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Research paper

Seismic and blast loading performance of a gypsum panelled prefabricated building

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Abstract

Urge for modern technologies and limited space leads to the idea of light weight building technology that can resist major loading conditions and can even be used in lands with very poor soil profile. For proper understanding of the structural response, building needs to be evaluated for natural hazards like seismic and manmade calamities like blast loading along with the normal forces acting on the structure. Whole building and structural components are also to be evaluated to study the progressive collapse of the building. This paper includes the study of static, seismic and blast loading effects on a conventional and a prefabricated building. The structural components and connections are also evaluated to forecast the strength of a prefabricated building using FE method. Gypsum wall panel incorporated with glass fibres and casted with cavities, as hollow and filled, are used as building panel. This study is useful in suggesting an innovative technology which is light in weight and cost effective with composite structural components.

Keywords: *Blast Analysis; Collapse; FE Method; Prefabricated Building; Seismic Analysis; Static Analysis.*

1. Introduction

In the present competitive and innovative world, time, cost and structural strength plays a prominent role in safety and serviceability of the structure. Recent advances in construction technology have feasible and economical solutions for problems like space limitation and occupancy requirements. The major solution of above mentioned problem lies in thought of prefabrication techniques. In the era of smart materials, material should be sustainable withstanding both static and dynamic loading conditions.

Chris P. Pantelides et al [11] studied on prefabricated composite floor-building system, where they used reinforced concrete T section with mechanical block outs in the webs and concrete piers to the wide flange steel beams. Allah Dad Ahmadi [12] studied on the designing and comparison of some samples of prefabricated concrete sandwiched ceiling slabs with lightweight concrete core using experimental and nonlinear analysis. Comparison of results was done to suggest their behaviour when come into structural action. Brian Uy et.al [13] suggested a better connection for demountable steel and composite structure. Fangxin Hu et al [14] conducted experimental study and FE analysis on the Seismic performance of three types of prefabricated steel beam-to-column connections.

B.W. Schafer et al [16] conducted an experimental study for the overall analysis of a cold formed double storeyed building suggested various collapse pattern and behavior of building under the action of loads. T Ngo et al [17] published his work on the basics of blast analysis using Finite element program. This work shows the basics of blast pressure effect and their analytical calculation.

B.M. Luccioni et al [18] conducted an analysis of building collapse under blast loads, where an actual building that has suffered a terrorist attack was analysed. The progressive collapse of building was carried out by conducting experimental studies.

The present investigation deals with experimental and finite element study of glass fibre reinforced gypsum panel casted with cavities and later filled with PCC and RCC. Further studies were extended to evaluate column to column bolted connection with various bolt patterns. Observations were carried out experimentally for static loading condition whereas finite element analysis was carried out for both static and dynamic loading conditions suggesting efficient bolt pattern. To have proper understanding, structural comparison of prefabricated and conventional building of similar functionality is reported.

2. Materials

2.1. Gypsum panel

Application of gypsum in construction industry has been remarkable. Gypsum is a byproduct of fertilizer industry leading to major environment issues. Hence effective utilization of gypsum is advisable. Its light weight marks a quantum leap in reducing the dead load of structure proving economical design. Gypsum has been used in construction industry for partition works, heat insula- tion etc. Glass fibres of length 10cm and diameter 2mm, aspect ratio of 50 were selected for reinforcing the gypsum panels. Figure 1 represents the dimensions of gypsum panel used.

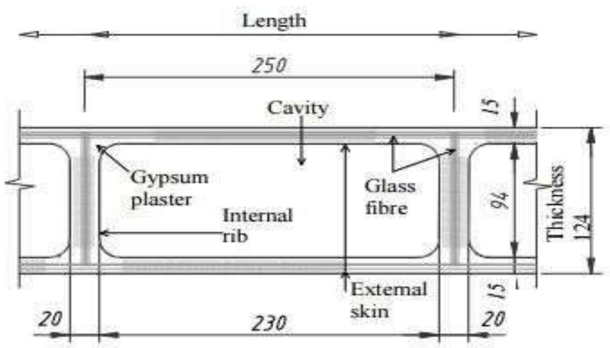

Fig. 1: Panel Dimensions [20].

2.2. Concrete

Light weight concrete with maximum aggregate size of 12mm with a density of 19 kN/m^3 is adopted for filling the cavities [20], making it stiffer and durable compared to hollow gypsum panels.

2.3. Steel

Steel structural members of ISMB 450 and ISMB 500 were used as beams and columns respectively. M20 HSFG bolts were used as connections. Column splices of dimension 150X210X12mm were used as connecting members between two column lengths.

3. Experimental investigation

3.1. Gypsum wall panel

The experiment is conducted confirming with ISO guidelines [20], later investigation was extended to modeling and analysis in ANSYS. Gypsum panel of dimension 5.35 X 3m is selected where the cavities are filled with PCC and RCC. Special attention is taken in filling of cavities, the concrete is placed in three layers of 1m height with time interval of 1 hour between layers. Usage of vibrators is not advisable within cavities. Experimental setup and procedure of compression test performed on all specimens as per guideline [20]. Figure 2 represents experimental setup of compression test.

