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Comparative Study on Seismic Analysis of R.C.C., Steel and Composite Frame Structures Using ETABS and SAP2000

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ABSTRACT: In designing a building, apart from safety which is of utmost important, economy is another aspect to be considered. Therefore, it is very important to compare the behavior of building with respect to the material used in construction. Nowadays, the construction of a multi-storey building is more demanding as the population of our country is growing faster. The need for shelter in highly populated cities is more and more demanding which lead to an increase in the land cost. Also, further horizontal expansion will not be possible due to the unavailability of space. So the only solution is the vertical expansion. In the present work, a G+50 multi-story building which has irregular plan, as well as vertical has been considered with three building material: R.C.C., steel and composite structure was analyze and a comparison is made between them. The building is to be designed as per the Indian standard code. The building is modelled in ETABS and SAP2000. Response spectrum method is used for analysis and the results obtained is compared with the manual calculation. SAP2000 gives more accurate result so time history analysis with El Centro as a ground motion will also be performs in SAP2000 only and comparison will be made between time history and response spectrum method. Result shows that by comparing the different material used in construction, composite structures experience less base shear as compared to RCC and steel structures. And, by comparing the method of analysis, time history method gives more base shear as compared to response spectrum method. However, there are not much different in results by comparing the different software use that is ETABS and SAP2000.

KEYWORDS: R.C.C, Steel, Composite, ETABS, SAP2000, Response Spectrum Method, Time History Method.

I. INTRODUCTION

A multi-story building is a self-contained housing unit that occupies only part of the building. Such a building may be called a multi-story building. The construction of multi-story buildings depends on the availability of materials at site. At present, there are mainly three different types of building material are used i.e., R.C.C., steel and composite structures. R.C.C. (Reinforced Cement Concrete) is a concrete that contain steel bars as reinforcement bars or rebar. The grades of concrete as per as IS 456:2000 are M10, M15 and M20 as ordinary concrete, M25, M30, M35, M40, M45, M50 and M55 as standard concrete and M60, M65, M70, M75 and M80 as high strength concrete. An RCC as framed structure is an assemble of slabs, beams, columns, and foundation inter-related to every different as a unit. The load transfers in this kind of structure takes place from the slabs to the beams, from the beams to the columns, from columns to the foundation and then finally transfers it to the soil. The Steel structure is a structure which is made from the organized combination of custom-designed structural steel members (such as I, T, C, L and Steel Tube section) so as to meet the architectural and engineering requirements of users. The Grades of steel section available are Fe250 and Fe345. Composite structures may be defined as the structures which is made up of two different types of materials such as steel section and concrete, are used for beams, columns and/or slab. The possible way of getting composite structure is either by encasing a steel section inside a concrete material or by constructing a column by RCC and a beam by steel section which are tied together by shear studs at their interface. The reason why composite construction is often so good because concrete is good in compression and steel is good in tension.

II. RELATED WORK

Mahmoud *et al.* (2016) performed a time history analysis of reinforced concrete frame buildings. The analysis is performed by taken considering a set of different building models. The buildings consider are a bare frame (without infill walls), frame with fully infill walls and a frame models with infill panels and soft story located at base level, 3rd



story level, 6th story level, 9th story level and 12th story level. Time history Analysis with El Centro and Loma Prieta ground motion were used to performed the seismic analysis for the considered structures. ETABS were used to models and performs the analysis of the buildings. They found that by considering masonry infill action reduces the induced storey displacements as compared to the bare frame case. However, the induced storey moments and storey shear forces increase with the incorporation of masonry infill action. Also, the level of soft storey has a significant role on the induced storey shear forces under the far-fault Loma Prieta earthquake especially at lower storeys. However, under El Centro earthquake, the level of soft storey seems to be slightly significant.

Moslehet et al. (2016) investigated the seismic behaviour of RC building structures designed according to FEMA-356 and ATC-40. Two RC buildings of six-story which is irregular in shape were considered. The building consists of 6 floors aboveground and 3 underground floors. The modelling program SAP2000 was used for non-linear analyses of the structure. The displacement profiles resulting from each non-linear analysis are compared to the response of the push-over analysis. The displacements of the buildings are said to be more flexible in a longitudinal direction and stiffer in transverse direction. They also found that there is an abrupt change in inter-story rotation of building 1 in the transverse direction between 0.29g-0.33g which shows the large rotation in the 6th story. These may be because of the non-linear behaviour of the structure. According to ATC-40, the drift ratio of both the buildings are stable in both the direction. However, according to FEMA-356, the drift ratio of building 1 is vulnerable in the longitudinal direction. Building 1 showed good performance in terms of strength, stiffness and deformation as compared with building 2.

