Seismic Strengthening of RC Beam Column Joint Using Honey Comb Sandwich Panels

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Abstract - *The beam- column joint in RC frame should have tolerable strength and stiffness to resist the internal forces induced by the framing members. In many earthquakes cases reported the consequences of poor performance of beam-column joints due to lack of proper seismic design considerations. This paper will introduce an innovative method for strengthening the joint. A sandwich-structured composite is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight core. This paper evaluated an analytical study on the performance of joint strengthened with 3 different sandwich panels; phenolic aramid paper with CFRP as skin material, aluminum honeycomb with aluminum sheet metal as skin and polyurethane foam with GFRP as skin material. Analytical study reveals that there is significant increase in ultimate load carrying capacity of beam column joint strengthened with sandwich panels.*

Key Words: **honeycomb sandwich panel, seismic strengthening, beam-column joint, H-lam, I-lam, PU foam**

1. INTRODUCTION

Seismic strengthening is upgradation of certain building system (existing) to make them more resistant to seismic activity. Strengthening will be a better policy rather than the complete replacement of building part. Joints are the part of column at a depth of beam. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members. Many of the RC framed buildings in India were constructed without sufficient design consideration for joints. Study on various earthquakes cases all over the world shows the consequences of poor performance of beam column joint. Exterior joints are more vulnerable because of a sudden geometric discontinuity and also, they are not confined by beams from all the sides. A number of researches are carried out on various seismic strengthening technique like concrete jacketing steel jacketing, FRP wrapping, etc. The purpose of the rehabilitation is to prevent columns or joints from a brittle shear failure and shift the failure towards a beam flexural hinging mechanism, which is a more ductile behaviour.

1.1 Sandwich Panels

A sandwich-structured panel is a special class of composite materials that is made-up by attaching two thin but stiff coverings to a lightweight core. The core material is usually low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density. Open- and closed-cell-structured foams like polyether sulfone polyvinylchloride, polyurethane, polyethylene or polystyrene foams, balsa wood, syntactic foams, and honeycombs are commonly used core materials. Sometimes, the honeycomb structure is filled with other foams for added strength. Open and closed cell metal foam can also be used as core materials. Laminates of glass or carbon fiber-reinforced thermoplastics or mainly thermoset polymers are widely used as skin materials. In some cases, Sheet metal is also used as face skin. The core is fused to the skins with an adhesive or with metal components by brazing together.

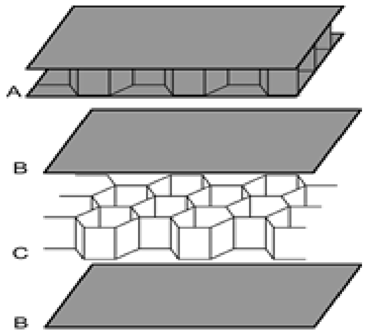

Figure 1: Honey comb sandwich panel [15]

Figure 2: Polyurethane foam cored sandwich panel [16]