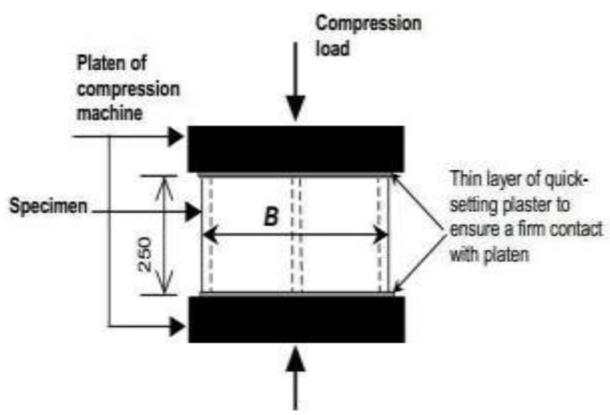

Fig. 2: Compression Testing Setup [20].

Result of load bearing capacity test on gypsum panel is provided in section 5.1.1.

3.2. Beam to column connection

Experiment is carried out on a scaled model as shown in Figure 3.

Fig 3: Bolted Beam to Column Connection.

Connections are tested on Compression testing machine connected with J clamps to hold the specimen as in Figure 4. The capacity of CTM used is 25 tonne. Result of experimental study is presented in 5.1.2.

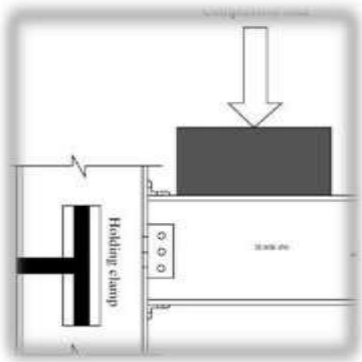

Fig. 4: Experimental Setup.

3.3. Beam to beam connection

Beam to beam connection chosen for the study is as shown in Figure 5

Fig. 5: Bolted Beam to Beam Connection.

Experimental setup is same as shown in Figure 4. Result of experimental study is presented in 5.1.3.

3.4. Column to column connection

Experiment investigation was carried out on a scaled model shown in Figure 6. Connections are tested under static loading in UTM with a loading rate of 1 tonne per minute. Maximum capacity of UTM used for the test is 25 tonne. The test setup is shown in Figure 7.

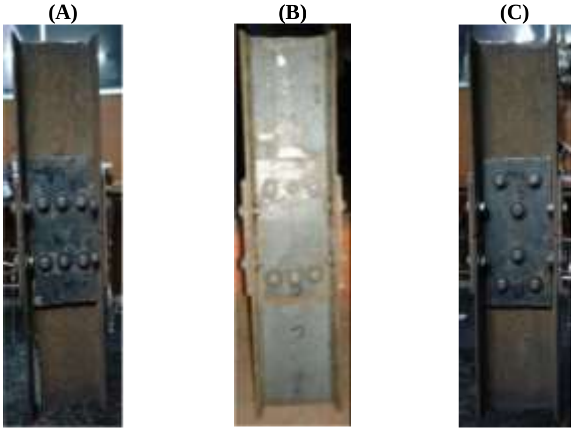

Fig. 6: Bolted Column to Column Connections; A) Staggered Pattern; B) Linear Pattern with Less Gauge Distance; C) Linear Pattern with Greater Gauge Distance.

Fig. 7: Experimental Setup.

Strength of bolt for linear pattern and staggered pattern was calculated as per the codal provision given in IS 800:2007 [2] and the results are presented in 5.1.4.

4. Finite element analysis

Finite element analysis is the programmed computerized method to analyse the behaviour of a model, when established into practice.

4.1. Gypsum panel

Finite element analysis is carried out on to the model with dimensions as in Figure 1, and later the results were compared to experimental results. Gypsum panel is analysed for both static and dynamic loading. Table 1 represents the properties assigned to the model for finite element analysis.

Table 1: Properties of Gypsum Panel Reinforced with Glass Fibres. [20]

Weight- light weight	40 kg/ sqm	Flexural strength	21.25 kg/cm^2
Axial load capacity	160 kN/m{16 tons/ m}	Tensile Strength	35 kN/ m
compres- sive strength	73.2 kg/cm2	Ductility	4
Unit Shear strength	50.90 kN/m	Fire re- sistance	4 hr rating (700- 10000 C)
Thermal Resistance R	0.36 k/W	“U “Val- ue	2.85W /M^{2}K
Thermal conductivity	0.617	Elastic Modulus	3000- 6000 Mpa
Sound transmis- sion{STC}	40	Water absorption	< 5%

From the table it is clear that the panel itself can withstand considerable strength and can be used as a load bearing wall when used in combination with structural steel and light weight concrete. Figure 8 shows the finite element model of Gypsum panel

