Seismic Evaluation and Retrofitting of RC Beam-Column Joint using FRP by Pushover Analysis using ETABS

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Abstract- *The objective of the paper is to study the seismic behavior by Non-linear static analysis or Pushover analysis of multi-storied building and retrofitting is to be done for the desired members or joints. But the beam-column joints play a critical role in ensuring performance of RC framed structures in resisting the design force, particularly induced by earthquake force. It is very important to design beam-column joint precisely because the individual member such as a beam or column in case of considerable damage can be strengthened by some methods, but a beam-column joint cannot be strengthened once it form the plastic hinge. In this paper a method for the determination of the parameters of plastic hinge properties for structure containing RC framed structures in the pushover analysis is proposed. Seismic evaluation of the structure is to be done by Static Analysis according to IS Code 1893:2002 (Part 1) and calculate the base shear. Then pushover analysis or non-linear static analysis is to be done by ETABS. The main output of this analysis is base shear versus roof displacement curve. After that Aramid Fiber Reinforced Polymer (AFRP) is assigned on the beam-column joints, and then once again pushover analysis is done. Compare both the structures i.e. original and retrofitted.*

Keywords- Pushover analysis, Earthquake analysis, Plastic hinges, Static analysis, ETABS, Retrofitting

I. INTRODUCTION

With the immense loss of life and property witnessed in the last couple of decades alone in India, due to failure of structures caused by earthquakes attention is now given to the evaluation of the adequacy of strength in framed RC structures to resist strong ground motion. In RC frame structure, portion of column that are common to beams at their intersection are called beam-column joints. Beam-column joints are critical components of a frame both in terms of structural stability and its seismic performance. Shear failure of beam-column joints is one of the main causes of collapse of many moment-resisting RC frame buildings in recent earthquakes. A variety of techniques have been developed to strengthen beam-column joints. These techniques include the use of steel and concrete jacketing. More than a decade ago, a new technique for strengthening structural elements emerged. This involves the use of FRP (Fiber Reinforced Polymers) which is widely used as an externally bonded reinforcement in critical regions of RC elements.

In general the performance of framed structures depends on the individual members such as beam-column when there is only gravity load acting on the structure. But when lateral load acting on the structure then performance of the structure depends not only with the individual member, also with the integrity of the joints. The analysis and design of RC framed structure has been carried out as per IS Codes of practice (IS 456:2000 and IS 1893 part 1:2002). Hence it is clear that unless the beam column joints are designed to sustain these forces and deformations, the performance of the structure will not be satisfactory under all the loading conditions, especially under seismic condition. Software available to perform nonlinear static (pushover) analysis are ETABS, SAP, ADINA, SC-Push3D Extended Three Dimensional Buildings Systems (ETABS) and Structural Analysis Program finite element program that works with complex geometry and monitors deformation at all hinges to determine ultimate deformation. It has built-in defaults for ACI 318 material properties and ATC- 40and FEMA 273 hinge properties. Also it has capability for inputting any material or hinge property. ETABS 9.7 deals with the buildings only. The analysis in ETABS 9.7 involves the following four step.1) Modeling, 2) Static analysis, 3) Designing, 4) Pushover analysis Steps used in performing.

II. METHODOLOGY

Building and Loading:-

a) G+10 storey RC framed structure is to be considered in this study.
b) Combination of gravity load and earthquake load.

Modelling and Analysis Method

a) 3D modelling for analysis using ETABS.

b) The structure is analyzed by Static analysis using IS 1893 (Part 1):2002 and Non-linear static analysis or Pushover Analysis using ETABS.