Arslan et al. (2016) conduct a study on evaluation of in-plan irregular RC frame buildings based on Turkish seismic code. A total of 8 different RC frame buildings with and without beam discontinuity in plan and having different torsional irregularity, with five and seven story were considered. Three method of evaluation was used i.e., Linear elastic method (LEM), Nonlinear static procedure (NSP) and Nonlinear time history analysis (NTA). The result of inelastic displacement demand shows that some of the members are in damage state by using LEM and NSP while using NTA all the members were found safe. They conclude that it's may be due to the conservative limits of LEM and NSP which makes it differs from those of NTA. According to TSC 2007, the drift ratio was found to be under the limits for life safety performance level by all the above mention method.

Hu et al. (2012) performed a study on high-rise structure with oblique columns by ETABS, SAP2000, MIDAS/GEN and SATWE. The structure consider here was a twenty-nine story with three floors underground and twenty-six floors above ground. Response spectrum method was executed and ETABS, SAP2000 and SATWE are the software used for finding the overturning moment and comparison is made between them. Result found that the overturning moment (ratio) of the column in X and Y direction respectively are 32.10% and 24.80% by ETABS, 52.86% and 54.77% by SAP2000 and 57.91% and 51.80% by SATWE which is a large difference of columns' overturning moment ratio between others tool and ETABS. They conclude that may be ETABS may miss the statistic of oblique columns, which need to be paid attention to in future design. However, the inter-story displacement under both the direction and both the above methods where within the code limited values.

Joshi et al. (2010) performed a linear and nonlinear static analysis for assessment of progressive collapse potential of the multi-storied building. The buildings are evaluated using GSA (General Service Administration) guidelines. The buildings consist of four bays in the longitudinal direction of 5 m and three bays in the transverse direction of 5 m, which is of four and ten story. Modelling software SAP2000 are used for linear static and nonlinear static analysis. Results shows that the first hinge form at a location where DCR (Demand Capacity Ratio) is maximum and continues through the location having higher DCR in various displacement level. They conclude that there is a high possibility that the member components exceeded its elastic limits during column a failure scenario at the location where the DCR exceeds the permissible values.

Chintanapaddeet al. (2004) performed the seismic demands for vertically irregular frames by nonlinear response history analysis. A total of forty-eight irregular frames, all 12 story high with strong columns and weak beams are considered. Three types of irregularities i.e., stiffness, strength and combined stiffness and strength are consider and introduced in eight different locations along the height of the buildings. They found that all the three types of irregularities have very little influence on floor and roof displacements as long as the irregularity is in the mid or upper story. However, if irregularity is at the base story or lower half of the building, there's a significant influences the height wise variation of floor displacement. Using nonlinear response history, they conclude that by introducing a soft storey, the story drifts demand increases in the modified and neighboring storey while a stiff storey decreases the drift demand in the modified and neighboring storey. On the other hand, using MPA the drift demand for the irregular frame

was similar to that of regular frame, except in the lower storey of the frame with stiff first or lower half, for which the bias is large.

III. METHODOLOGY

The building considered here is a residential building having G+50 story with the provision of parking at the ground floor. The Plan of the building is an assume once which have both irregularities i.e., plan and vertical irregularities. The plan and elevation of the building is as shows in Fig 1 and Fig 2. A total of 16 bays in the longitudinal direction and 5 bays in the traverse direction are used upto ten story. 2 bays from each corner of longitudinal direction are cut out from 11th upto 20th story. Another 2 bays from each corner of longitudinal direction are cut out from 21st upto 30th story. From 31st to 40th story another bay from each corner are cut out in traverse direction. Another bay from each corner are cut out in traverse direction from 41st to top story. Three building materials are used: R.C.C., steel and composite. The size of members was decided based on trials, till the members pass the design check. However, in case of steel structure bracing system is provided as the structure shows large displacement values. The internal wall of the structure is said to be built with A.C.C. block (Autoclaved Aerated Cement) and the external wall with glazing so that the load of the structure reduces. The grade of concrete, reinforcing bars and steel are taken as M60, HYSD550 and Fe345 respectively which is taken on a safer side. The parameter taken are given in Table 1. The building is modelled and analyse in ETABS and SAP2000. Response spectrum method (RSM) will used for the analysis. However manual calculation for base shear will be carried out and match the result with the once obtained by software. Time history method (THM) with El Centro ground motion will be performed in software which give more accurate results to manual calculation. A total of 9 structures are model, 3 in ETABS and 6 in SAP2000. The building is design as per Indian Standard codes. IS 875: 2015 for load calculation, IS 1893 (part I): 2002 for earthquake, IS 456: 2000 for R.C.C. and IS 800: 2007 for steel.