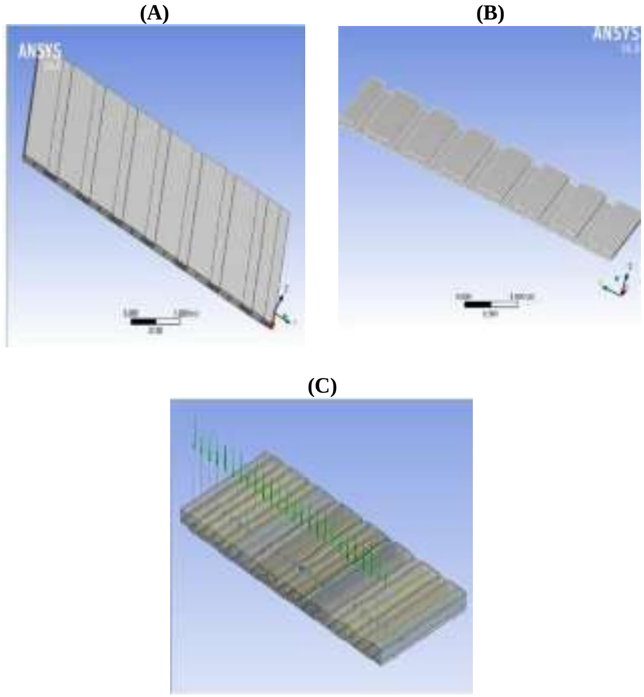

Fig. 8: Model of Gypsum Panel Strengthened with Glass Fibres A) Hollow Panel B) PCC Filled Panel C) RCC Filled Panel.

4.1.1. Static analysis

Static model of gypsum panel was analysed for hollow and filled conditions. Results of static analysis of gypsum panel is presented in 5.2.1.

4.1.2. Dynamic analysis

Both seismic and blast analysis were done for gypsum panel in hollow and filled conditions. Seismic analysis was investiged according to codal provisions given in IS 1893:Part 4 [6] and analysis was carried out using complete quadratic combination (CQC) method by assigning the collected time – acceleration graph (Figure 9) from prior earthquakes. Results of seismic analy- sis is shown in 5.2.1a).

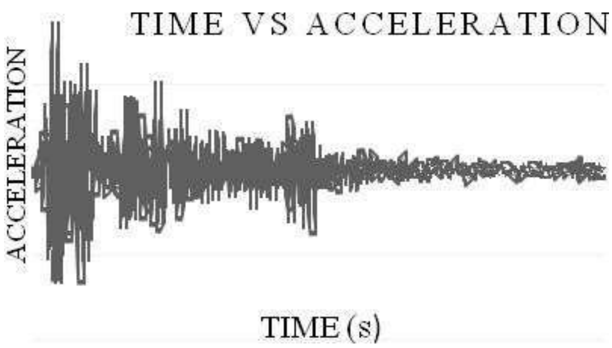

Fig. 9: Time vs. Acceleration Graph [19].

Blast analysis is done in explicit dynamics platform of finite element program, considering time step as the main factor. Tri- nitro toluvene (TNT) blast of weight 36 kg and standoff distance 500

mm was modelled and are assigned to the model by remapping technique.
Time step is calculated using CFL (Courant- Fried Rich's Levy) Condition eq (1). [19]

$$\Delta t \leq f \times \left(\frac{h}{c}\right) \min \quad (1)$$

Where t is the time increment, f is the stability time factor (0.9 by default), h is the characteristic dimension of an element and c is the local material sound speed in an element [19]. In this analysis the value of Δt is considered as 3ms, which is obtained from equation (1). Result of blast analysis is reported in 5.2.1 b).

4.2. Beam to column connection

Connection of a beam section of ISMB 450 to a column section of ISMB 500 is analysed using finite element method. The beam to column connection is modelled in ANSYS using the same dimension as in Figure 3 and the model is shown in Figure 10.

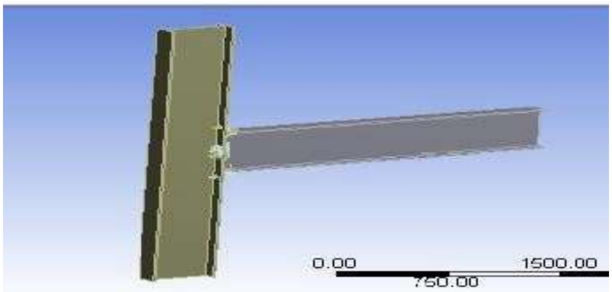

Fig. 10: Model of Beam to Column Connection.

Static analysis of beam to column connection was carried out and the results are presented in 5.2.2.

4.2.1. Seismic analysis

Seismic analysis of beam to column connection was carried out as mentioned in 4.1.2. Result of seismic analysis is reported in 5.2.2 a).

4.3. Beam to beam connection

Connection of two beam lengths of ISMB 450 are analysed by using finite element analysis. Figure 11 shows the model of beam to connection in ANSYS.

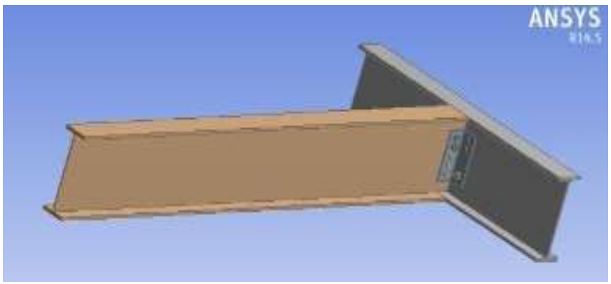

Fig. 11: Model of Beam to Beam Connection.

Results of static analysis are presented in 5.2.2.

4.3.1. Seismic analysis

Seismic analysis of beam to column connection was carried out as mentioned in 4.1.2. Result of seismic analysis is reported in 5.2.2 a).

