SEISMIC RESPONSE OF MASS AND STIFFNESS IRREGULAR MULTI-STORIED STRUCTURE WITH COMPOSITE COLUMNS

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Abstract - *The present work seeks to investigate the seismic behavior of typical SMRF framed structure with two types of composite columns. The main objective of this paper is to evaluate the comparison of composite columns i.e., Concrete-Filled Steel Tube and Concrete Encased I Section. This paper is mainly emphasis on the structural behavior of multi-storied structure with mass and stiffness irregularity with two different types of composite columns. The present work deals with the seismic behavior of 15 storey building assessed through dynamic analysis (response spectrum method) as per IS 1893:2002 for seismic zone IV and medium type of soil, using ETABS 2015 software package. Comparison of above two composite columns will be done to find which is more effective against lateral loads. The models were analysed and results are tabulated and comparison of various parameters like time period and frequency, storey displacement, storey drift and storey overturning moments.*

***Key Words*: Concrete filled steel tube, Concrete encased I section, mass and stiffness irregular buildings, Response Spectrum analysis, Time period, Storey Displacement, Storey Drift.**

1. INTRODUCTION

The buildings in India are constructed with RCC and the adoption of steel structures is generally confined to industrial buildings, which have acquired prominence by adopting composite structural elements. The most important and most frequently encountered combination of two materials steel and concrete, with the application in multi-story commercial buildings and factories, as well as in bridges. These materials can be used in mixed structural systems, for example, concrete cores encircled by steel tubes, as well as in composite structures where members consisting of steel and concrete act together compositely. These essentially different materials are completely compatible and complementary to each other, they have almost the same thermal expansion, they have an ideal combination of strengths with concrete efficient in compression and the steel in tension, concrete also gives corrosion protection and thermal insulation to the steel at elevated temperatures and additionally can restrain slender steel sections from local or lateral-torsional buckling. However, in recent times, the composite columns are gaining popularity for use in multi-story buildings by virtue of their excellent static and earthquake resistant properties such as lower mass, high strength, rigidity and stiffness, significantly high toughness and ductility, large energy dissipation capacity. Due to these reasons, composite members are gaining importance for the making of sky-scrapers, infrastructure growth and especially for high rise structures of seismic regions in the world.

According to IS- 1893- Part I: 2002, a building shall be considered as irregular in elevation if it satisfies at least one of the following five conditions:

1. Soft storey (stiffness discontinuity) - This type of storey exists when a lateral-stiffness becomes less than 70% of its above storey or less than 80% of its average stiffness.
2. Weak storey (strength discontinuity): This type of storey exists when the strength becomes less than 80% of its above storey.
3. Vertical Geometric Irregularities: The lateral-force-resisting systems in a horizontal dimension of any storey should be greater than 150% of its adjacent storey.
4. Mass Irregularity: Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200% of that of its adjacent stories. In case of roofs, irregularity need not b considered.
5. In-plane Discontinuity in vertical resisting lateral force: A in plane offset of the lateral-load-resisting elements which is greater than a length of those elements.

1.1 Composite columns

A steel-concrete composite column is a compression member, comprising either a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel and is generally used as a load-bearing member in a composite framed structure. The load carrying capacity of composite columns is more than that of the bare reinforced column and the structural steel column included in the system.

Concrete Filled Steel Tubular (CFST) members utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high-rise and multi-story buildings as columns and beam-columns, and as beams in low-rise industrial buildings where a robust and efficient structural system is required. The distribution of materials in the cross section also makes the system very efficient in term of its structural performance. The steel lies at the outer perimeter where it performs most effectively in tension and bending It also provides the greatest stiffness as the material lies farthest from the centroid. In Concrete Filled Steel Tube (CFST) Structural System high-strength concrete is used for filling steel tubes. These members are ideally suited for all applications because of their effective usage of construction material. Composite columns with fully and partially concrete encased steel sections concrete-filled tubular section are generally used in composite construction.

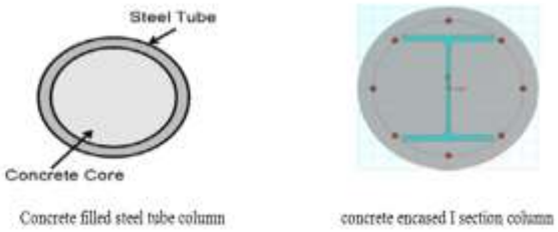

Fig. 1 Composite columns

1.2 Advantages of composite columns

- Increased strength for a given cross-sectional dimension.
- Increased stiffness, leading to reduced slenderness and increased bulking resistance.
- Good fire resistance in the case of concrete encased columns.
- Corrosion protection in encased columns.
- Significant economic advantages over either pure structural steel or reinforced concrete alternatives.
- Identical cross sections with different load and moment resistances can be produced by varying steel thickness, the concrete strength, and reinforcement. This allows the outer dimensions of a column to be held constant over a number of floors in a building, thus simplifying the construction and architectural detailing.
- Erection of high rise building in an extremely efficient manner.
- Formwork is not required for concrete filled tubular sections.

