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STUDY OF THE BEHAVIOUR OF RC AND RCS FRAME

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ABSTRACT

Composite Reinforced concrete-Steel (RCS) frames which consist of Reinforced Concrete (RC) columns and Steel (S) beams were represented to combine the advantages of pure RC and Steel frames. This system permits the primary steel beam to run continuous through the reinforced concrete column. The main challenge in design of RCS frames was the connection between steel beam and Reinforced concrete column. In this paper RC and RCS frames are designed using relevant codes of design. Behaviour of RC and RCS joints are studied through static analysis that is performed in ANSYS software. It is concluded that the RCS joint experienced less stress and strain as compared to RC joint. Additionally behaviour of G+13 story structure of RC and RCS frames are studied through linear dynamic analysis (Response spectrum). The results show a good improvement on overall behaviour of RCS structure over RC structure.

KEYWORDS: RC frame; RCS frame; Finite Element Method; Linear dynamic method.

1. INTRODUCTION

Construction activity is an integral part of infrastructure and industrial development of the any country. India is the fastest growing country across the world. In major cities of India cost of land is high so there is limitation of horizontal expansion of structure and we left with only solution is vertical expansion of structure. Generally in India reinforced concrete structures are widely used for low rise building because it is economical and easy for construction. However as height of structure increasing from medium to high rise the reinforced concrete structure is no longer economical also it is not easy for construction. As height of a structure increases, its mass increases, overall stiffness of structure decreases and natural period of a building also increases. Also there is restriction on span length and formwork is also hazardous. So structural engineers facing challenges for effective and economical design of structure. For medium to high rise structure steel and concrete composite structure is common solution. Composite structure has higher strength and stiffness. The main advantage of composite structure is effective combination of both materials. In composite structure speed of construction is fast and reduces the restriction for long span.

Conventional rc frame

Frame structures are formed with a combination of beams, column and slab. Reinforced concrete (RC) frames consist of horizontal elements called as beams and vertical elements called as columns. The connection between beam and column is rigid. These structures are cast monolithically. Column is most important element in these type of frame work which is primary load carrying element of a structure. RC frame provides resistance to both gravity and lateral loads. The extensive use of reinforced concrete construction, especially in developing countries, is due to its relatively low cost compared to other material such as steel.

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Fig. 1 Typical RC frame

RCS Frame

The composite frame is a system of reinforced concrete column and steel beam which carries horizontal or vertical load through frame action. In Reinforced Concrete-Steel (RCS) composite frames, steel beams pass continuously through the column. The advantage of these structures lies in their effective combination of good characteristics of both materials. Reinforced concrete columns are most cost-effective than steel columns, since the cost of concrete is relatively low and RC columns features good performance in terms of resisting compressive column loads. Furthermore, composite floors are lighter than RC floors leading to reduction in the weight of the building, foundation cost and inertial forces. This system takes advantages of long span capabilities of steel beams to provide column free space. In this type of composite construction steel beam passes continuously through the column for avoiding interruption of the beam at the column face and eliminating the need for welding or bolting of the beam at the column face.

Fig. 2 Typical RCS frame

2. METHODOLOGY

Researcher has used the finite element method for analysis of the joints and linear dynamic method for analysis of the frames. The methodology includes design of reinforced concrete joint and composite joint using relevant code of design. With using relevant computer software (ANSYS), 3D modelling of reinforced concrete joint (RC) and reinforced concrete steel beam composite joint (RCS) are prepared. Further a comparative study between RC and RCS composite frame for lateral deflection, story drift and base shear is carried out.

3. COMPOSITE STRUCTURE

Composite structure is a combination of two different material. For structure steel and concrete is the best composite material because both materials have nearly equal coefficient of thermal expansion. Concrete pore solution has high pH, it creates a protective layer around steel which doesn't allow corrosion of steel. In this chapter development of composite structure is discussed as follows.

Beam-column composite joints

There are two different types of RCS joint; one is through beam type connection in which steel beam runs continuously through concrete column and second is through column in which beam flanges are interrupted at the column face to accommodate a variety of reinforcing bar arrangement and to facilitate the placement of concrete in the joint. The main challenge in design of RCS frame is connection between concrete column and steel beam, thus so many research is carried on connection detail of joint. Vertical bearing failure and panel shear failure, these two basic modes of failure are observed in composite joint connection. In vertical bearing failure beam rotates within the joint which resulting into crushing of concrete above and below the joint, due to crushing of concrete there is a gap between steel beam and concrete column. In panel shear failure, same behaviour of failure occurs as conventional reinforced concrete frame and steel frame. In RCS joint, shear failure development of concrete strut and yielding of steel web occurs within joint region.