5. Column to column connection

Connection of two column lengths are analysed by finite element analysis. ISMB 500 steel I beam of length 1500mm connected with three different bolted patterns (as shown In Figure 6) was modelled in ANSYS (Figure 12).

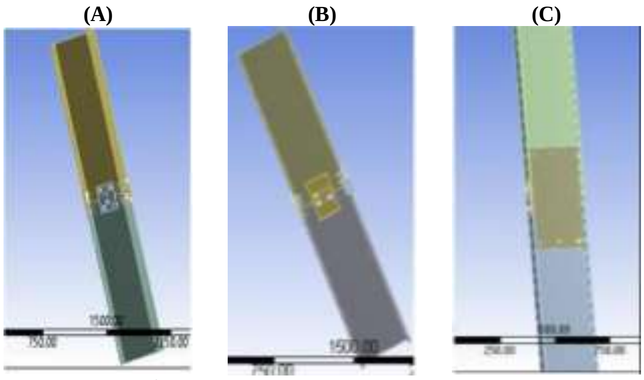

Fig. 12: Model of Column to Column Connection A) Pattern 1 B) Pattern 2 C) Pattern 3.

5.1. Static analysis

Column to column connections were analysed for pretension force along with Static analysis Static analysis of bolt can be observed accurately, if the pretension force applied to bolt is optimum. Results of static analysis are shown in 5.2.4.

5.2. Dynamic analysis

Dynamic analysis of column-column connection was done in the same procedure as mentioned in 4.1.2. Results of dynamic analysis are shown in 5.2.4 a) and b).

5.3. Building

An eight storeyed building was modelled in design and analysis software, then analysed for static and dynamic loads. ISMB 450 and ISMB 500 steel sections were assigned as beams and columns respectively, gypsum panels were assigned as floor and wall panels. This structure was analysed for static and dynamic conditions
Blast analysis was done using time history non linear dynamic analysis by in cooperating triangular time function. Nonlinear direct integration method is adopted for the dynamic blast analysis of the whole building to study the progressive collapse. The study of Umesh khandi [22] supports non linear direct integration method with triangular time function. The beam and column ends should be assigned with moment hinges for the nonlinear dynamic analysis. ELECENTRO curve with highest possible frequency is assigned to the model with an iteration step 1180. Results of static and dynamic analysis are reported in 5.2.5.

6. Results and discussion

6.1. Experimental investigation

6.1.1. Gypsum panel

Results of experiments on gypsum panel are tabulated in Table 2.

Table 2: Strength of Different Panels

Trial	Axial load bearing capacity (kN/m)		
	Normal panel	Panel filled with PCC	Panel filled with RCC
1	160	178	208
2	162	181	210
3	160	179	198

It is clear that glass fibre reinforced panel with RCC shows better result, taking the advantage of concrete and steel capability of handling compression and tension respectively. It enhances the effective bonding between concrete, steel and panel making it as an integral unit.

6.1.2. Beam to column connection

Breaking load for a scaled model of beam to column connection
= 12.3 tonne
Result of experimental analysis on beam to column connection show that it is capable to withstand heavy loads.

6.1.3. Beam to beam connection

Breaking load for a scaled model of beam to beam connection
= 11.3 tonne
Result of experimental analysis on beam to beam connection shows that it is capable to withstand heavy loads, but the load value is less than that of a beam to column connection.

6.1.4. Column to column connection

Figure 13 shows the experimental results of column-column connection presented in Figure 6.

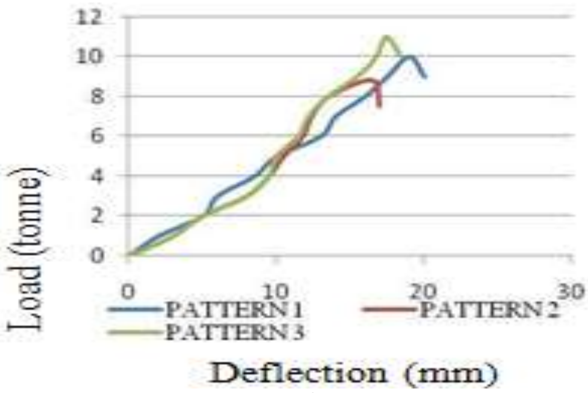

Fig. 13: Load Deflection Curve.

Breaking strength of pattern 1 = 10.2 tonne breaking strength of pattern 2 = 8.5 tonne breaking strength of pattern 3 = 11 tonne.
Breaking strength of pattern 1 = 10.2 tonne breaking strength of pattern 2 = 8.5 tonne breaking strength of pattern 3 = 11 tonne.
From the load – deflection curve it is clear that pattern 3 can transfer more load in static condition even with considerable deflection. But it fails to withstand the maximum load for long period of time. On the other hand pattern 1 can withstand load for relatively long span of time, but it fails on lower loads. Experimental result shows that the superiority of the bolt depends on the intended use of connections. In case of column-column connection, the ultimate load carried by the specimen is less than that of beam to beam connection and beam to column connection. The breaking strength of pattern 3 is closer to that of beam to beam connection. Pattern 3 is suggested for the prefabricated building.

6.2. Finite element analysis

6.2.1. Gypsum panel

Static analysis results of gypsum panels are reported in Table 3.

