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Seismic Analysis of Hybrid Coupled Shear Wall System with GFRP Coupling Beams

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Abstract - *Hybrid coupled walls (HCWs) are comprised of two or more reinforced concrete wall piers connected with coupling beams of steel or a different material distributed over the height of the structure. Extensive research over the past several decades suggests that such systems are particularly well suited for use in regions of moderate to high seismic risk. Coupled wall systems are often used in high-rise buildings because of their superior strength and stiffness. In such a system, coupling beams distributed along the building height are designed as the components that undergo inelastic deformation and dissipate seismic energy. While traditional reinforced concrete (RC) coupling beams, if detailed appropriately, show adequate seismic performance, and once damaged, these components are expensive and time-consuming to repair. In this project, a multi storied building with hybrid coupled shear wall system with Glass Fiber Reinforced Polymer (GFRP) coupling beams is modelled in SAP and the seismic behavior is studied. The same system is modelled with conventional RC coupling beams and the behavior of the systems are compared. Also different GFRP sections such as Channel and I are used for Coupling beams and the performances are studied under the same loading conditions.*

***Key Words*: GFRP, Coupled Shear Wall, Seismic Analysis, High Rise Buildings, Reinforced Concrete**

1. INTRODUCTION

Earthquake causes considerable damage to a large number of RCC high-rise buildings and tremendous loss of life. Therefore, it is necessary to offer adequate earthquake resistant provisions with regard to planning, design, and detailing in high-rise buildings to withstand the effect of an earthquake and minimize disaster. As an earthquake resistant system, the use of coupled shear walls is one of the potential options in comparison with moment resistant frame (MRF) and shear wall frame combination systems in RCC high-rise buildings.

1.1 Coupled Shear Walls

In concrete structural walls, a regular pattern of openings is often required to accommodate windows, doors, and/or mechanical penetrations. Efficient seismic structural systems particularly suited for ductile response with very good energy dissipation characteristics can be achieved when these openings are arranged in a rational pattern where a number of walls are interconnected or coupled to each other by beams at the floor and roof levels. These systems are generally referred to as coupled structural walls with the implication that the connecting beams, which may be relatively short and deep, are substantially weaker than the walls. The walls, which behave predominantly as cantilevers, can then impose sufficient rotations on the coupling beams to make them yield. If suitably detailed, the beams can dissipate a significant amount of energy distributed over the entire height of the structure.

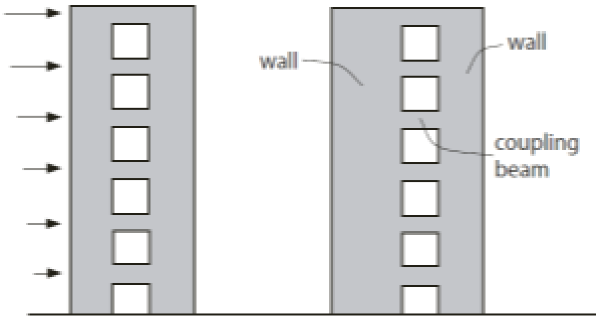


Fig -1: Coupled Shear Wall

1.2 Hybrid Coupled Shear Wall Systems

The hybrid coupled wall system overcomes the defects and disadvantages faced by the conventional RC coupled beams. As the name indicates this system uses wide varieties and combinations of structural components such as concrete, steel beams, post tensioning on steel as well as concrete beams, plywood, cross laminated timber, shape memory alloys etc. Steel coupling beams or steel-concrete composite coupling beams provide an attractive alternative, since they are more stable, hysteretic behaviour and easy repair, if the connections between steel elements and RC wall facilitate link replacement. This system can also be used with rocking shear wall which works under the concept of rocking mechanism.

The general action of the hybrid coupled shear wall is, when a seismic load is acted upon the system these forces are resisted through a combination of flexural action of the walls and frame action between the coupling beams and the walls. This forms an axial tension-compression couple. The overturning moments are partially resisted by this couple rather than the individual flexural action of walls. The energy dissipation can be distributed over the entire height of the structure. There will be a sacrificial element in the system which dissipates energy and yield earlier to protect the structure from damages. Later this element can be replaced easily.

2. SEISMIC ANALYSIS

The 12 storied reinforced concrete building with Glass Fibre Reinforced Polymer (GFRP) coupling beam is modelled in SAP2000. The lateral forces have been resisted by a dual system consisting of special moment resisting frames (SMRF) and reinforced concrete coupled shear walls. Floor to floor height is 3.1 m and plinth height is 1.2 m above footing bottom. Parapet wall height is 1.2 m at terrace. Building is located in seismic zone IV. Hard soil strata is considered for analysis and soil structure interaction is neglected. Building importance factor is 1. Response reduction factor R =5.

