Seismic Performance of Steel and Composite Frame Structure by Non-Linear Static Method

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Abstract - *In India for low-rise buildings. reinforced concrete structures are being preferred over the years due to its convenience and its cost effectiveness together. But for medium to high-rise buildings these RC structures are no longer suitable due to its increased dead load, less stiffness, span restriction and hazardous formwork. So for efficient design of all buildings which are subjected to considerable wind & earthquake load steel and composite structures are widely accepted now a days. Use of composite material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies and for steel its rapid erection, high ductility, lesser dead load proved to be an advantageous. This paper the demonstrated comparison of Steel and RCC-steel composite frame structure when they are subjected to similar lateral loading by nonlinear static analysis in which it compares performance of high rise frame structure. storey for steel and composite (steel-concrete) when it is subjected to earthquake load which increases incrementally for each new storey. Both steel and Steel- concrete composite construction has gained wide acceptance worldwide as an alternative to pure steel and pure concrete construction. Composite construction combines the best of both steel and concrete along with lesser cost, speedy construction, fire protection etc. whereas steel has high strength to weight ratio. It is observed that the performance of steel structure is on higher side than that of the steel- concrete composite frame structure.* How it can be best solution for high rise structure as compared to other conventional R.C.C structure.

***Key Words*: Non-linear static analysis, Performance point, Composite structures, FEMA-356 etc.**

1. INTRODUCTION

The use of Steel in construction industry is much low in India as compared to other developing countries. It shows that economy of Steel is not the reason behind that. There is a huge potential for increasing the volume of Steel in construction, especially the current development needs in India. India, being a third largest steel producer and if we are not using it yet then it is heavy loss for the country. Also, it is evident that now-a-days, the composite sections using Steel encased with Concrete are economic, cost and time effective solution in major civil structures such as bridges and high rise buildings. Concrete (RCC) is very significant material which is being used in every residential as well as commercial project in India and world as well. Though it possesses an inherent heaviness, mass and strength but one can opt for steel and composite as key construction material as they have proved themselves as one of the finest material which responds to the lateral forces with less damage as compare to conventional RCC. With Proper designing with steel and composite sections can give better performance in earthquake prone areas. The advancement in building, Information, modeling has integrated design, detailing, and fabrication of steel which will result in desired and safe performance under earthquake loading. In the present study, modeling of the steel and composite frame under the lateral loads has been designed and analyzed by IS 1893:2016 using ETAB2018 software. In this paper we done comparative analysis of steel composite frame structure with parameters like Base shear and displacement at performance point, plastic hinge formation, Time period and pushover curve.

1.1 STEEL STRUCTURE

Structural steel differs from concrete in its attributed compressive strength as well as tensile strength. Structural steel can be developed into nearly any shape, which are either bolted or welded together in construction. Structural steel can be erected as soon as the materials are delivered on site, whereas concrete must be cured at least 1–2 weeks after pouring before construction can continue, making steel a schedule-friendly construction material. Steel Structure which includes structural steel framing, describes the creation of a steel skeleton made up of vertical columns and horizontal beams. This skeleton provides the support for the roof, floors and walls of the structure. The horizontal elements of the "I" are known as flanges, while the vertical element is termed the "web". I-beams are usually made of structural steel and are used in construction and civil engineering. I sections are widely used in the construction industry and are available in a variety of standard sizes and these section may be used both as beams and as columns. The typical cross-section of Steel I section is shown in figure 1.

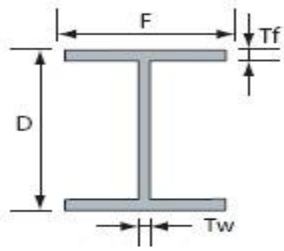


Fig -1: Typical cross section steel I section

1.2 COMPOSITE STRUCTURE

In the past, for the design of a building, the choice was normally between a concrete structure and a masonry structure. But the failure of many multi storied and low-rise R.C.C. and masonry buildings due to earthquake has forced the structural engineers to look for the alternative method of construction. Use of composite or hybrid material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies. In India, many consulting engineers are reluctant to accept the use of composite steel-concrete structure because of its unfamiliarity and complexity in its analysis and design. But literature says that if properly configured, then composite steel-concrete system can provide extremely economical structural systems with high durability, rapid erection and superior seismic performance characteristics. Steel and concrete although very different in nature, these two materials complement one another.