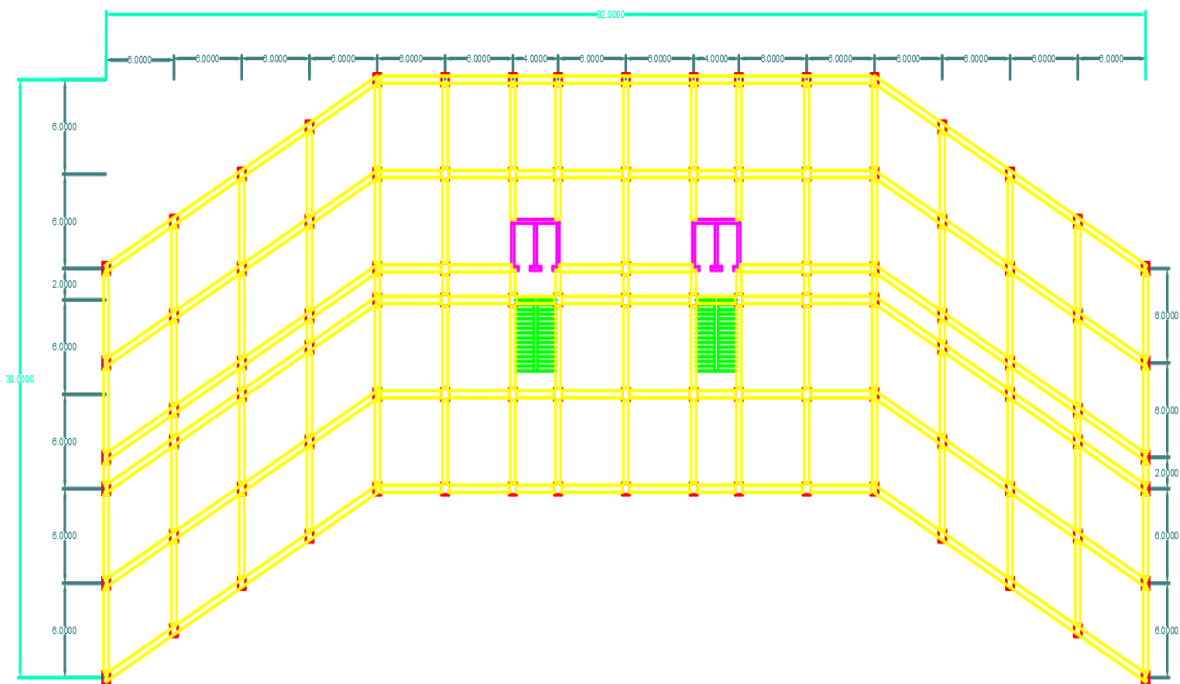


Fig. 1. Plan of a proposed building

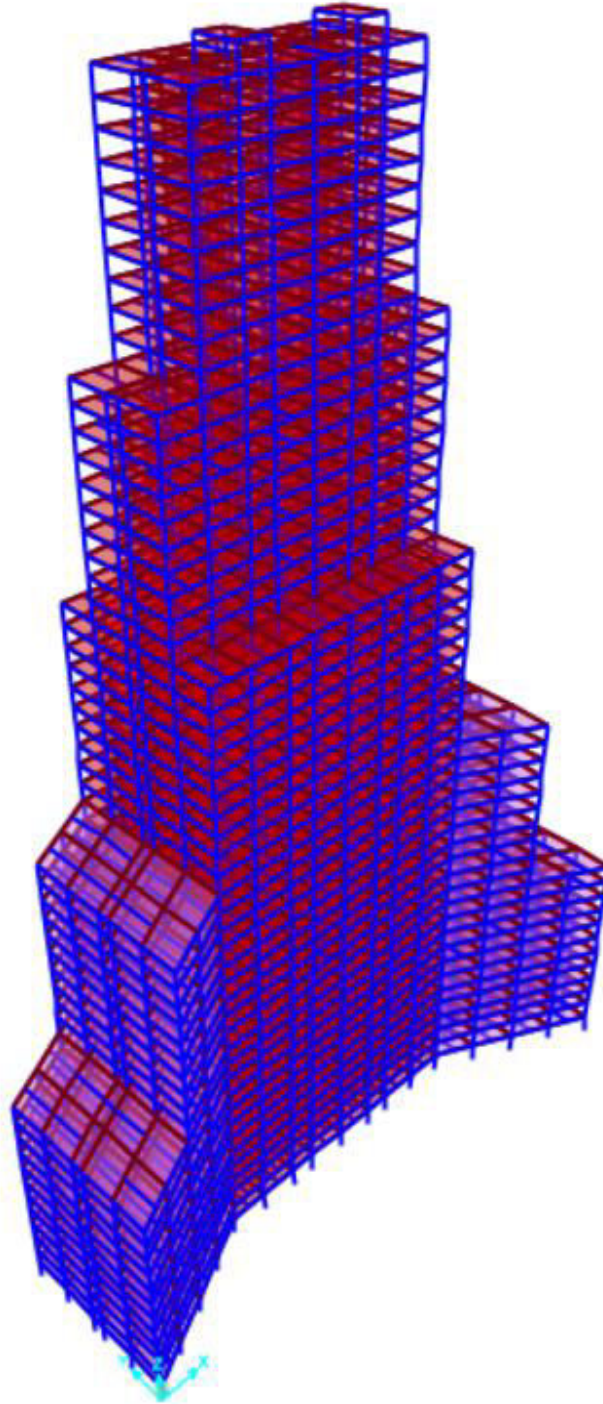


Fig. 2.Elevation of a proposed building

TABLE 1. Data taken for the proposed building

Parameter	Data
Height of each story	3 m
Thickness of slab	150 mm
Thickness of internal wall	150 mm
Thickness of glaze	50 mm
Floor Finish	0.52 kN/m ²
Live Load on Floors	2 kN/m ²
Live Load on Stairs	3 kN/m ²
Density of concrete	25 kN/m ³
Density of ACC block	6.5 kN/m ³
Density of Glaze	0.123 kN/m ³ (for 50 mm thickness)
Density of Steel	78.5 kN/m ³
Seismic Zone	IV (Zone factor = 0.24)
Soil Type	II
Importance Factor	1
Response reduction factor	5
Damping ratio	5%
Wind Speed	47 m/s
Column Size (RCC and Composite)	300x500 mm (41 st to top story) 400x600 mm (31 st to 40 th story) 500x700 mm (21 st to 30 th story) 600x800 mm (11 th to 20 th story) 700x900 mm (upto 10 th story)
Beam Size (R.C.C.)	300x450 mm (41 st to top story) 300x500 mm (31 st to 40 th story) 400x600 mm (21 st to 30 th story) 400x650 mm (11 th to 20 th story) 450x700 mm (upto 10 th story)
Column Size (Steel)	400x200x20 mm (41 st to top story) 500x300x25 mm (31 st to 40 th story) 600x400x30 mm (21 st to 30 th story) 700x500x40 mm (11 th to 20 th story) 800x600x50 mm (upto 10 th story)
Beam Size (Steel and Composite)	ISHB300-450 ISLB300-600 ISMB300-600 ISWB300-600
Bracing Size (Steel)	ISHB300-450 ISLB300-600 ISMB300-600 ISWB300-600
Secondary Beam Size (Steel and Composite)	ISHB150-300 ISLB150-300 ISMB150-300 ISWB150-300

IV. RESULTS

The result obtained from the analysis such as story displacement, story drift, base shear and overturning moment which are considered as very useful parameter for earthquake resistant design strategy will be discussed below:



Response Spectrum Method

Both software i.e., ETABS and SAP2000 are used for performing response spectrum analysis.