Table 3: Maximum Deflection Values and Frequency Values Corresponding to Different Mode Shape

Mode	Panel		Panel filled with PCC		Panel filled with RCC	
No;	Frequency	Deflection	Frequency	Deflection	Frequency	Deflection
1	0.0382	0.0991	87.671	0.0190	424.4	0.672
2	0.0420	0.0961	113.48	0.0182	533.1	0.432
3	0.0480	0.0997	158.65	0.0180	688.6	0.298
4	0.0577	0.0992	242.86	0.0187	830.9	0.103
5	0.0646	0.0971	226.42	0.0175	874.4	0.0987
6	0.7579	0.1076	272.12	0.0162	902.9	0.0784

It is clear that Panel filled with RCC is superior to hollow and PCC filled. It can withstand more frequency with minor deflection. This is because of stiffness offered by concrete and steel.

6.2.2. A) Seismic analysis

Seismic results of glass fibre reinforced gypsum panel are shown in Table 4.

Table 4: Seismic Analysis

Items	Maximum total deformation (mm) Gypsum panel	Panel filled with PCC	Panel filled with RCC
Deformation	22.562	5.235	0.345

The observation reports that panel filled with RCC behaves well under seismic loads with less deflection. These superior properties of RCC filled panel is due to resistance offered by the tension reinforcement against curving of panel.

6.2.2. B) Blast analysis

The results obtained from blast analysis of all panel specimens are shown in Figure 14.

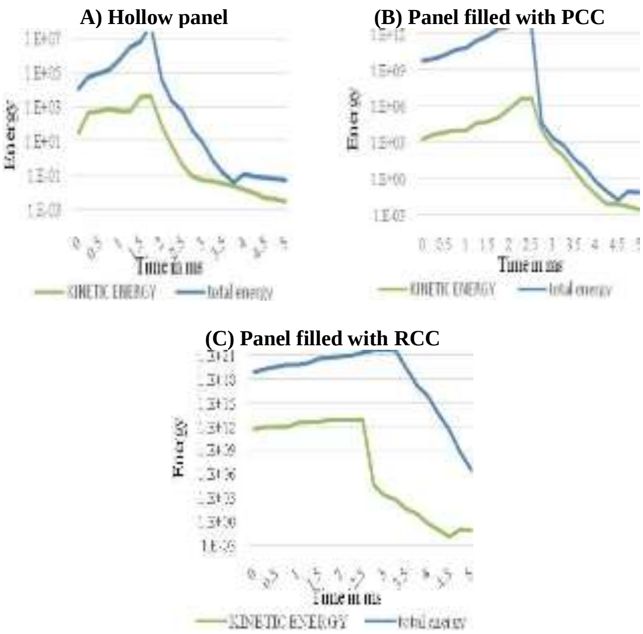

Fig. 14: Blast Analysis Result of Gypsum Panel Reinforced with Glass Fibres A) Hollow Panel B) Filled with PCC C) Filled with PCC.

Investigation proves that panel filled with RCC can withstand blast pressure for 17% more time, whereas for a normal masonry wall the time and energy is much lower. The concrete filled cavities attain well bonding with the panels due to the presence of pores and thus help in heat and sound insulation of the building. The material behaviour is satisfied when connected to each other by bolted connection.
In all cases the panel filled with RCC shows better result due to the strength of reinforcement bar. In case of static and seismic loading the reinforcement bar, will help in increasing the strength and reduce the curving of the panel.

6.2.3. Beam to column connection

Table 5 shows the static analysis results in terms of deflection corresponding to different mode shapes.

Table 5: Static Analysis

Mode shape	Deflection (mm)	Frequency (Hz)
1	1.1037	46.595
2	0.9321	71.132
3	1.3227	77.241
4	1.6039	91.936
5	1.4546	135.76
6	1.7267	136.13

Results of static analysis are obtained as mode shapes.

6.2.4. A) Seismic analysis

Seismic results of beam to column connection are shown in Figure 15.

(A) (B)

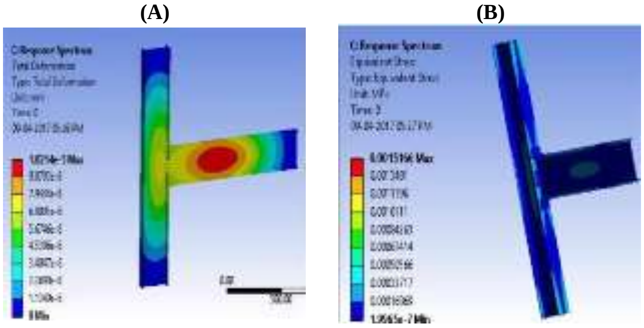

Fig. 15: Seismic Analysis of Beam to Column Connection.

From the seismic analysis results, deflection value of beam to column connection is negligible under the seismic loading. This shows the structural superiority of the connection.

6.2.5. Beam to beam connection

Results of static analysis are obtained as mode shapes. Table 6 shows the static analysis results in terms of deflection corresponding to different mode shapes.

Table 6: Static Analysis

Mode shape	Deflection (mm)	Frequency (Hz)
1	1.062	258.27
2	1.57	335.35
3	1.568	540.51
4	2.991	592.26
5	2.949	749.87
6	1.901	845.29

6.2.6. A) Seismic analysis

Seismic results of beam to column connection are shown in Figure 16.