2. LITERATURE REVIEW

Various studies reveal the application of sandwich panels in structural members. H lam is a sandwich panel with made up of aramid paper core sandwiched with CFRP [3]. Study shows that they are effective in enhancing flexural behavior of the strengthened RC beams [3]. Another work is carried out to determine the structural behavior of wood members strengthened with polymer composites [2]. It also shows the effect of H lam used as external repair and rehabilitation elements resulted in an appreciable increase of both strength and stiffness. The flexural behaviour of a new generation composite sandwich beams made up of glass fiber-reinforced polymer skins and modified phenolic core material in flatwise and edgewise positions have been studied [1]. The experimental investigation showed that under flexural loading, the composite sandwich beams in the flatwise position failed with sudden brittle type failure. In the edgewise position, the presence of fiber composite skins increased the ultimate strength of the beams. Another work is carried out to find the efficiency and effectiveness of carbon fiber reinforced polymers (CFRPs) in upgrading the shear strength and ductility of seismically deficient corner or knee reinforced concrete beam-column joints have been studied [13]. For this purpose, four as-built corner/knee joints were constructed with no transverse reinforcement, representing extreme case of pre-seismic code design construction practice of joints and encompassing many existing beam-column corner joints. Out of four, two will be taken as control specimen and remaining two are strengthened with CFRP layers. These repaired specimens were subjected to the similar cyclic lateral load history and their response histories were obtained. Response histories of control, repaired, and strengthened specimens were then compared. The results were compared through hysteretic loops, load-displacement envelopes, column profiles, ductility, and stiffness degradation. The comparison shows that CFRP sheets are very effective in improving shear resistance and deformation capacity of the corner beam-column joints and delaying their stiffness degradation [13]. Many studies are carried out for aluminum sandwich panel with aluminum honeycomb core theoretically and experimentally and reveals the strength characteristics of aluminum sandwich panels [7]. A series of strength tests are carried out on aluminum honeycomb-cored sandwich panel specimen in three-point bending, axial compression and lateral crushing loads. Another study is carried an experimental investigation on shear strength enhancement of reinforced concrete beams externally reinforced with fiber-reinforced polymer (FRP) composites [5]. A total of nine full-scale beam specimens of three different classes, as-built (un-strengthened), repaired and retrofitted were tested in the experimental evaluation program. Three composite systems namely carbon/epoxy wet layup, E-glass/epoxy wet layup and carbon/epoxy precured strips were used for retrofit and repair evaluation. Experimental results indicated that the composite systems provided substantial increase in ultimate strength of repaired and strengthened beams as compared to the pre-cracked and as-built beam specimens. Another paper summarizes the results of comprehensive experimental studies on half-scale bridge columns repaired and retrofitted with composite-material jackets [6]. Experimental results showed that all as-built columns developed an unstable behavior and failed in brittle shear mode. The common failure mode for all retrofitted samples was due to flexure with significant improvement in the column ductility. The repaired column demonstrated ductility enhancement over the as-built sample.

Detailed literature review shows that poor performance of non-seismically designed joints can be overcome using different strengthening techniques. It also concludes efficiency of sandwich panel as a strengthening material since it possesses high strength to weight ratio, high flexural strength, shear capacity, and low cost etc. No studies are conducted on the performance joints strengthened with sandwich panels. This study reveals performance of a typical non-ductile RC beam column joint strengthened with three different sandwich panel.

3. ANALYTCAL STUDY

3.1 General

In this study, investigations were carried out to evaluate performance of strengthened beam column joint compared to an un strengthened specimen. The analytical programme consists of modeling and analysis of joint strengthened with three different sandwich panel with same thickness. A typical exterior beam- column joint is designed with detailing as per IS 456:2000 (IS 2000) and scaled down. No shear reinforcement is provided at joint portion. Dimensions reinforcement details are shown in Table 1 and Table 2. Reinforcement detailing are shown in figure 3.

Table -1: Dimensions of specimen

Member	Dimensions (mm)
Beam size	100 x 140 x 765
Column size	100 x 140 x 1000
Joint size	100 x 140 x 140

Table -2: Details of Reinforcement for Beam-Column Joint Specimens

Beam	
Beam main bars	Beam stirrups
3 nos of 8mm Ø at top & 2 nos of 8mm Ø at bottom	3mm Ø bars @ 65mm c/c (450 mm from column face) remain @ 75 mm c/c
Column	
Column main bars	Column ties
4 nos of 8mm Ø	3mm Ø bars @ 100mm c/c

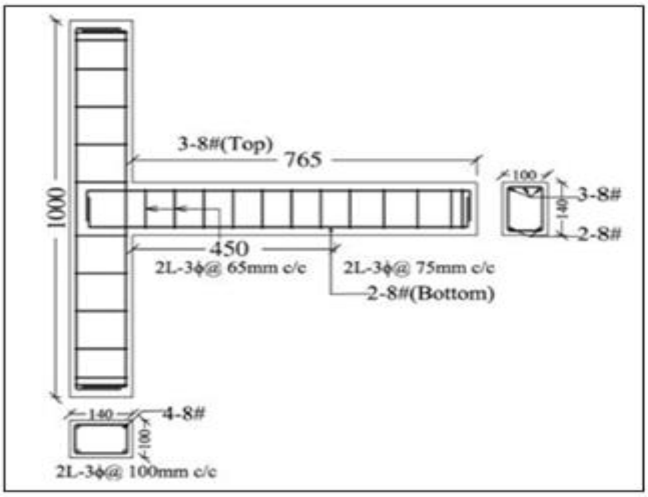

Figure 3: Dimension and reinforcement details of control specimens

Sandwich panels are of thickness 8 mm with 1mm face skin and 6 mm of core material thickness. The configuration selected for strengthening the joint is shown in figure 4. Panel is fully wrapped in column region and U wrapping in beam portion