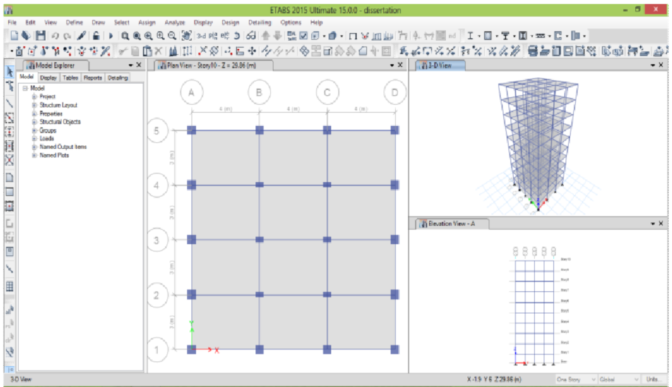

Fig. A- Plan, 3D view and elevation of the structure modelled by ETABS

A 12 m × 12 m, 10 storey multistory regular structure is considered for the study. Height of the structure is 29.86 m. Modeling and analysis of the structure is done by ETABS.

Preliminary Data

Length × Width = 12 m × 12 m
No. of storey = 10 (G+10)
Length of each bay in x- direction = 4 m (3 bays)
Length of each bay in y- direction = 3 m (4 bays)
Height of the structure = 29.86 m
Bottom storey = 2.5 m
Typical storey = 3.04 m
Support Conditions = Fixed
Size of beams = 500 × 250 mm
Size of exterior column = 500 × 500 mm
Size of interior column = 500 × 300 mm
Thickness of external wall = 225 mm
Thickness of internal wall = 100 mm
Depth of slab = 125 mm
Grade of concrete and steel = M20 and Fe 415

Loading consideration

Loads acting on the structure are dead load (DL), live load (LL) and earthquake load (EL)
DL = self weight of the structure, floor load, wall load, water proofing of the terrace and floor finish.
Live load on terrace level = 1.5 kN/m^2
Live load on floor level = 3 kN/m^2

Seismic Data

Zone factor = 0.16 (zone 3)
Soil type = medium
Importance factor = 1.5
Response Reduction factor = 5
Damping = 5%

Static Analysis of Structure using IS Code 1893:2002

Fundamental natural period of vibration T = 0.09 h/√d
= 0.09 × 29.86/√12
= 0.775 sec

For medium soil, the value of seismic acceleration coefficient
Sa/g = 1.36/T = 1.36/0.775 =1.754

Value of horizontal seismic coefficient, A_h = (Z/2) (I/R) (Sa/g)
= (0.16/2) (1.5/5) × 1.754 = 0.042

Dead load per floor

Items	Size (LBH) m^3	Number	Density	DL (kN)
Beam along x-axis	0.25 × 0.5 × 4	15	25	187.5
Beam along y-axis	0.25 × 0.5×3	16	25	150
Column (exterior)	0.5 ×0.5 ×3.04	14	25	266
Column (interior)	0.3×0.5×3.04	6	25	68.4
Slab	12×12×0.125	1	25	450
Wall (external)	12×3.04×0.225	4	20	656.64
Internal walls along x-axis	12×0.1×3.04	3	20	218.88
Internal walls along y-axis	12×0.1×3.04	2	20	145.92

∑W = 2143.34

For Ground Floor

Beam along x-axis = 187.5 kN
Beam along y-axis = 150 kN
Column (exterior) = 0.5×0.5×14×25×2.5 = 218.75 kN
Column (interior) = 0.3×0.5×2.5×6×25 = 56.25 kN
Slab = 450 kN
Walls (external) = 12×2.5×0.225×3×20 = 405 kN
Internal walls along x-axis = 12×0.1×2.5×20×3 = 180 kN
Internal walls along y-axis = 12×0.1×2.5×2×20 = 120 kN
Total load ∑W = 1767.5 kN

Live load on floor area

Live load is considered 1.5 kN/m^2 on terrace level and live load is considered 3.5 kN/m2 on floor level.
LL on each floor = 3.5×12×12 = 504 kN
As per IS 1893:2002 (Page no. 24) clause No. 7.3.1, Table no.8 only 25% LL is considered in seismic weight calculations.
25% of LL = 0.25×504 = 126 kN

Load Combination:- As per IS 1893:2000, the load combination DL+LL becomes;

DL + 25% LL = 2143.34 + 126

= 2269.34 kN per floor

LL on terrace level = 1.5×12×12

= 216 kN

25% of LL = 0.25×216

= 54 kN at roof level

Seismic Weight Calculation of the structure

W1 = 1767.5 + 126 = 1893.5 kN

W2 = W3 = W4 =W5 = W6 = W7 = W8 = W9 = W10 = 2269.34 kN per floor

Lumped mass at terrace level:-

In the calculation of seismic weight for the terrace floor 50% of the weight is considered for walls and columns.

