned beam strengthened with FRP and in case of frame with post tensioned beam alone it is 3.5KN.

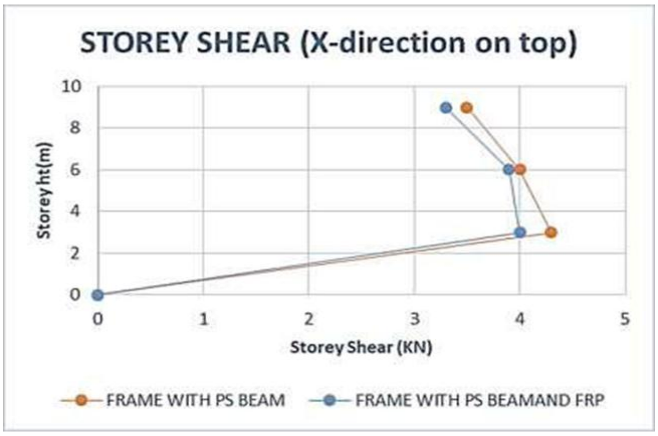

Fig-8 Storey shear versus Storey height graph

Table- 2 Storey shear corresponding to each storey height

Storey height (m)	Storey shear (KN)	
	Frame with PT beams	Frame with PT beams with FRP
9	3.5	3.3
6	4	3.9
3	4.3	4
0	0	0

4.3 Shear capacity versus Joint rotation

The Fig 9 shows the shear capacity of the two frames corresponding to joint rotations. The frame with post tensioned beam strengthened with FRP has more shear capacity against the joint rotation compared to the frame with post tensioned beam. Hence it is clear that frame with post tensioned beam and FRP have high load bearing capacity.

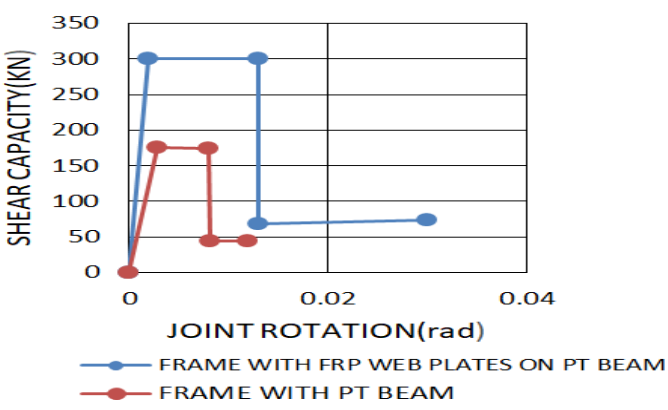

Fig-9: Shear capacity v/s joint rotation graph

Table-3 Shear capacity values corresponding to joint rotation

FRAME WITH PT BEAMS		FRAME WITH PS BEAM AND FRP	
Shear capacity (KN)	Joint Rotation (rad)	Shear capacity (KN)	Joint Rotation (rad)
0	0	0	0
175	0.0028	300	0.002
174	0.008	300	0.013
44	0.0081	68	0.013
44	0.012	74	0.03

4.4 Energy dissipation and cumulative energy dissipation

The Fig 10 and Fig 11 shows the energy dissipation and cumulative energy dissipation corresponding to each loading steps. The energy dissipation is higher for the frame with post tensioned beam strengthened with FRP.

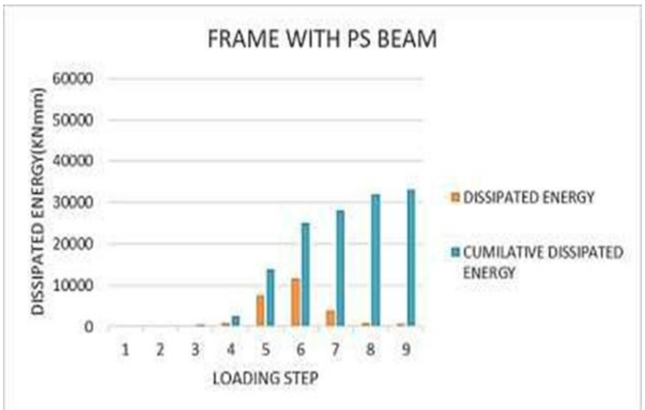

Fig-10 Energy dissipation and cumulative energy dissipation graph of frame with post tensioned beam

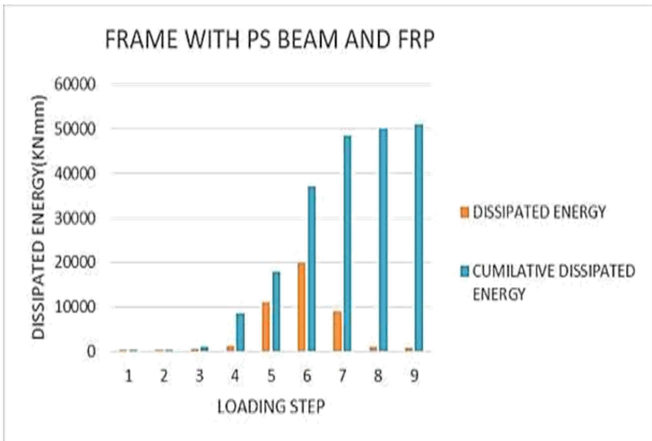

Fig-11 Energy dissipation and cumulative energy dissipation graph of frame with post tensioned beam strengthened with FRP.

Table-4 Energy dissipation and cumulative energy dissipation values corresponding to each loading step

Loading step	Frame with PT beams		Frame with PT beams and FRP	
	Dissip-ated energy (kNmm)	Cumulati-ve dissipated energy (kNmm)	Dissipat-ed energy (kNmm)	Cumulat-ive dissipated energy (kNmm)
1	100	150	50	80
2	180	300	80	90
3	250	400	600	980
4	900	2500	1200	8500
5	7500	14000	11000	18000

5. CONCLUSIONS

The seismic performance of post tensioned beam with and without FRP is analyzed using ETAB software. Here response spectrum analysis is carried out.

- Introduction of FRP plates to post tensioned beam increases the shear capacity of the frame.
- The post tensioned beams with FRP have higher strength and load bearing capacity.
- The energy dissipation of the post tensioned beam with FRP is higher compared to other frame.
- The frame with post tensioned beam strengthened with FRP is better for the seismic performance.

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