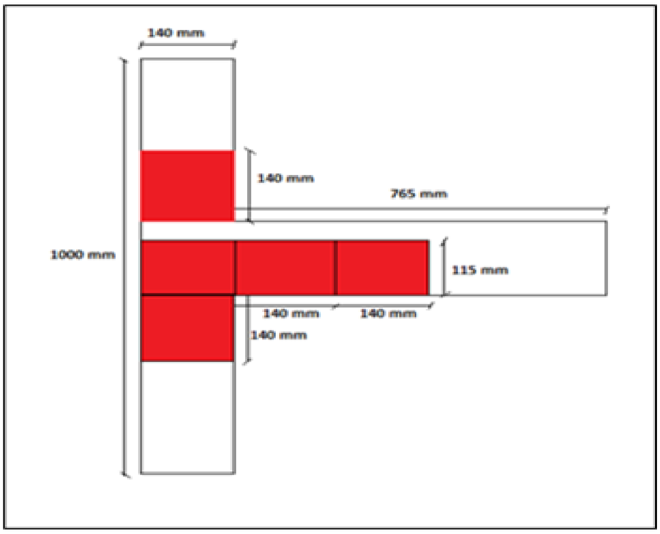

Figure 4: Configuration of panel wrapping

Three types of sandwich panels used are;

Phenolic aramid paper core with CFRP face sheets – H lam

Aluminum honeycomb core with aluminum face sheet - I lam

Polyurethane foam core with GFRP face sheet - PUG

3.2 Material properties

Following table 3, 4 & 5 shows the material properties used for analysis.

Table -3: Material properties

Properties	values
concrete	
compressive strength	30 N/mm²
Young's modulus	27386 N/mm²
Poisson's ratio	0.18
rebar	
Young's modulus	200000 N/mm²
Poisson's ratio	0.3
yield tensile strength	415 N/mm²

Table -4: Material properties of core materials

Properties	CFRP [11]
Young's modulus in long. Dir.	77300 N/mm²
Poisson's ratio	0.22
Young's modulus in transverse. Dir.	4600 N/mm²
Poisson's ratio	0.3
tensile strength	846 N/mm²
	GFRP [11]
Young's modulus in long. Dir.	28900 N/mm²
Poisson's ratio	0.26
Young's modulus in transverse. Dir.	4000 N/mm²
Poisson's ratio	0.3
tensile strength	464 N/mm²
	Al sheet [7]
Young's modulus	69000 N/mm²
Poisson's ratio	0.33
tensile strength	367 N/mm²
tangent modulus	500 N/mm²
plastic strain at rupture	0.13

Table -5: Material properties of face skins

Properties	Phenolic aramid paper [3]
density	48 kg/m³
Young's modulus	50 N/mm²
Poisson's ratio	0.4
Yield stress	5 N/mm²
Tangent modulus	0
plastic strain to failure	1.00E-05
	Aluminum honey comb [7]
density	54.4 kg/m³
Young's modulus	250 N/mm²
Poisson's ratio	0.04
Yield stress	190 N/mm²
Tangent modulus	49 N/mm²
	polyurethane foam [14]
density	62 kg/m³
Young's modulus	26.7 N/mm²
Poisson's ratio	0.32
Yield stress	1.24 N/mm²
Tangent modulus	2.4 N/mm²

3.3 Analytical modeling

Modeling and analysis performed using the software ANSYS17.0 WORKBENCH. Element type opted for modeling concrete member is SOLID65 and for rebar element link180 is adopted. Sandwich panels are modelled using the element SHELL181. Mesh size of 22 mm is selected and this size gives finer result in analysis. Fig 5-7 illustrates the ansys model of joint, rebars and panels

3.4 Loading pattern and boundary conditions

For stimulating seismic loading in the specimen, a displacement controlled quasi static cyclic loading were applied laterally on top of column. Displacement is applied from zero to 45 mm and the applied cyclic displacements were divided into a series of increments called load steps and load sub steps. A constant axial load of 110 kN is applied at top column in downward direction. This force is induced for adding dead weight and live load on joint. At the bottom of column, a hinge support and at the free end of beam, a roller support are provided. Load pattern and boundary conditions are illustrated in Fig 8