(A) (B)

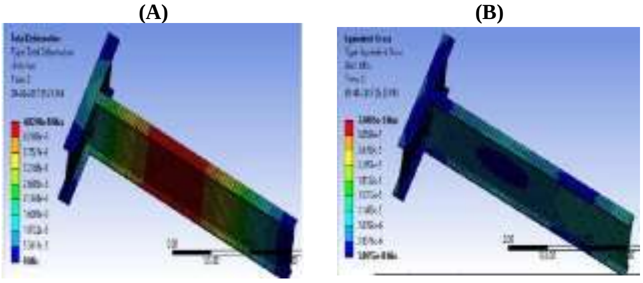

Fig. 16: Seismic Analysis of Beam to Beam Connection.

From the seismic analysis results, deflection and stress value is negligible under seismic loading. This shows the structural superiority of the connection to conventional building materials.

6.2.7. Column to column connection

Results of static analysis are obtained as mode shapes. Figure 17 shows the consolidated results of deflection corresponding to different mode shapes.

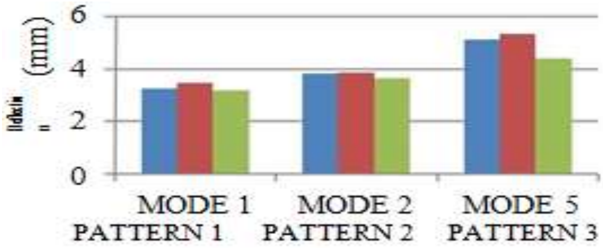

Fig. 17: Deflection vs. Mode Shapes.

From the static analysis, it is clear that deflection of pattern 3 will be very less irrespective of frequency of modal analysis. While comparing experimental and FE analysis results, pattern 3 shows superiority in case of supporting and transferring more loads. But when time factor is considered pattern 1 will be superior as given in IS 800: 2007 [2].

These properties of connections can only be obtained if the pretension force applied to bolt while tightening is optimum. Results from pretension analysis are shown in Figure 18.

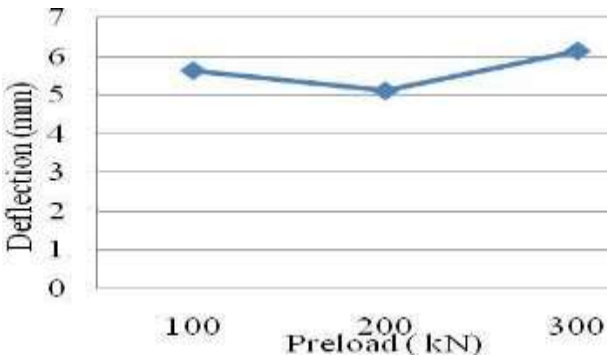

Fig. 18: Pretension versus Deflection.

The pretension analysis results (Figure 18) show a decrease in deflection in between preload of 100 kN and 200 kN. Hence careful analysis was carried out to investigate the pretension force in that area of loading and shown in Figure 19.

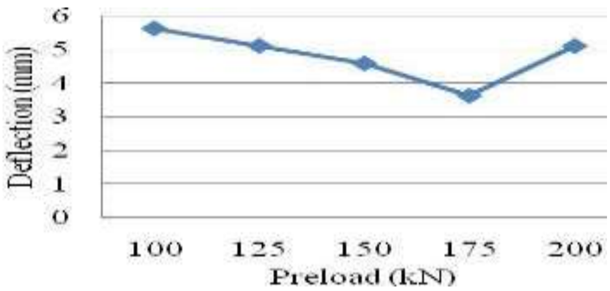

Fig. 19: Pretension versus Deflection for A Preload of 100-200 Kn.

Pretension analysis curve shows a continuously decrease upto 175 kN and beyond that the deflection value is increasing. Thus 175 kN is considered as the optimum preload which allows least deflection. This value proves accurate when compared with equation suggested by IS: 800: 2007 [2].

6.2.8. A) Seismic analysis

Seismic analysis for two column length connection is tabulated in Table 7. it is observed that pattern 3 (Figure 12) behaves well under seismic loading with least deflection possible among the three patterns.

Table 7: Deflection Obtained from Seismic Analysis

Trial	Deflection in mm		
	Pattern 1	Pattern 2	Pattern 3
1	7.5	9.3	6.7

6.2.8. B) Blast analysis

Blast analysis for two column lengths resulted in the Figure 20.