W11 = 187.5 + 150 + (266/2) + (68.4/2) + 450 + (656.64/2) + (218.88/2) + (145.92/2)

= 1465.42 kN

Total weight W = 1465.42 + (9×2269.34) + 1767.5 = 23656.98 kN

The value of base shear, V_b = Ah × W

= 0.042 × 23656.98

= 993.59 kN

Distribution of Design Force- The design base shear Vb computed above shall be distributed along the height of the building as per the following expression

$$Q_i = V_b \times W_i h_i^2 / \sum W_i h_i^2$$

Floor	Height (m)	$W_i h_i^2$	Base shear Q
1	2.5	12205.62	1.758
2	5.54	69649.67	10.031
3	8.58	167060.64	24.062
4	11.62	306416.27	44.133
5	14.66	487716.56	70.246
6	17.70	710961.52	102.401
7	20.74	976151.15	140.597
8	23.78	1283285.44	184.834
9	26.82	1632364.40	235.112
10	29.86	1306597.19	188.191

$\sum W_i h_i^2 = 6952408.46$

III. PUSHOVER ANALYSIS BY ETABS

Pushover analysis is non linear static analysis in which provide ‘capacity curve’ of the structure. It is a plot of total base force vs. roof displacement. The analysis is carried out up to failure; it helps determination of collapse load and ductility capacity of the structure. The pushover analysis is a method to observe the successive damage state of the building. In Pushover analysis structure is subjected to monotonically increasing lateral load until the peak response of the structure is obtained.

FORCE DEFORMATION BEHAVIOR OF HINGES

- Point A corresponds to unloaded condition.
- Point B represents yielding of the element.
- The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins.
- The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable.
- The residual resistance from D to E allows the frame elements to sustain gravity loads.
- Beyond E, the maximum deformation capacity, gravity load can no longer be sustained.

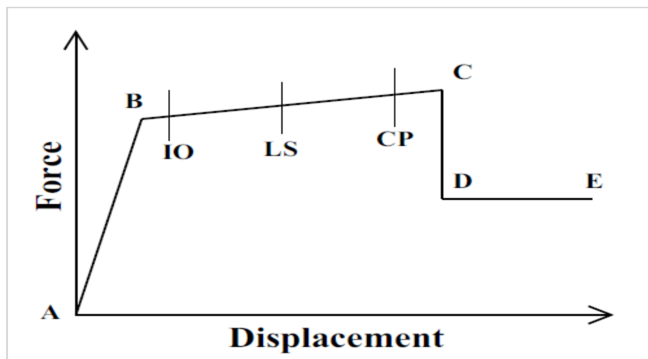

Fig. B- Force versus Displacement curve

After assigning all the properties of the model, the displacement-controlled pushover analysis of the model is carried out. The model is pushed in monotonically increasing order until target displacement is reached. The software ETABS includes several default hinge properties that are based on average values from ATC-40 for concrete members and average values from FEMA-273 for steel members.