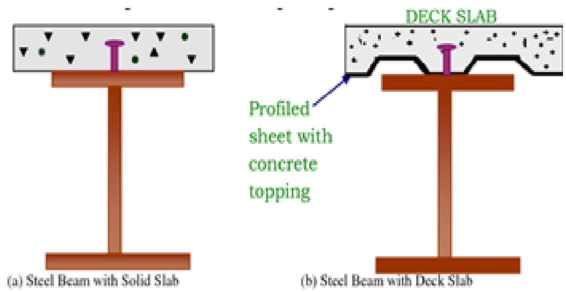


Fig -2: Typical composite cross section

In composite construction it is very necessary to use the shear connectors as the total shear force at the interface between concrete slab and steel beam is about eight times the total load carried by the beam. Use of these mechanical shear connectors transmits the longitudinal shear along the interface and it also prevents the separation of steel beam and concrete slab at the interface. The commonly used type of shear connector as per IS: 11384-1985. There are three main types of shear connector; Rigid, Flexible and anchorage shear connectors. For this study rigid type shear connectors are used.

1.3 Shear Connectors

The total shear force at the interface between concrete slab and steel beam is approximately eight times the total load carried by the beam. Therefore, mechanical shear connectors are required at the steel-concrete interface. These connectors are designed to (a) transmit longitudinal shear along the interface, and (b) Prevent separation of steel beam and concrete slab at the interface. Following are the commonly used types of shear connectors as per IS: 11384-1985

- Rigid shear connectors
- Flexible shear connectors
- Anchorage shear connectors

2. OBJECTIVE OF THE STUDY

1. To investigate suitability of structure in case of safety and serviceability.
2. To compare the performance of steel and composite building under seismic loading by pushover analysis.
3. To analyze the maximum capacity of deformation that structure can undergo against lateral forces without failure.
4. To study the progressive failure of high rise steel and composite frame structure when subjected to identical seismic condition.

3. METHODOLOGY

3.1 PUSHOVER ANALYSIS

The pushover analysis is a method to observe the successive damage states of a building. The method is relatively simple to be implemented, and provides information on strength, deformation and ductility of the structure and distribution of demands which help in identifying the critical members likely to reach limit states during the earthquake and hence proper attention can be given while designing and detailing. This method assumes a set of incremental lateral load over the height of the structure.

Static Nonlinear analysis is done by using the method of Pushover analysis. In this analysis, a structure will be subjected to gravity loading and a monotonic displacement controlled sideways load pattern which continuously rises through elastic and inelastic behaviour until an ultimate point is reached. Deformation of push over analysis shown in fig.3

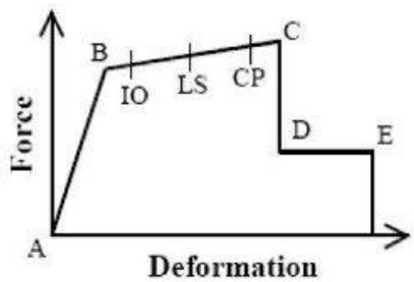


Fig-3: Pushover Curve

The nonlinear static procedure (NSP) described in FEMA-356 and ATC-40, when pushover analysis is used carefully it provides useful information that cannot be obtained by linear static or dynamic analysis procedure.

3.2 MODELING APPROACH AND ASSUMPTIONS

At each step, the base shear and the roof displacement can be plotted to generate the pushover curve .This method is relatively simple and provides information on the strength, deformation and ductility of the structure and distribution of demands. This permits to identify the critical members likely to reach limit states during the earthquake by the formation of plastic hinges. On the building frame load/displacement is applied incrementally, the formation of plastic hinges, which will be lie in the level shown in fig no. 3 like Immediate Occupancy, Life safety and Collapse Prevention.