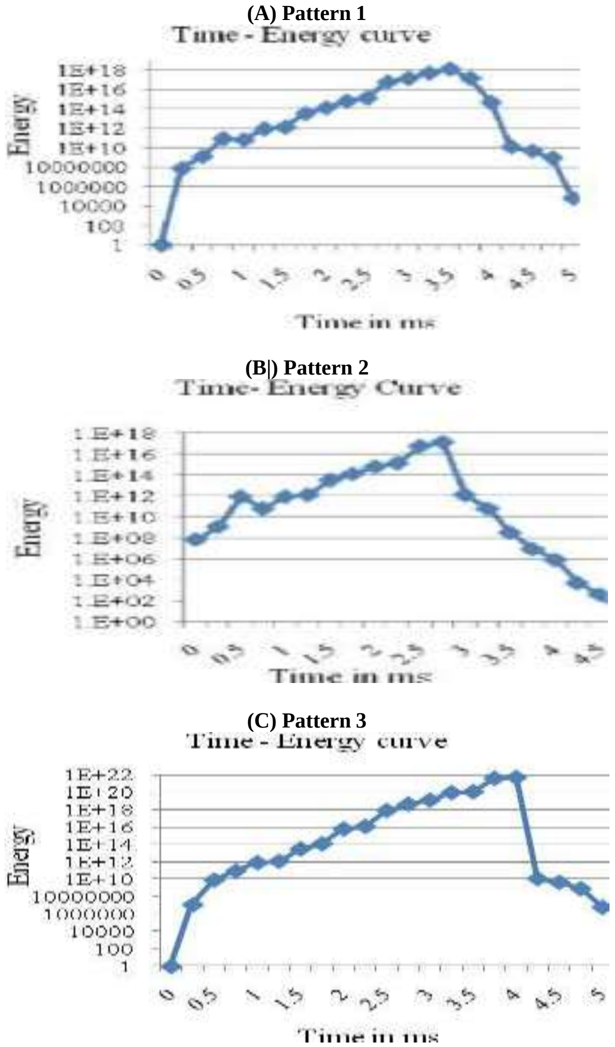

Fig. 20: Blast Analysis.

It was observed that pattern 3 can resist the blast load for more timefor about 3.75ms, without undergoing much variation in terms of energy, deflection and pressure effects. Damage caused by blast loading is less for pattern 3 because of their lower deflection rate and their ability to withstand higher internal energy developed under loading.

6.2.9. Building

Figure 21 shows the result of blast analysis of conventional building. Δx the value of response on x direction and Δy indicates the value of response in y direction. (Figure 21- 26).

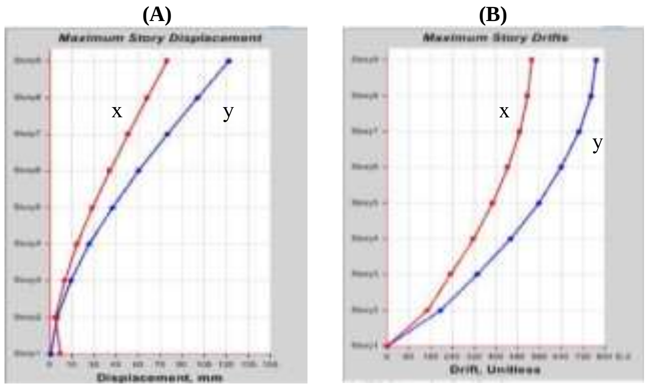

Fig. 21: Static Analysis Result of Conventional Building A) Storey Dis- Placement Response and B) Storey Drift Response.

Figure 22 shows the static analysis result of a prefabricated building.

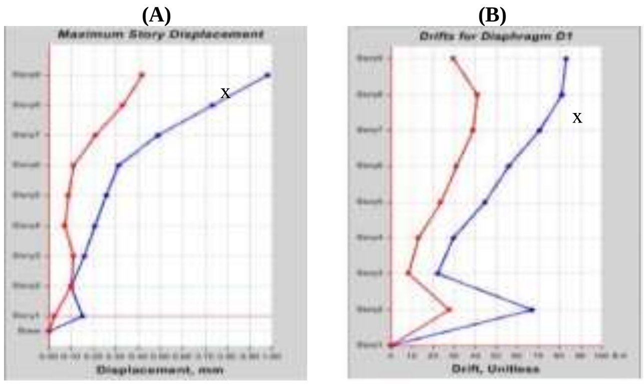

Fig. 22: Static Analysis Result of the Prefab Building A) Storey Displace- Ment Response and B) Storey Drift Response.

From Figure 21 and 22 it is observed that the storey displacement for the prefab building is much less than the conventional building. This shows the structural superiority of the prefabricated building under normal load. For a steel framed structure the drift is limited to H/60 to H/100 according to AISC steel design guide [22], H is the height of the building. The value of allowable drift value is in between 0.35 and 0.5833, but the drift value of prefabricated building is 98% less than the allowable value. From the drift value, it is clear that prefabricated structure is much superior to conven- tional building even under static loading Superiority of the prefab- ricated building is mainly due to the properties of composite mate- rials used.

5.2.10. A) Seismic analysis

Figure 23 shows the response of the conventional building under seismic load.

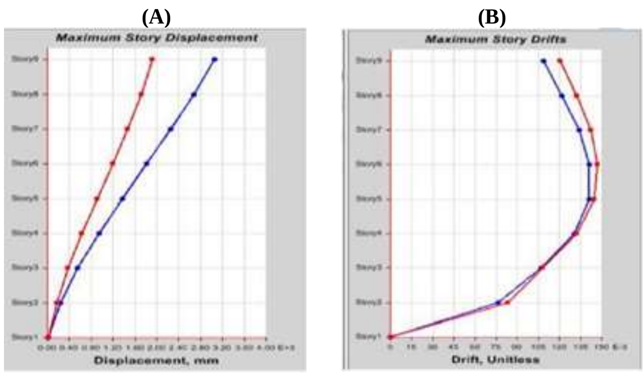

Fig. 23: Response of Conventional Building under Seismic Load A) Sto- Rey Displacement Response and B) Storey Drift Response.