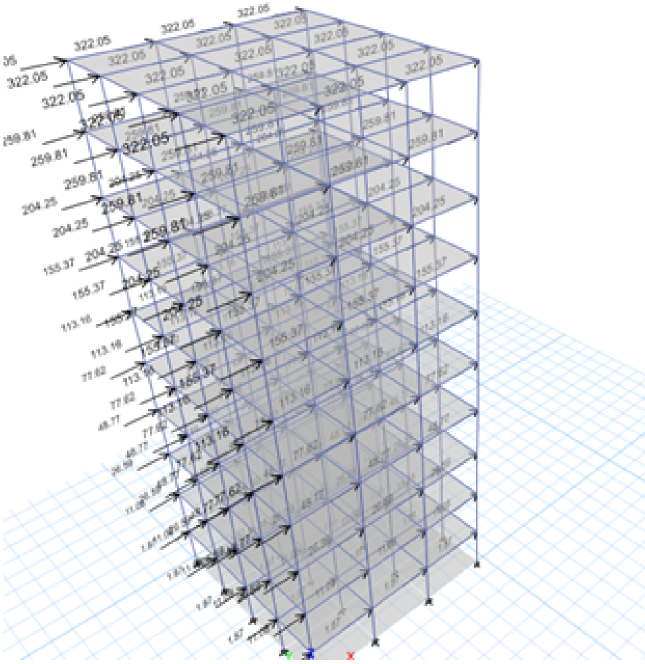

Fig C- Pushover load applied in x-direction

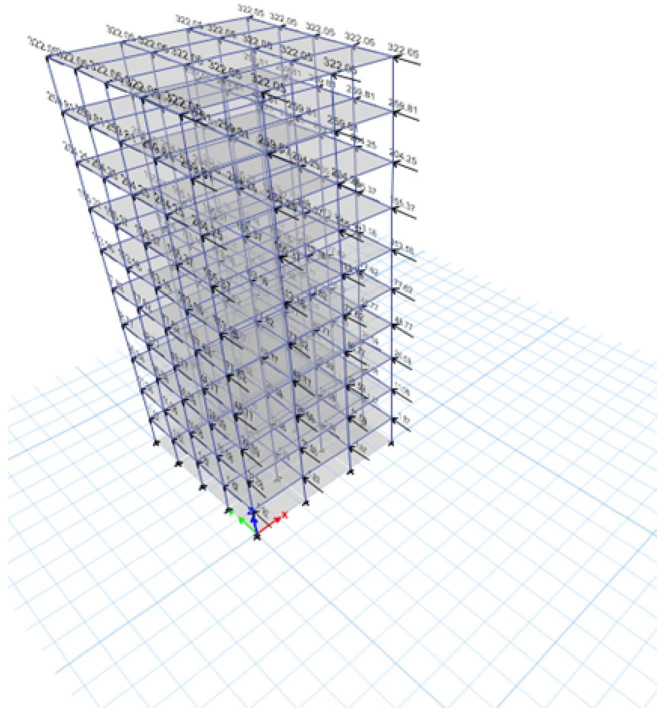

Fig E-Pushover load applied in y-direction

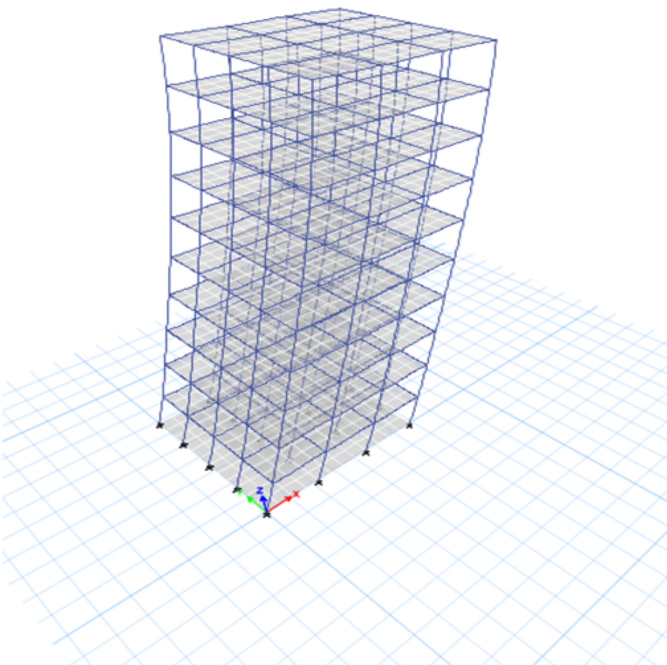

Fig D-Deformed 3D view in x-direction

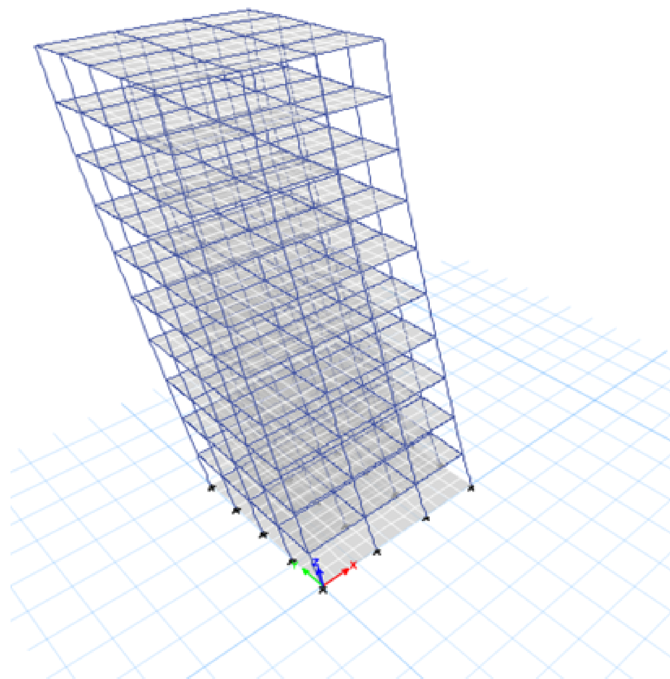

Fig F-Deformed 3D view in y-direction

Data of pushover curve for the existing structure

Step	Displacement	Base Force	A-B	B-IO	IO-CS	LS-CP	CP-C	C-D
0	0	0	152	0	0	0	0	0
1	10.9	1.87	146	6	0	0	0	0
2	17.6	11.08	140	12	0	0	0	0
3	34	26.59	136	16	0	0	0	0
4	39.2	48.77	130	22	0	0	0	0
5	85.1	77.62	118	10	24	0	0	0
6	95.3	113.16	116	12	24	0	0	0
7	132.9	155.37	114	10	10	18	0	0
8	162.4	204.25	114	6	12	20	0	0
9	241.2	259.81	110	8	10	20	0	4
10	296	322.05	110	8	10	20	0	0
11	300	326.12	112	10	12	16	0	0