Story Displacement

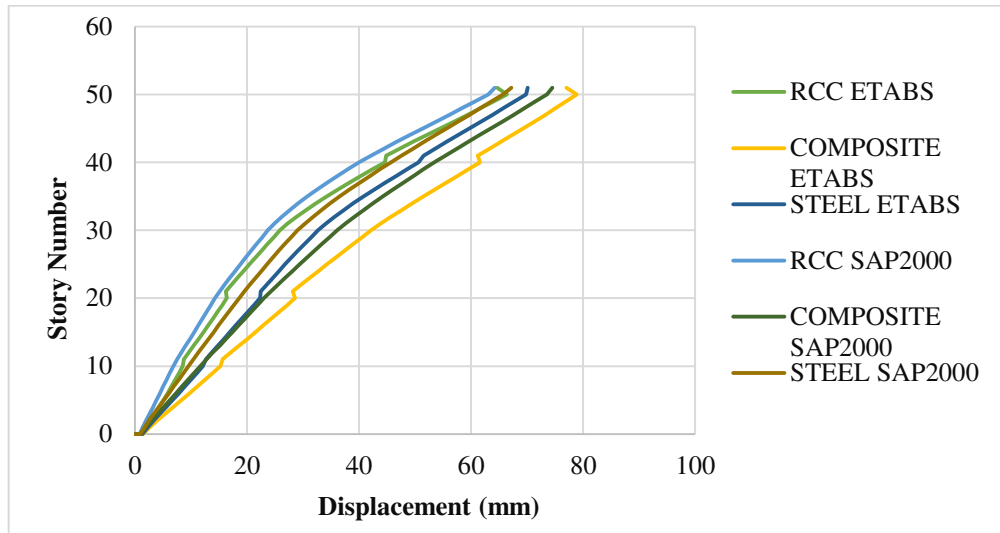


Fig. 3. Induced story displacement using response spectrum method

From the above fig, the maximum story displacement using response spectrum method in was found to be 66.379 mm and 64.2044 mm in RCC structure, 78.857 mm and 74.5165 mm in composite structures and 70.111 mm and 67.2076 mm in steel structure by ETABS and SAP2000 respectively which is at the top story. By comparing the different material used, the maximum story displacement is found in composite structure which could be due to lighter self-weight of the structure and the minimum story displacement was found in RCC structure which could be due to higher self-weight of the structure [as suggested by Mahmoud *et al.* (2016)]. Steel structure are lighter in self-weight as compared to composite, but however in steel, the present of bracing system (which are not provided in RCC and composite structures) could have increase the stiffness of the structure, hence reduced the displacement. However, by comparing ETABS and SAP2000, there is not much difference in story displacement values.

Story Drift

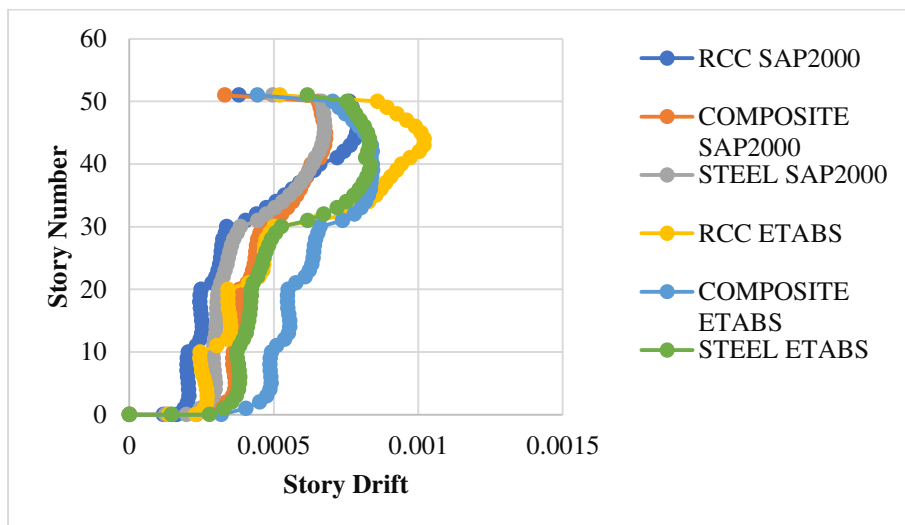


Fig. 4. Induced story drift using response spectrum method



From the above fig, the maximum story drift using response spectrum method was found to be 0.000820 and 0.000788 in RCC structure, 0.000678 and 0.000679 in composite structures and 0.000670 and 0.000676 in steel structure by ETABS and SAP2000 respectively. By comparing the different material used, the maximum story drift is found in RCC structure and the minimum story displacement was found in steel structures. Steel structure are lighter in self-weight as compared to RCC and composite, but however in steel, the present of bracing system (which are not provided in RCC and composite structures) could have increase the stiffness of the structure, hence reduced the story drift. Also, there is slight abrupt change of story drift whenever the mass of the building is reduced which can be due to the structure suffers from strength and stiffness discontinuities [as suggested by Mahmoud *et al.* (2016)]. However, the story drift does not shows much difference in values between ETABS and SAP2000.