The maximum story drift of the structure above the isolation system calculated by response spectrum analysis shall not exceed 0.015h [5], where h is the total height of the structure. The drift and displacement value of the prefabricated building is 92% less than the conventional building.
Figure 24 shows the response of the prefabricated building under seismic loading.

(A) **(B)**

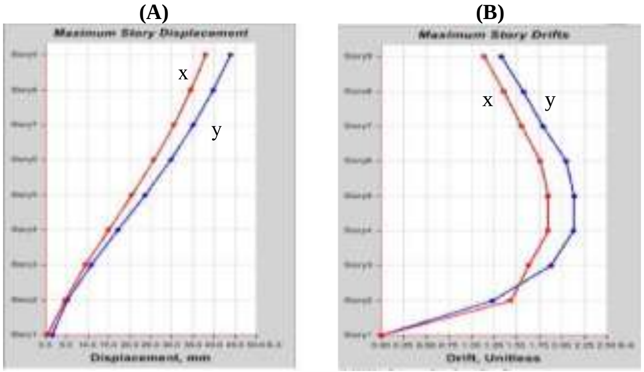

Fig. 24: Seismic Response of Prefabricated Building A) Storey Displace-Ment Response and B) Storey Drift Response.

Prefabricated building shows a small or negligible displacement due to its reduced self weight. Steel frames used as structural components are adequate to take up sufficient loads during an earthquake.

5.2.10. B) Blast analysis

Figure 25 shows the response of a conventional building to blast loading.

(A) **(B)**

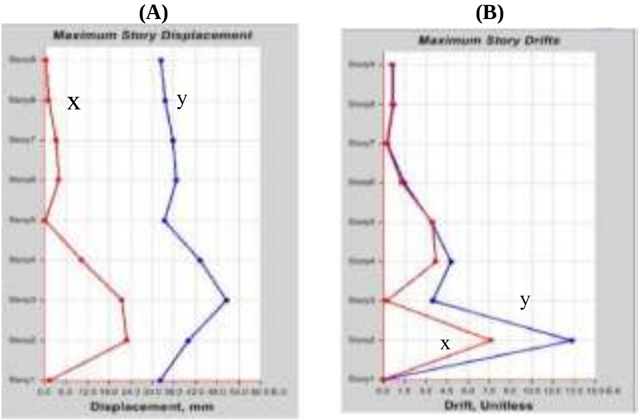

Fig. 25: Blast Response of A Conventional Building A) Storey Displace-Ment Response and B) Storey Drift Response.

The maximum story drift of a force resisting system or structure, analysed by time history analysis shall not exceed 0.020h, where h is the total height of the structure [22]. Allowable drift value is 0.7, which is calculated as per the IS codal provision [22] and the actu- al value is 90% less than the limiting value, but greater than the prefab building which is shown in the Figure 26.

(A) **(B)**

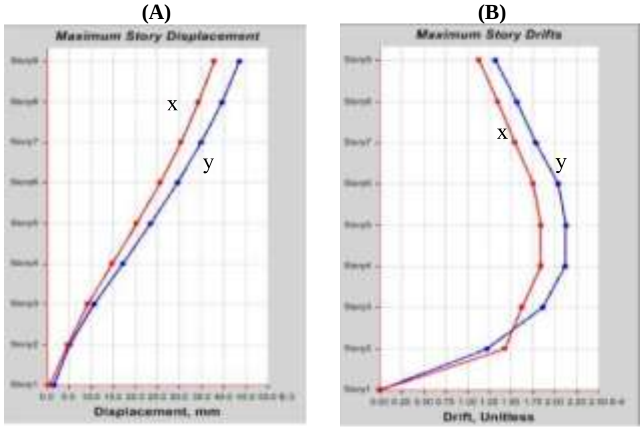

Fig. 26: Blast Response of A Prefab Building A) Storey Displacement Response and B) Storey Drift Response.

Prefabricated building shows structural superiority than conventional building due to their reduced weight and shows minimum displacement even at the 2nd and 3rd storey, where the blast loading is directly applied. For a steel framed building the maximum al-lowable drift is limited to 0.025 h [22], where h is the height of the building. Allowable drift value is 0.875, which is calculated as per the IS codal provision [22] and the actual value is negligible when compared to the limiting value. The drift value of prefabricated building is 10% less than the conventional building and this shows the structural superiority of prefabricated building over conven-tional building of same functionality.

7. Conclusion

From this study, the panel filled with RCC proves to be stronger than that of hollow and PCC filled panels. The high strength is due to the concrete and steel reinforcement embedded in their cavities. The strength of such panels can be further increased by adding steel plates of thickness 5mm on both sides of the panel. The panel filled with RCC proves to be structurally superior to normal masonry wall and are more superior to the normal panel.
Pattern 3 is superior compared to 1 and 2, due to their bolt configuration. Bolts are arranged along a line in pattern 3 and the loads get uniformly distributed among the bolts when comes to structural action. Structural superiority of the bolt can be achieved only if the bolt is tightened with optimum bolt pretension.
Based on the results obtained from normal, seismic and blast analysis carried out on both prefabricated and conventional building model, results of prefabricated buildings is observed to be much better than the conventional building. It can be concluded that prefabricated building materials is far superior to any conventional building material. This study enlightens the scope of an innovative technology which is light in weight cost effective with composite structural components.

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