2. LITERATURE SURVEY

- Comparative study on seismic analysis of multi-storied buildings with composite columns": Due to a large population and small per capita area, need of tall buildings becomes more essential in the society. The limitations of the available land frequently restrict the freedom of an engineer to create a perfect structure. In such situations the buildings will have to be designed in various shapes even with oblique corners so as to utilize the maximum benefits of the available land. As earthquakes are one of the greatest damaging natural hazards to the building, the design and construction of tall structures which is capable of resisting the adverse effects of earthquake forces are the most important. Concrete-filled steel tubular columns have excellent earthquake resistant properties such as high strength and ductility and large energy absorption capacity. The objective of this paper is to evaluate the comparison of composite columns with concrete filled steel tube and composite encased I section column. This paper mainly emphasizes the structural behavior of the multi-story building for different plan configurations like Rectangular, C, L and H shape with two different column properties. It is also to compare and find which building with the composite column is more effective against lateral loads. Modeling of 15- story buildings are analyzed using ETABS 2015. The results are tabulated, compared and final conclusions are framed. From the outputs of ETABS, various results are obtained. And these results are evaluated by preparing various graphs.

- (April 2015) "Comparison of Seismic Behavior of a Typical Multi-Storey Structure with Composite Columns and Steel Columns": The present work seeks to investigate the seismic behavior of a typical ordinary moment resisting framed structure with composite columns and conventional Steel columns and examine the key design issues involved. The present study deals with the seismic behavior of a typical (G+12) storied framed structure assessed through the equivalent static method of analysis as per IS: 1893-2002 for moderate seismic zone III using ETABS software package. The analyses are performed on a suite of 2 types of ordinary moment resisting framed 3D space models with different column types – Steel and CFST. The analysis is carried out and the results are compared in terms of critical earthquake response parameters such as base shear, story drifts, roof displacements, and story overturning moments.

- April 2013) "Comparison of R.C.C. And Composite Multi-storeyed Buildings": Steel-concrete composite construction means steel section encased in concrete for columns & the concrete slab or profiled deck slab is connected to the steel beam with the help of mechanical shear connectors so that they act as a single unit. In this present paper, steel-concrete composite with R.C.C. options is considered for the comparative study of G+15 story office building which is situated in earthquake zone IV & wind speed 39m/s. Equivalent Static Method of Analysis is used. For modeling of Composite & R.C.C. structures, stand-pro software is used and the results are compared and it is found that composite structure is more economical.

- (November 2015) “Comparison of Seismic Behavior of a Structure with Composite and Conventional Columns”: An extensive study has been carried out on the behaviour of the composite column in a structure. In composite column construction, steel and concrete are united in such a manner that the advantages of the materials are employed in an efficient manner. By bonding and friction between steel and composite material, these materials will accept the external loading in composite columns. In this study comparison of the composite and conventional structure is carried out. Just varying the design of column i.e., by using composite and conventional column and keeping all other structural members same for both the structures. Composite column design is carried out according to Euro code 4 and conventional column design is by IS 456-2000. The buildings are taken to be true to be placed in III seismic zone. Seismic design is followed by IS 1893-2002. There are many different types of the composite column from those we have taken concrete encased composite column for our analysis. Concrete encasement would increase the load resistance of steel column.

- (April 2014) “Comparative study of RCC and steel-concrete composite structures”: Steel concrete composite construction has gained wide acceptance worldwide as an alternative to pure steel and pure concrete construction. The use of steel in the construction industry is very low in India compared to many developing countries. There is a great potential for increasing the volume of steel in construction, especially in the current development needs India and not using steel as an alternative construction material and not using it where it is economical is a heavy loss for the country. In this paper study of four various multi-storied commercial buildings i.e. G+12, G+16, G+20, G+24 are analyzed by using the STAAD-Pro software. Where design and cost estimation is carried out using MS-Excel programming and from obtained result comparison can be made between R.C.C and composite structure.