Table -1: Geometric Properties

SECTION DETAILS	DIMENSIONS(mm)
Beams	400 x 700
Column 1	900 x 900
Column 2	750 x 750
Slab Thickness	150
Outer Wall Thickness	230
Inner Wall Thickness	150
Shear Wall Thickness	300
GFRP Coupling beam 1	300 x 1600
GFRP Coupling beam 2	300 x 800

Table -2: Material Properties

Material	Unit weight (kN/m^3)	Yield Stress (MPa)	Expected Tensile Strength (MPa)	Compressive Strength (MPa)
Concrete	25	-	-	25
Reinforcement	76.9729	415	518.750	-
Brick	20	-	-	-

The material properties of GFRP are:
Modulus of Elasticity = 50 GPa
Poisson's ratio = 0.22
Weight per unit volume = 1716 kg/m^3 = 16.83 kN/m^3

2.1 Loading Calculation

The Dead loads are calculated as per IS 875: 1987(part1). The density of R.C.C is assumed to be 25kN/m^3 and the density of masonry (including Plastering) is assumed to be 20 kN/m^3, floor finishes load is 1kN/m^2 and roof treatment is 1.5 kN/m^2 .The Dead Load due to slabs has been transferred to beams by following yield line pattern of load distribution. Live load on floor is 3 kN/m^2 and Live load on roof is 1.5 kN/m2.The seismic load is calculated, as per IS 1893:2002 (Part 1). Various load combinations using the primary load cases discussed above have been used to check the stability of the building as well as of its structural components.

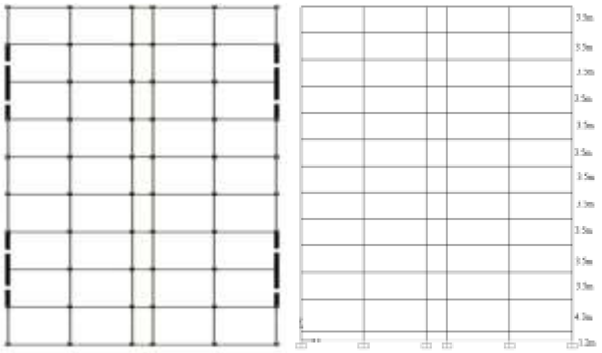


Fig -2: Plan and Elevation

2.2 Modelling

The structure is modelled in SAP2000 v16. The beams and columns are modelled as frame elements. The slabs and shear walls are modelled as thin shell elements. The shear walls are provided at four places in the longitudinal direction throughout the height of the building. There are two sets of shear walls provided at each of the positions which are connected by using Reinforced Concrete Coupling Beams. The coupling beams are then interconnected by rigid links. The infill walls are not modelled and weight due to it is taken as uniform loads over the periphery beams. Linear static analysis is carried out for the system