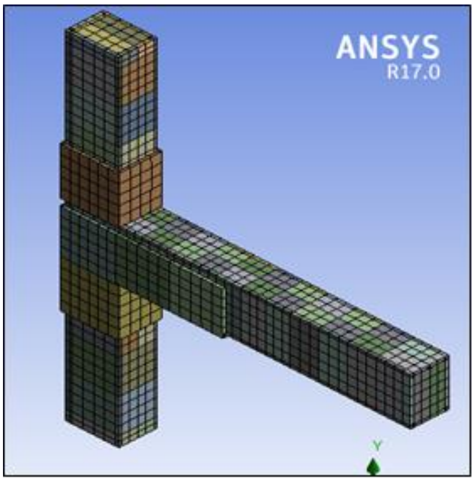

Figure 5: ANSYS model

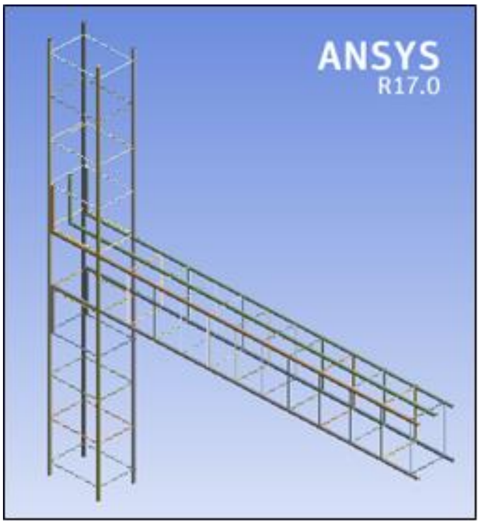

Figure 6: ANSYS model

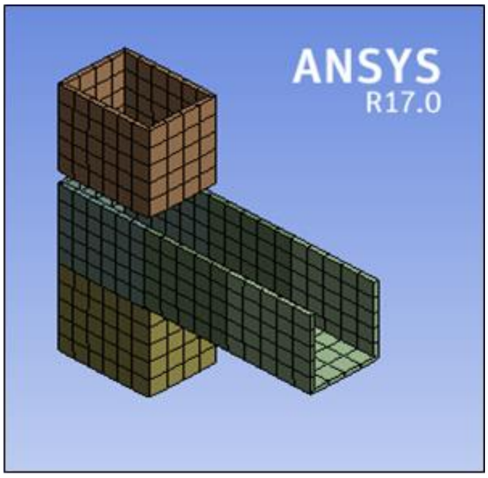

Figure 7: Sandwich Panel Model

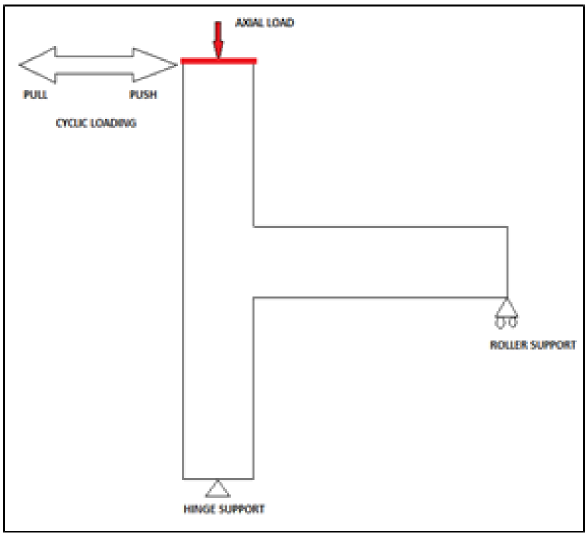

Figure 8: Loading Pattern & Boundary Conditions

4. RESULTS AND DISCUSSIONS

Performance of beam column joint, strengthened with sandwich panel compared with load-displacement behavior. Designations of the specimens are given in the table below.

Table 6: Designation of Specimens

Specimen	Designation
Control Specimen	BCJ - CS
strengthened with H lam sandwich panel	BCJ - H lam
strengthened with PUG sandwich panel	BCJ - PUG
strengthened with AL sandwich panel	BCJ – I lam

4.1 Load-Displacement behavior

The tests were conducted under displacement controlled cyclic lateral loading as discussed previously. The lateral load displacement envelope of the tested beam-column joint specimens and are presented in Figs. 9-12