3. BUILDING DESCRIPTION

Table -1: Specification for Response spectrum analysis

Properties of building	Buildings with composite columns	
	CFST(Concrete Filled Steel Tube)	CES(Concrete Encased I section)
Material properties		
Grade of concrete	M_{30}	M_{30}
A grade of reinforcing steel	HYSD 500	HYSD 500
Unit weight of concrete	25 kN/m^3	25 kN/m^3
Sectional properties		
Column type	Circular	Circular
Column size	D=600mm, t=16mm	D=600mm, t=16mm (ISHB400)
Beam size	ISWB 550	ISWB 550
RC slab	150mm	150mm
Wall thickness	230mm	230mm
Building details		
No. of bays in X-direction	7	7
No. of bays in Y-direction	7	7
The width of bays in X-direction	8m	8m
The width of bays in Y-direction	6m	6m
Height of storey	3.5m	3.5m
Type of support	Fixed	Fixed
Seismic data		
Earthquake zone	IV	IV
Damping ratio	5%	5%
Importance factor	1.5	1.5
Type of soil	Medium	Medium
Response reduction factor	5(SMRF)	5(SMRF)
Poisson’s ratio	0.15	0.15

4. Modeling OF STRUCTURE

4.1 Regular building

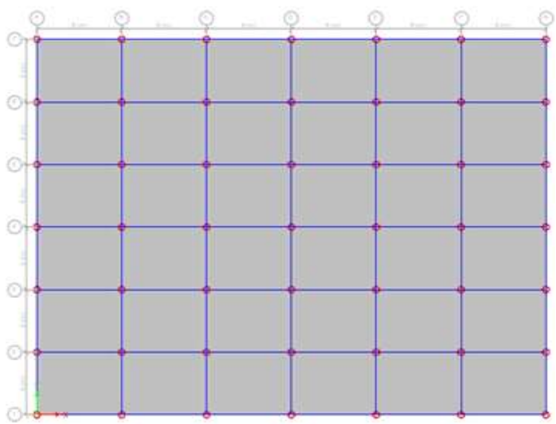

Fig. 1 Regular building plan

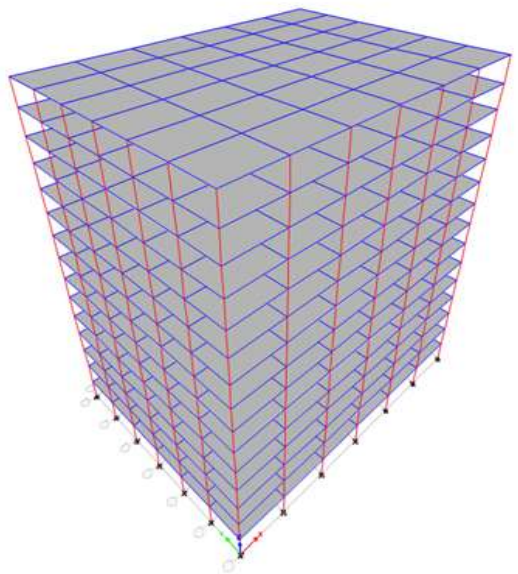

Fig. 1 3D view of t Regular building

4.2 Mass irregular building

The structure is modeled as same as that of the regular structure except the loading due to swimming pool is provided in 6th and 12th floor.

The depth of swimming pool considered – 1.5m

Loading due to swimming pool – 15kN/m^2 @ 6th floor and 30kN/m^2 @ 12th floor

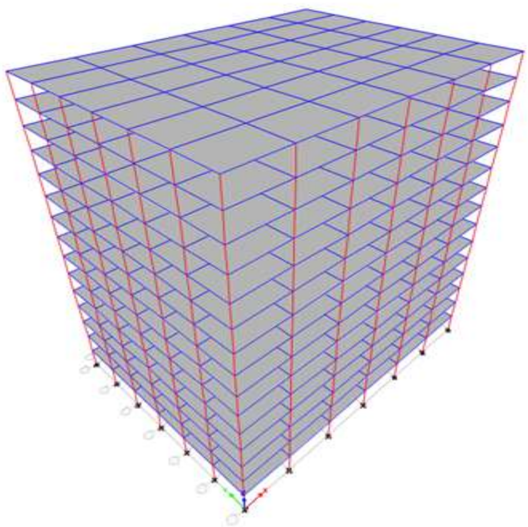

Fig. 1 3D Mass irregular building

4.3 Stiffness irregular building

The structure is same as that of regular structure but the ground storey has a height of 4.5m and doesn't have brick infill.Therefore,Stiffness of ground floor/stiffness of other floors= $(3.5/4.5)^3$=0.47<0.7.Hence as per IS 1893 part 1 the structures stiffness irregular.