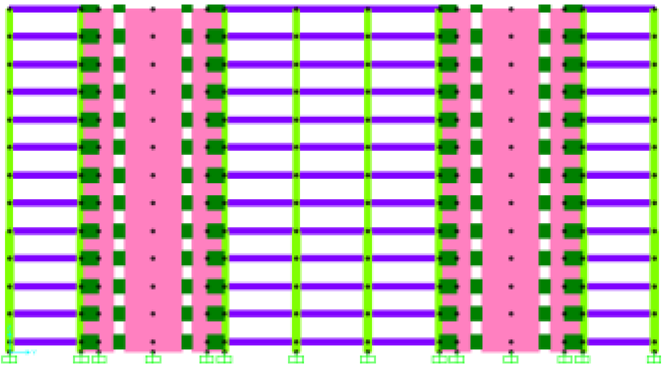


Fig -3: Side view

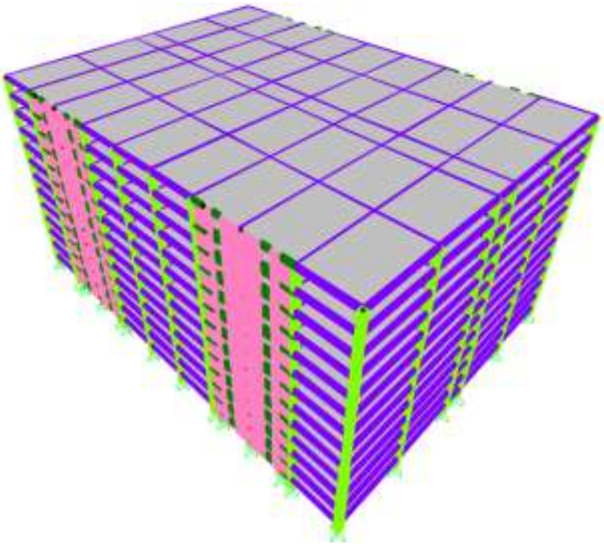
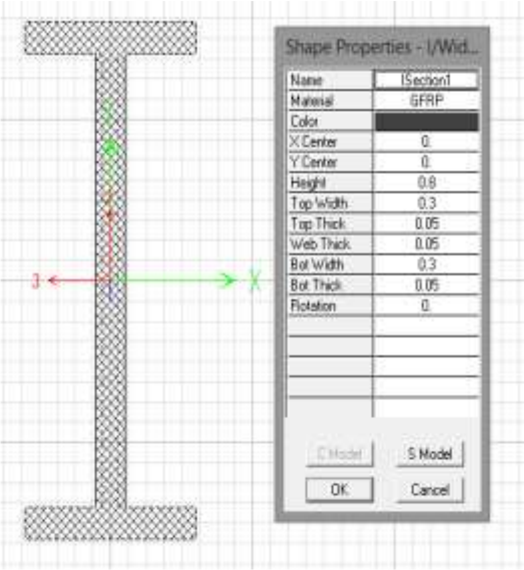


Fig -4: Extruded 3D view

2.3 Coupling Beams with GFRP I-sections

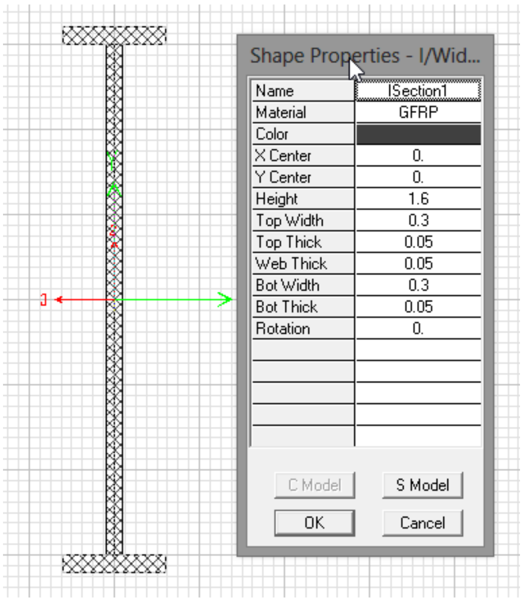
The structure is modelled again with the same properties and loading conditions but with GFRP I-section Coupling beams. The GFRP coupling beams are provided as I-sections. The I-sections are designed in the Section Designer as shown in Fig 5. The dimensions are given similar to that of the rectangular section.



Shape Properties - I/Wid...

Name	ISection1
Material	GFRP
Color	■
X Center	0
Y Center	0
Height	0.8
Top Width	0.3
Top Thick	0.05
Web Thick	0.05
Bot Width	0.3
Bot Thick	0.05
Rotation	0

(a)



Shape Properties - I/Wid...

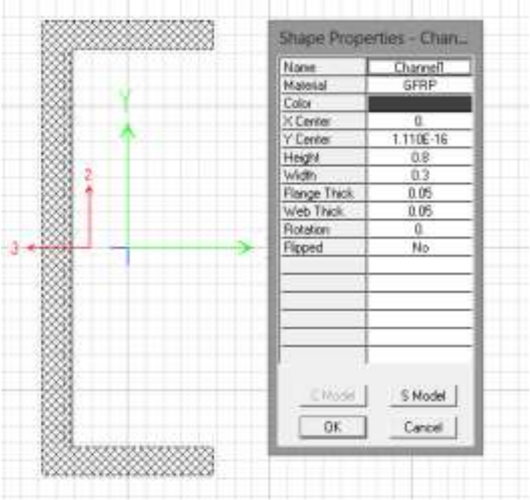
Name	ISection1
Material	GFRP
Color	■
X Center	0.
Y Center	0.
Height	1.6
Top Width	0.3
Top Thick	0.05
Web Thick	0.05
Bot Width	0.3
Bot Thick	0.05
Rotation	0.