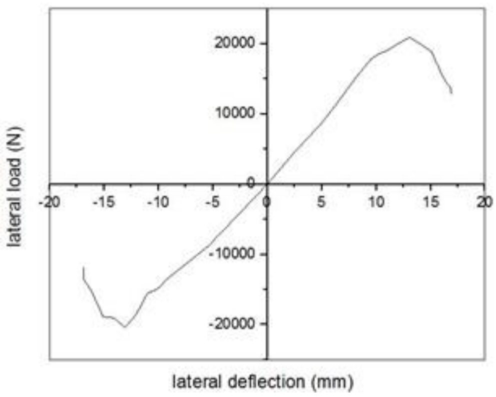

Figure 9: Lateral Load vs Lateral Deflection: BCJ – CS

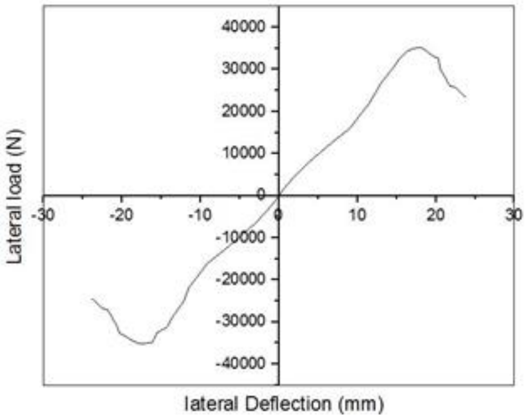

Figure 10: Lateral Load vs Lateral Deflection: H-lam

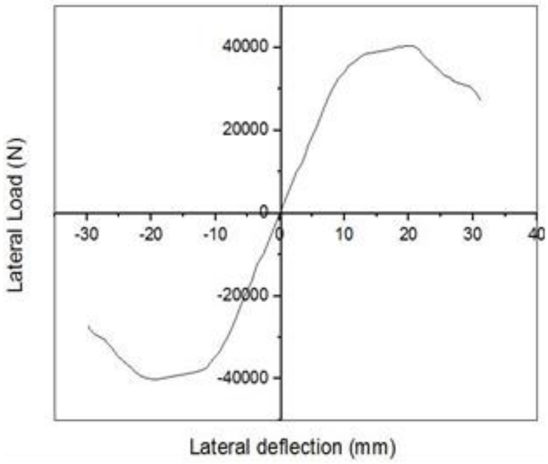

Figure 11: Lateral Load vs Lateral Deflection: I lam

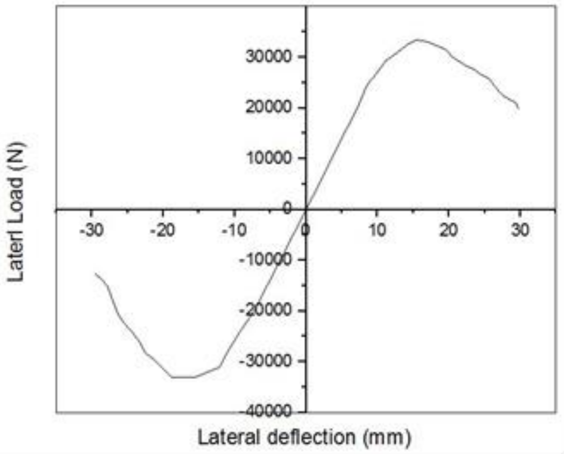

Figure 12: Lateral Load vs Lateral Deflection: PUG

Table 7 shows the ultimate peak load and ultimate displacement of both control and strengthened specimen. Control specimen reached an ultimate load of 20.68 kN. The specimen strengthened with H-lam is capable of reaching a peak load 1.7 times of control specimen whereas specimen strengthened with polyurethane foam cored sandwich panel is capable of reaching a peak load of 1.6 times of control specimen. Th specimen strengthened with aluminum sandwich panel reached maximum peak load about 1.95 times of control specimen.

Table -7: Peak Test Load

Sl. No.	Specimen	Average peak load (kN)	% increase in load
1	BCJ - CS	20.68	-
2	BCJ - H lam	35.23	70
3	BCJ - PUG	33.2	60
4	BCJ - AL	40.42	95

5. CONCLUSION

Based on the finite element study, the following conclusions can be drawn:

- The specimen strengthened with polyurethane foam cored sandwich panel shows 60 % increase in ultimate load compared with control specimen
- The specimen strengthened with H-lam sandwich panel shows 70 % increase in ultimate load compared with control specimen
- The specimen strengthened with aluminum sandwich panel shows 95 % increase in ultimate load compared with control specimen

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