Base Shear

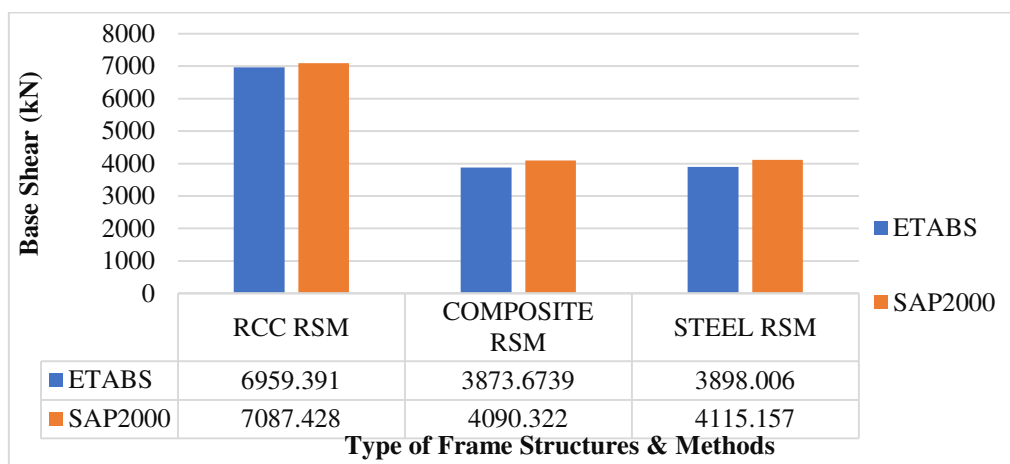


Fig. 5. Induced base shear values using response spectrum method

From the above fig, the maximum base shear is found in RCC structure which could be due to the higher self-weight of the structure and least in composite structure which could be due to lighter self-weight of the material [as suggested by Mahmoud *et al.* (2016)]. However steel structure are also light in weight as compared to composite structure but may be the present of bracing system in steel structure which could have increase the weight of the structure. However, there is not much difference in base shear between ETABS and SAP2000.

Overtuning Moment

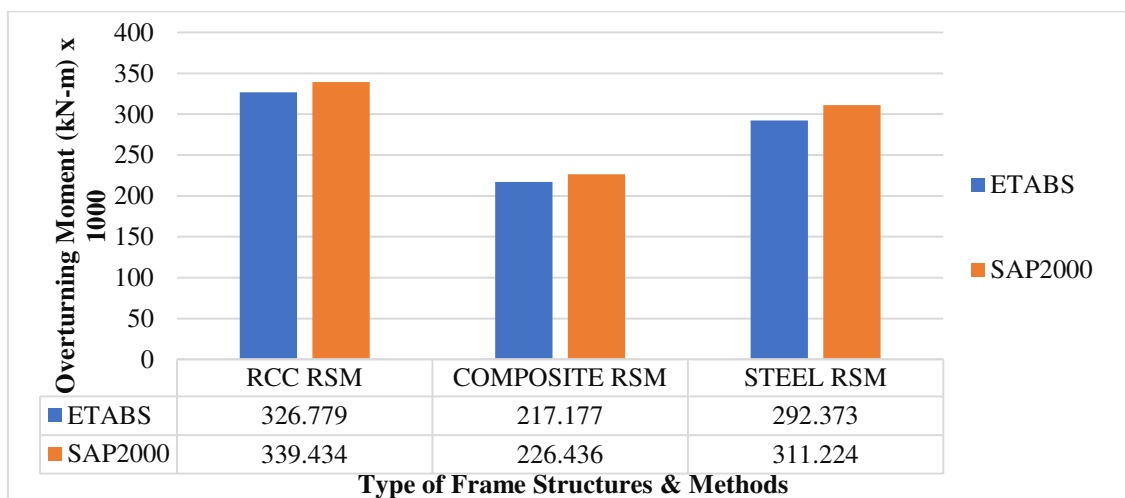


Fig. 6. Induced overturning moment using response spectrum method



From the above fig, the maximum overturning moment is found in RCC structure which could be due to the higher stiffness of the structure and least in composite structure which could be due to lower stiffness of the structure [as suggested by Mahmoud *et al.* (2016)]. However, there is not much difference in base shear between ETABS and SAP2000.