(b)

Fig -5: (a) Properties of I-section on the top floor; (b) Properties of I-section upto the 11th floor

2.4 Coupling Beams with GFRP Channel sections

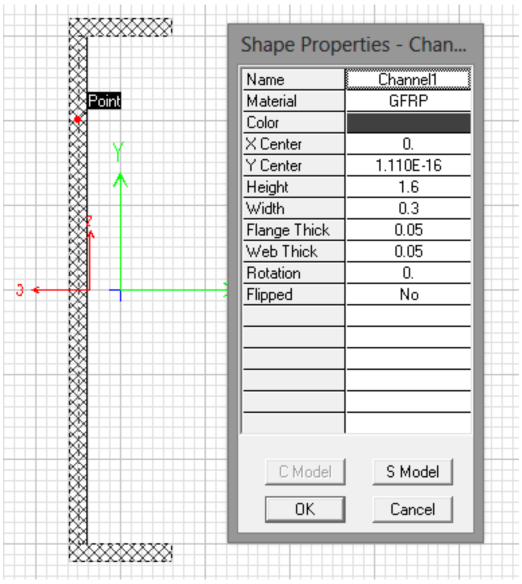
The structure is modelled again with the same properties and loading conditions but with GFRP Channel section Coupling beams. The GFRP coupling beams are provided as Channel sections. The I-sections are designed in the Section Designer as shown in Fig 6. The dimensions are given similar to that of the rectangular section.



Shape Properties - Chan...

Name	Channel1
Material	GFRP
Color	■
X Center	0.
Y Center	1.110E-16
Height	0.8
Width	0.3
Flange Thick	0.05
Web Thick	0.05
Rotation	0.
Flipped	No

(a)



Shape Properties - Chan...

Name	Channel1
Material	GFRP
Color	■
X Center	0.
Y Center	1.110E-16
Height	1.6
Width	0.3
Flange Thick	0.05
Web Thick	0.05
Rotation	0.
Flipped	No

(b)

Fig -6: (a) Properties of Channel section on the top floor; (b) Properties of Channel section upto the 11th floor

4. RESULTS AND DISCUSSIONS

The values of Modal Periods & Frequencies, Base Shear and Displacement obtained from the Linear Static Analysis are as follows.

Table -3: Modal Periods and Frequencies

	Rectangular section		I-section		Channel Section	
StepNo:	Period	Frequency	Period	Frequency	Period	Frequency
Unitless	Sec	Cyc/sec	Sec	Cyc/sec	Sec	Cyc/sec
1.000	1.826	0.531	1.815	0.531	1.814	0.551
2.000	0.784	1.254	0.928	1.254	0.928	1.078
3.000	0.757	1.297	0.900	1.297	0.900	1.111
4.000	0.585	1.646	0.581	1.646	0.582	1.719
5.000	0.319	2.972	0.318	2.972	0.318	3.144
6.000	0.248	4.515	0.290	4.515	0.291	3.440
7.000	0.238	4.608	0.280	4.608	0.281	3.559
8.000	0.207	4.834	0.206	4.834	0.206	4.853
9.000	0.172	5.805	0.172	5.805	0.172	5.815
10.000	0.172	5.809	0.172	5.809	0.172	5.819
11.000	0.170	5.872	0.170	5.872	0.170	5.888
12.000	0.170	5.876	0.170	5.876	0.170	5.892

Table -4: Base Shear

Output Case	Rectangular	I-section	Channel section
Text	KN	KN	KN
EQX	4409.87	4377.26	4377.38
EQY	10630.60	8823.25	8823.04

Table -5: Storey Displacements

Storey	Rectangular section Displacement (mm)	I-section Displacement (mm)	Channel section Displacement (mm)
0.00	0.00	0.00	0.00
1.20	0.12	0.12	0.12
4.30	1.20	1.19	1.19
7.40	2.80	2.87	2.87
10.50	4.85	4.82	4.82
13.60	6.9	6.89	6.89
16.70	9.16	9.10	9.10
19.80	11.37	11.29	11.29
22.90	13.47	13.37	13.37
26.00	15.40	15.30	15.30
29.10	17.13	17.02	17.02
32.20	18.59	18.47	18.47
35.30	19.73	19.60	19.60
38.40	20.56	20.43	20.43

The GFRP Channel and I sections gave good performance over GFRP Rectangular section and Concrete Coupling beam systems under the same loading conditions. Also the GFRP light sections require less amount of material compared to other sections used. The base shear occurred in Channel and

I sections were less than those occurred in Rectangular section. Also, the GFRP light sections have undergone less displacement than the rectangular section. Also the GFRP light sections require less amount of material compared to other sections used.

CONCLUSION

- The introduction of GFRP doesn't make much difference in the values of time period, base shear, modal participation and displacement.
- The GFRP I and Channel sections performed better than the Concrete Coupling beams under the same loading conditions.
- The GFRP coupling beams used less area of material compared to concrete coupling beams and still performed well.
- Of different sections of GFRP, Channel and I sections gave more performance than rectangular section with the same area.
- GFRP has a high strength to weight ratio than concrete which helps in reducing the quantity and overall cost of construction.
- It can be replaced easily after damage than reinforced concrete coupling beams.
- Therefore it can be taken as a good alternative for concrete coupling beams even though it cannot withstand high temperatures.

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