In the Present work building model G+15 Steel and Composite are situated in zone V with subsoil type medium - II were analyzed in ETAB software. All the sections are design by LSM from respective codes using trial and error method. All earthquake forces are considered as per IS 1893:2016. The basic planning and loading for the steel and Composite structures are kept similar for the study. The details of steel and composite frame structure are as shown in Table No.[1] Codes used for design of structural members mentioned in below table No.1:

Steel design: IS 800:2007 Composite designs: AISC LRFD 99

3.3 DETAILS OF STRUCTURE

Modeling & designing for both steel and composite frame structure done by keeping basic plan and Specification as same.

Table1: Frame Structure Details

PARTICULARS	STEEL FRAME	COMPOSITE FRAME
BEAM SIZE	ISMB350	ISMB350
COLUMN SIZE	ISWB 600	ISMB450 Encased in 700*700mm
SLAB/DECK	100mm DECK	100mm DECK
TOTAL STOREY HEIGHT	46.5m	46.5m
TYPICAL STOREY HEIGHT	3m	3m
PLAN	25x20m	25x20m
CONCRETE GRADE	M-25	M-25
Rebar	HYSD415	HYSD415
STEEL	FE345	FE345
ZONE	V	V
IMPORTANCE FACTOR	1	1

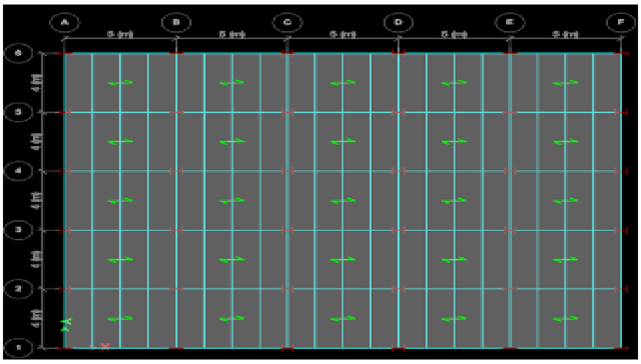


Fig -4: General plan view of frame structure

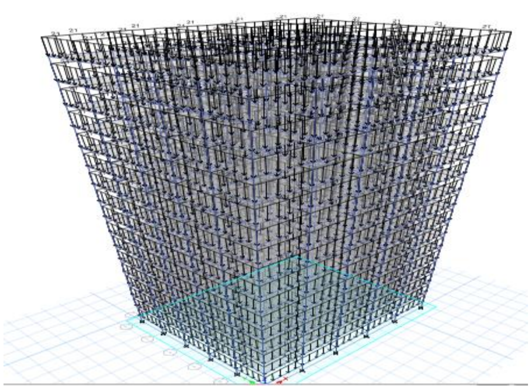


Fig-5: General 3D view of frame structure after Assigning Loads.

4. RESULT AND DISCUSSION

4.1 BASE SHEAR AND DISPLACEMENT

Table -2: Base shear and Displacement at performance point

No. of story	Steel		Composite	
	Displacement in mm	**Base shear in kN**	**Displacement in mm**	**Base shear in kN**
(1)	**(2)**	**(3)**	**(4)**	**(5)**
G+15	367.13	9342.8	258.9	8222.06