Manual Base Shear Calculation

$$\begin{aligned} \text{Base reaction, } V_b &= A_h \times W \\ \text{Where } A_h &= (Z/2) \times (I/R) \times (S_a/g) \\ &= 0.00984 \\ W &= 727793 \text{ kN (for details seismic weight, please contact author)} \\ \text{Therefore, } V_b &= 7161.484 \text{ kN} \end{aligned}$$

As, the base reaction value is More accurate to SAP2000. Therefore time history analysis will be performed in SAP2000 only with El Centro as a ground motion and a comparison will be made between results obtained by response spectrum method and time history method.

Time History Method

Only SAP2000 are used for performing time history method as it give more closed values to the manual base shear calculation.

Story Displacement

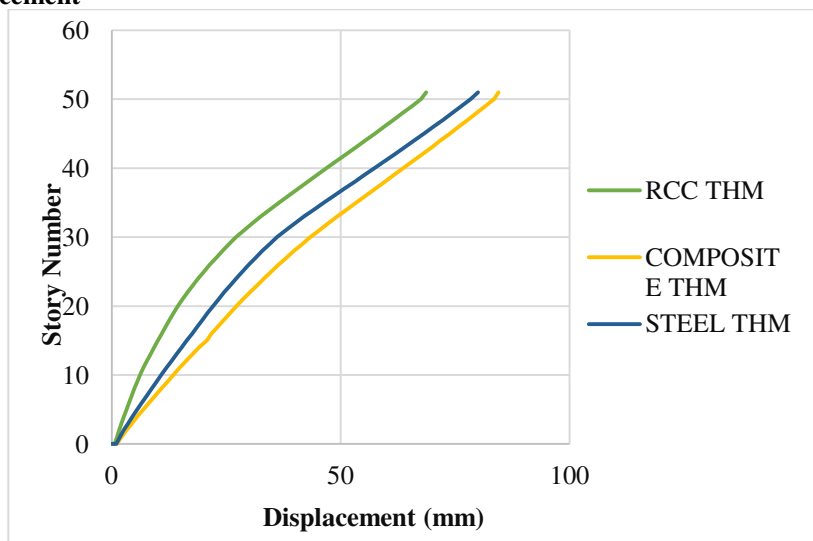


Fig. 7. Comparison of story displacement between methods

From the above fig, the maximum story displacement using time history in SAP2000 was found to be 68.6675 mm in RCC structure, 84.5146 mm in composite structures and 79.9811 mm in steel structure. When compared to those of response spectrum methods it was found to be more in time history method. This could be due to the conservative limits of response spectrum method [as suggested by Arslan *et al.* (2016)]. However, all the values are within the permissible limit of IS 456:2000.



Story Drift

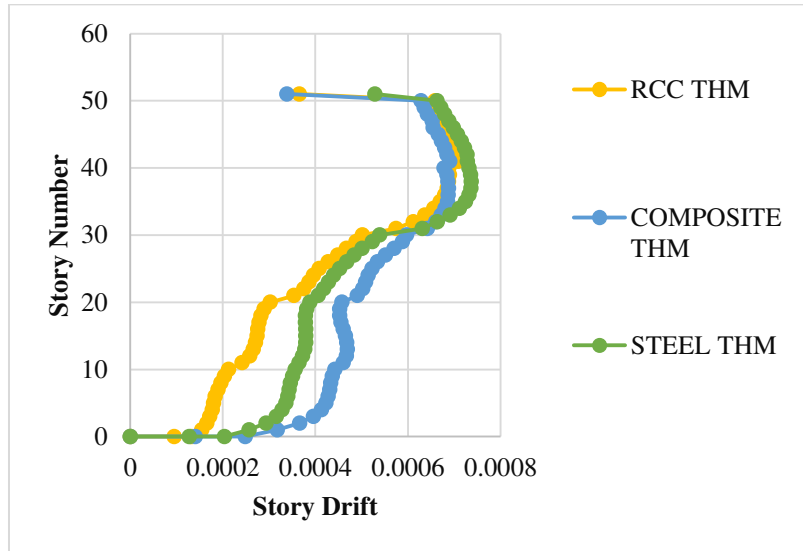


Fig. 8. Comparison of story drift between methods

From the above fig, the maximum story drift using time history in SAP2000 was found to be 0.000709 in RCC structure, 0.000688 mm in composite structures and 0.000683 mm in steel structure. When compared to those of response spectrum methods it was found to be less in time history method. This could be due to the conservative limits of response spectrum method [as suggested by Arslan *et al.* (2016)]. However, all the values are within the permissible limit of IS 1893:2002.