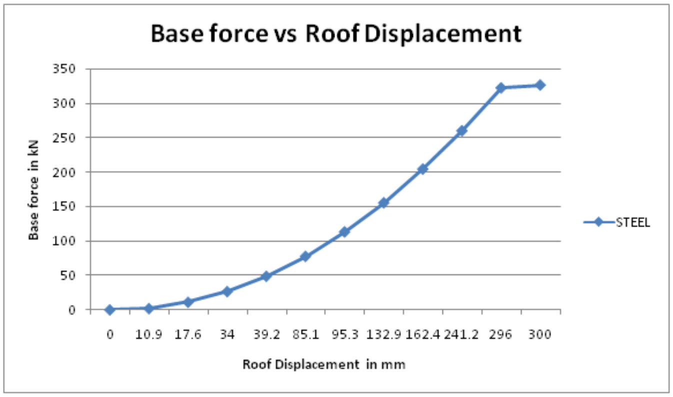

Fig G- Graph of Base Force vs Displacement for steel

Fiber Reinforced Polymers

FRP is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, aramid, carbon and basalt.

Aramid Fiber

Aramid fiber is most commonly known as Kevlar, Nomex and Technora. Aramids are generally prepared by the reaction between an amine group and a carboxylic acid halide group.

Retrofitting of RC beam column joint using FRP

Generally due to earthquake load, beam-column joints are the critical regions of the structure. So it should be retrofitted by Fiber Reinforced Polymers (FRP). In this paper we use aramid fiber at beam-column joint as a retrofitted material and pushover analysis is to be done for the retrofitted structure by ETABS. Then compared both the structures.