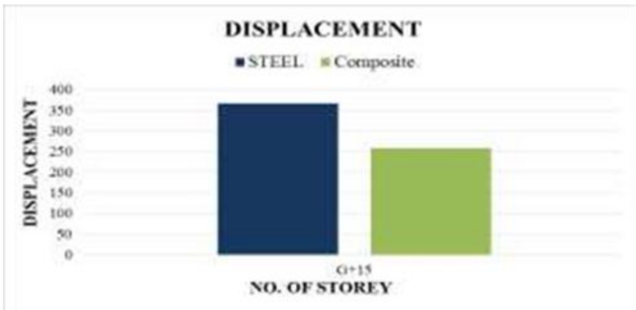


Chart -1: Displacement at Performance point

Table No-2 shows the displacement and corresponding base shear of steel and composite frame structure at performance point. The graph obtained from the values of displacement symbolizes that due to high ductility of steel section steel structure can go under maximum displacement before its failure whereas composite structure is able to show less deformation against the lateral forces. The base shear value of steel structure is less as compare to composite structure due its less self-weight which responsible for the greater performance of steel structure than that of composite against the seismic forces.

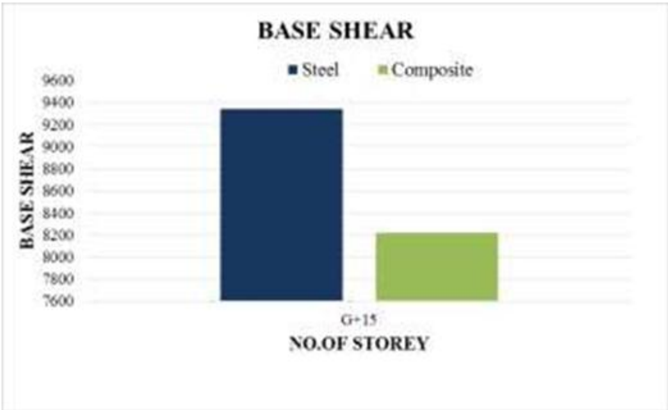


Chart -2: Base Shear at Performance point

4.2 TIME PERIOD AT PERFORMANCE POINT

Table -3: Time period at performance point

No. of Storey	Steel	Composite
	Time period in sec	**Time period in sec**
(1)	**(2)**	**(3)**
G+15	3.876	3.104

Chart -3: Time period at Performance point

Table No. 3 shows that time period of G+ 15 steel structures is 3.876sec whereas in case of composite it is 3.104sec which indicates that steel structure takes more time to start oscillating back an fourth after application of lateral forces due to its higher flexibility in comparison with composite frame structure.

4.3 PUSHOVER CURVE

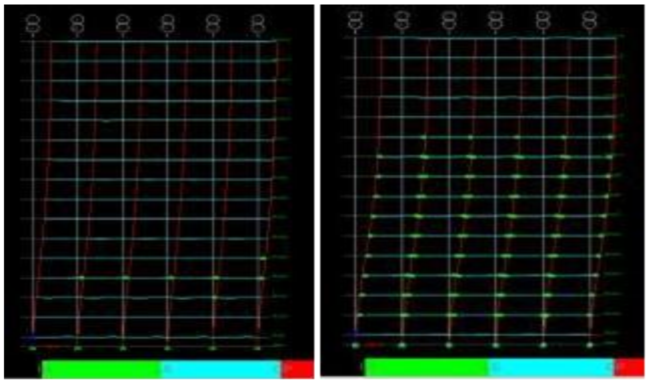
Table -4: Yield point of steel and composite structure

Type of Structure	Yield Displacement in mm	Yield Base Shear in kN
Steel	316.57	8400.22
Composite	223	7717.14

Chart -4: Yield Displacement and Base Shear

Table no.4 shows the yield displacement and its corresponding base shear for steel and composite frame structure. This is the progressive post elastic behavior of both the structures forming a Pushover curve as shown in chart 4.