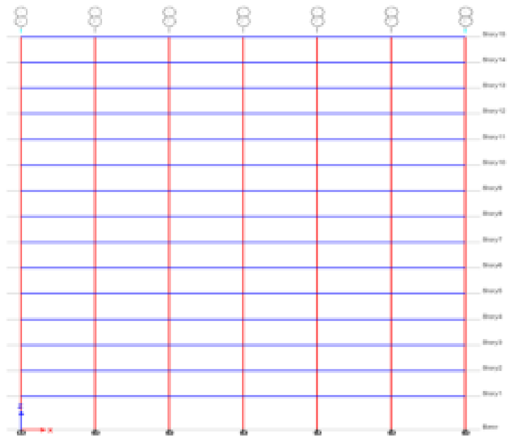

Fig. 1 Elevation of stiffness irregular building

5. RESPONSE SPECTRUM ANALYSIS

The response spectrum represents an envelope of upper bound responses, based on several different ground motion records. For the purpose of seismic analysis, the design spectrum given in figure 1 of IS: 1893(Part 1): 2002 is used. This spectrum is based on strong motion records of eight Indian earthquakes. This method is an elastic dynamic analysis approach that relies on the assumption that dynamic response of the structure may be found by considering the independent response of each natural mode of vibration and then combining the response of each in the same way. This is advantageous in the fact that generally only a few of the lowest modes of vibration have significance while calculating moments, shear and deflections at different levels of the building.

6. RESULTS AND DISCUSSION

The results of each building model are presented in this chapter. The analysis carried out for dynamic analysis (Response spectrum), the results are obtained for fifteen storey building. The result like Fundamental time period and frequency, Storey drift and Storey displacement are presented and compared with 15 storey building model for regular and different irregularities with Concrete-Filled Steel Tube (CFST) and Concrete Encased I Section (CES) composite columns on medium soils in seismic zone IV.

6.1 Time period

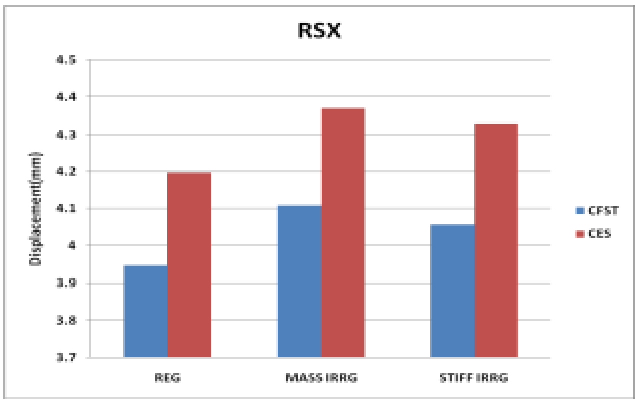

Chart 1: Comparison of time period

The time period reduces with the use of CFST column compared to CES column is shown in above figure for each of the buildings. As the time period reduces the stiffness of the building increases because time period is inversely proportional to the stiffness of the building.