Material Property Data in ETABS

Weight per unit volume = 23.5631 kN/m^3
Mass per unit volume = 2402.77 kg/m^3
Modulus of Elasticity = 2482.13 MPa
Poisson's ratio μ = 0.2
Coefficient of thermal expansion = 0.0000099 1/C
Shear Modulus, G = 10342.14 MPa

Data of Pushover Curve for the retrofitted structure Data of Pushover Curve for the retrofitted structure

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total
0	0	0	0	0	0	0	0	0	0	0	0
1	6.7	1.87	142	10	0	0	0	0	0	0	152
2	10.3	11.08	140	10	2	0	0	0	0	0	152
3	21	26.59	134	8	10	0	0	0	0	0	152
4	29.4	48.77	130	12	10	0	0	0	0	0	152
5	63.1	77.62	130	18	4	0	0	0	0	0	152
6	76	113.16	120	20	12	0	0	0	0	0	152
7	91	155.37	114	16	16	4	0	0	0	0	152
8	102	204.25	114	20	8	10	0	0	0	0	152
9	142	259.81	110	22	12	8	0	0	0	0	152
10	161	322.05	110	24	16	2	0	0	0	0	152
11	173.4	326.50	116	22	8	2	0	4	0	0	152
12	216.4	341.62	120	16	4	6	0	6	0	0	152

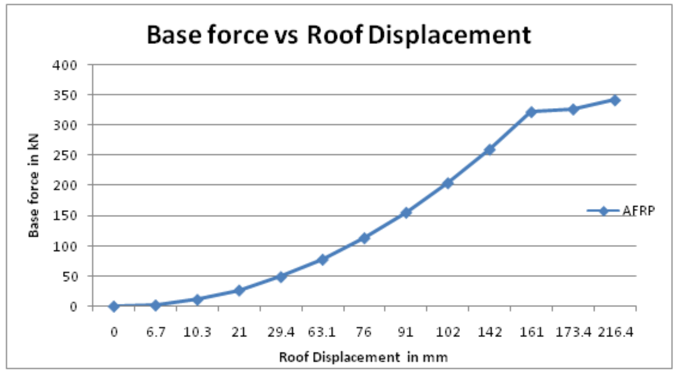

Fig H- Graph of Base Force vs Displacement for AFRP

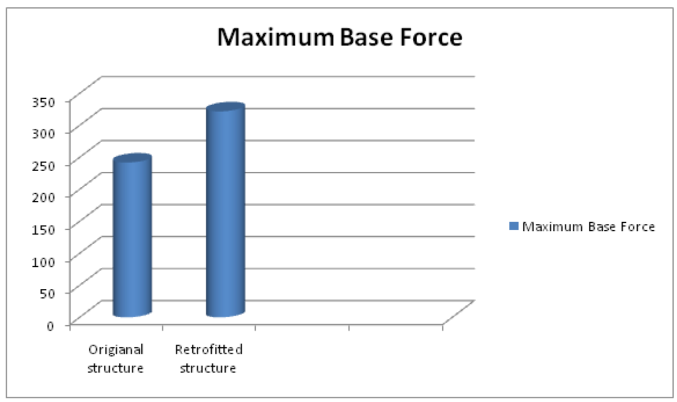

Fig I- Comparison of Maximum Base Force for Original and Retrofitted Structure

Fig J- Storey drift graph of the original structure

IV. CONCLUSION

a) The pushover analysis is a simple way to explore the non-linear behavior of structure.
b) Load carrying capacity of the AFRP reinforced structure is higher than steel reinforced structure which is major advantage.
c) It is found that the maximum displacement is 242 mm at base force of 260 kN upto the point of failure. After retrofitting by AFRP at beam-column joints maximum displacement is 173.4 mm at base force of 322 kN. This shows that as we added the AFRP at the joints, the displacement of the structure is decreasing at higher loads and performance of the structure is becoming well within the permissible lilmits.
d) Since AFRP bars with smaller thickness possess higher strength, the congestion of reinforcement in beam-column joint is less.
e) Comparison of storey drift of the existing and retrofitted structure shows that structure after retrofit have less storey drift

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