Base Shear

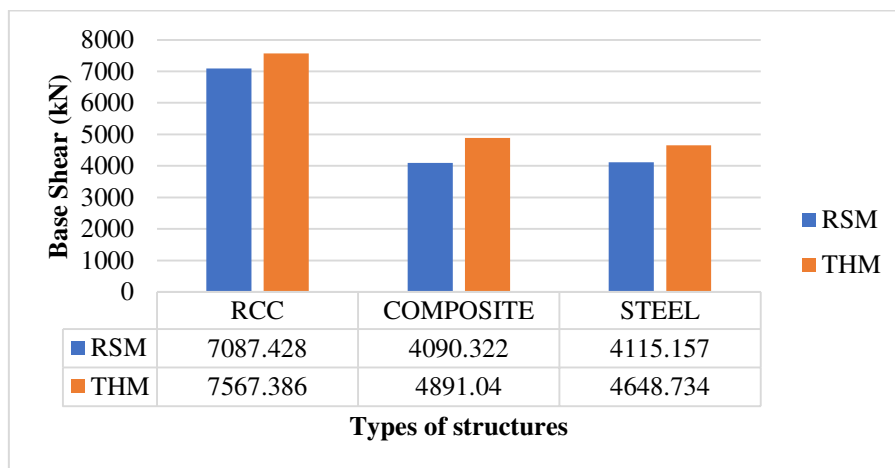


Fig. 9. Comparison of base shear between methods

From the above fig, by comparing the method used, it can be seen that there is an increase in base shear in time history method as compared to response spectrum method. Therefore, design using response spectrum method may lead to unsafe design of structures.



Overturning Moment

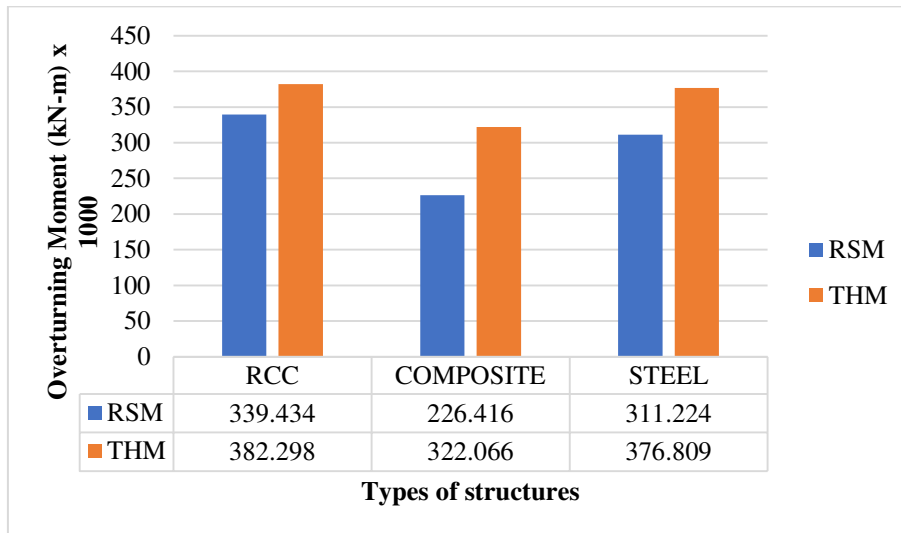


Fig. 10. Comparison of overturning moment between methods

From the above fig, by comparing the method used, it can be seen that there is an increase in overturning moment in time history method as compared to response spectrum method.

V. CONCLUSION

From the above study, the following conclusion can be made:

- By comparing the different material used i.e., R.C.C, composite and steel structure it can be seen that Composite and steel structure experience less story drift, base shear and overturning moment as compared to R.C.C. structure. Hence using composite structure will be very economical as load of the structure is reduced.
- Comparing the method used i.e., response spectrum and time history method it can be seen that the base shear and overturning moment is increasing using time history method. Hence, while designing a multi-story building it is important to consider time history analysis as response spectrum may lead to unsafe design.
- However, by comparing the two modelling software i.e., ETABS and SAP2000 there is not so much different in result. But I would suggest SAP2000 as it gives more accurate results compared to the manual calculation than ETABS.

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