6.2 Storey Displacement

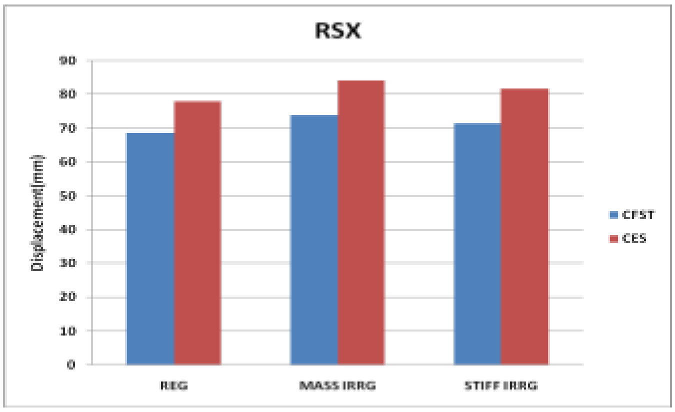

Chart 2: Comparison of displacement along X direction

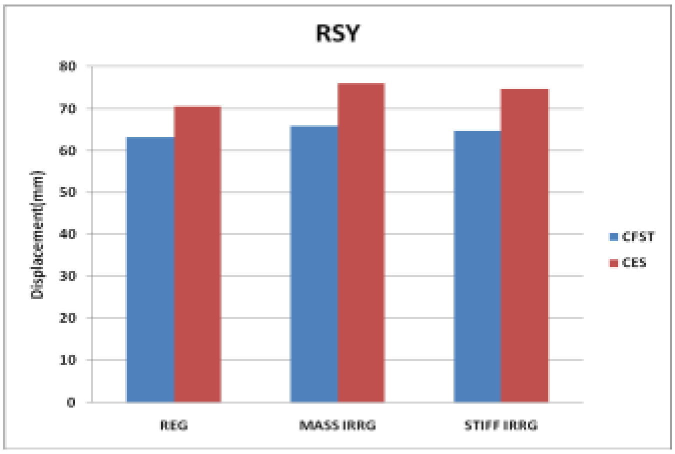

Chart 3: Comparison of displacement along Y direction

The storey displacements were found to be lesser in case of CFST columns compared to CES columns. The stiffness irregular with CFST column performed well due to increased in the reduction percentage when compared to CES column.

6.3 Storey Drift

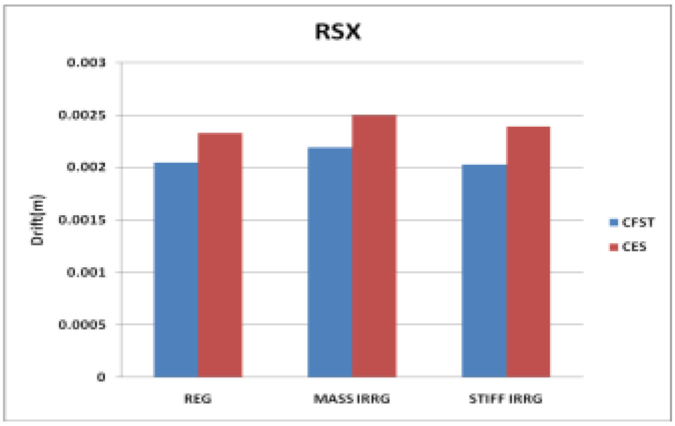

Chart 4: Comparison of drift along X direction

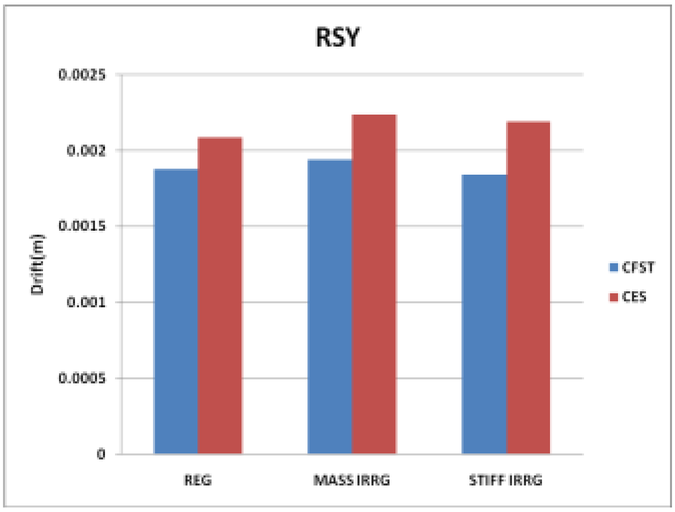

Chart 5: Comparison of drift along Y direction

The storey drift were found to be lesser in case of CFST columns compared to CES columns. Stiffness irregular building with CFST column performed well due to increased in the reduction percentage when compared to CES column.

7. CONCLUSIONS

In this present study the attempt is made to find which type of composite column is effective to resist the lateral deformation in a multi-storied building by response spectrum analysis. The time period, storey displacement and drift are plotted and compared for each of the model. The following conclusions are made based on analysis:

- In case of regular building with CFST composite column the time period reduced by 5.93%,the displacement reduced by 11.75% and 10.3 % (both in x and y direction) and the storey drift reduced by 12.24% and 10.4% (both x and y direction) compared to CES composite column.

- In case of mass irregular building with CFST composite column the time period reduced by 5.95%,the displacement reduced by 12% and 13.41 % (both in x and y direction) and the storey drift reduced by 12.43% and 13.45% (both x and y direction) compared to CES composite column.
- In case of stiffness irregular building with CFST composite column the time period reduced by 6.28%,the displacement reduced by 12.53% and 13.46 % (both in x and y direction) and the storey drift reduced by 15.26% and 15.75% (both x and y direction) compared to CES composite column.
- From the above analysis results, it was concluded that CFST columns performed well in all the above three cases compared to CES columns; hence it is better to adopt the CFST columns for both regular and irregular buildings.

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