4.4 PLASTIC HINGE FORMATION

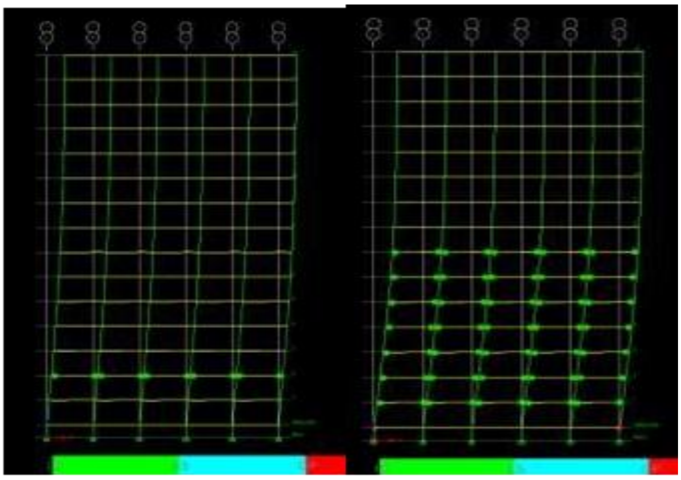


a)Yield Point (b) Ultimate Point

Fig-6: (a) and (b): Formation of hinges for G+15 steel frame Structure

Figure No. 6 (a) shows that the hinge formation of steel structure at step number 126th in which it can be seen that, the formation of plastic hinges taking place and they are in immediate occupancy level as it is in green color similarly in

Figure No. 6 (b) it can be observed that it is the ultimate (416th) stage of hinge formation for steel in which no members are near CP level.



(a) Yield Point (b) Ultimate Point

Fig-7: (a) and (b) Formation of hinges for G+15composite frame Structure

Figure No.7 (a) and (b) shows the formation of plastic hinges in G+ 15 composite frame structures in which figure no. 7 (a) indicates that at the step number 56th plastic hinges just started to developed means structure is in early stage where hinges are just in between B-C and as the load on the structure increases incrementally by the principle of displacement control in pushover analysis and finally reaches to its ultimate (117th) stage of state where number of plastic hinges are near the collapse prevention as some of hinge points are in red mark.

4.5 PERFORMANCE POINT

Fig-8: performance point of G+15 Steel Structure

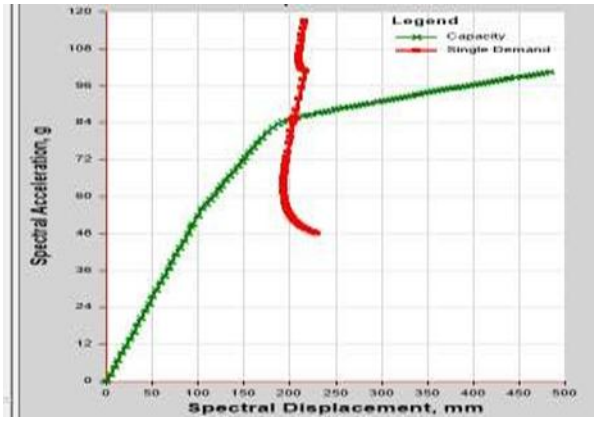


Fig-9: performance point of G+15 composite Structure

Fig-8 shows that the demand curve intersecting capacity curve of steel frame structure at the IO(immediate occupancy) whereas fig-9 indicates that composite structure achieved performance point after IO level. So it can be clearly state that from obtained result steel structure shows more reserved strength than that of the composite structure before its ultimate collapse state.

5. CONCLUSIONS

From the obtained results the following conclusions are made:

1. In case of composite frame, yielding starts at the displacement at 223mm which is 29.55% lesser than the yield displacement of steel frame in pushover curve.
2. Base shear of composite frame structure is more than that of steel structure as the steel possesses less self-weight.
3. Plastic hinges are forming in early stage of deformation in case of composite structure due to its less ductility than that of steel.
4. From the performance point obtained in the fig-8 and 9, it can be concluded that steel structure has greater reserve strength to resist against lateral forces in comparison with composite structure.
5. From the obtained performance point it is concluded that due to high ductility and less weight Steel structure behaves well in seismic excitation.
6. After comparing both structures, steel structure resists the forces for longer time as compared to composite structure.
7. So from the comparative study it can be concluded that steel structure are more feasible in seismic excitation as it has been proved better than

composite in every result parameter considered for the study.

8. Pushover analysis concludes that the steel frame structure proved itself as a one of the safe choice for construction in seismic zone.

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