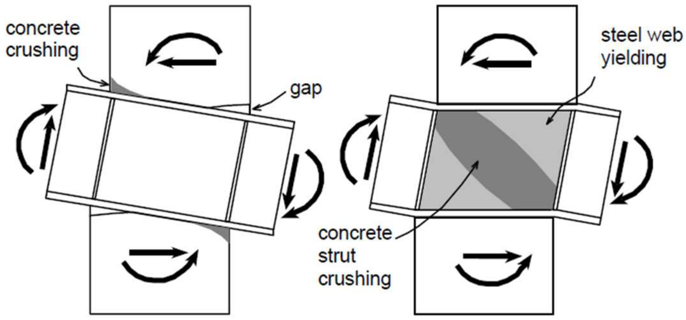

Fig. 3 Basic mode of failure

Elements of composite joint

Various components of RCS composite joint have been shown in fig 4. For effectively force transformation between steel beam and concrete column, these all components were used. Diagonal shear strut mechanism within beam flange is developed due to face bearing plate and steel band plates. They are used for confinement of concrete above and below the steel beam while joint shear resisted by mobilized concrete outside the beam. Ties are provided by making hole through steel beam for concrete confinement and stabilize the vertical column reinforcement.

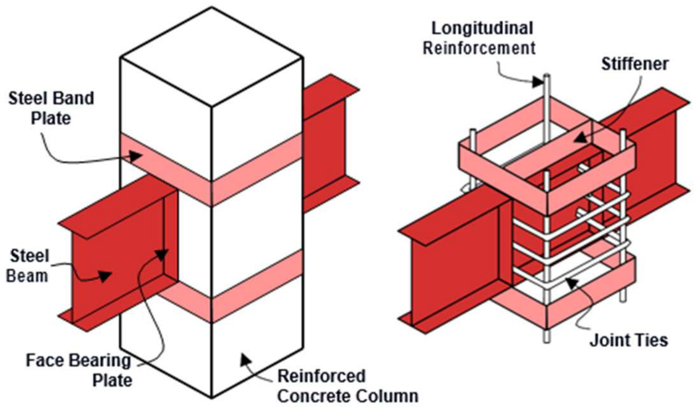

Fig. 4 Elements of composite joint

Advantages of composite structure

1. While construction speed of RCS frame can be increased by allowing a vertical spread of construction activity, so that multiple trades can work simultaneously.
2. By using concrete column, stiffness and damping of structure is increases and cost of decreases.
3. By using steel beam, energy dissipation capacity of structure increases and dead load of structure decreases.
4. Long span beam can be used.

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4. MODELING

Geometrical configuration

Reinforced Concrete Column and Beam

Reinforced concrete column and beam is designed based on recommendation given by IS 456-2000. As per Indian standards, the design of reinforced concrete column and beam must/should follow recommendation given by IS 456-2000. The major difference between conventional frame column and composite frame column is the arrangement of longitudinal steel reinforcement. In composite frame column's longitudinal steel reinforcement is arranged such that it allows continuous passage of steel beam through the joint.

Steel Beam

As per Indian standards, it requires that the design of steel beam shall be in accordance with the IS 800-2007. Width to thickness ratio of steel beam is 5.23 ($b/t_f \leq 9.4\varepsilon$). This is meant to ensure that steel beam cross-sections can develop plastic hinges and have rotation capacity required for failure of structure by plastic mechanism.

Details of RC joint model

For the present dissertation study RC joint model is designed based on guidelines given by Indian standard code. Height of column is 3m and length of beam is 1.2m. Design of columns and beams are taken under the provision of IS 456-2000. The overall geometrical configuration and description of RC joint is given in table 1.

Table 1 Configuration of RC model

Sr No.	Section	Reinforcement details
1	Column 450 X 450 mm	Longitudinal reinforcement 12- 20 mm ϕ
		Stirrups 8 mm ϕ @ 150 mm c/c 2-legged
2	Beam 300 X 600 mm	Bottom reinforcement 2- 16 mm ϕ & 1- 25mm ϕ
		Top reinforcement 3-16 mm ϕ
		Stirrups 8 mm ϕ @ 150 mm c/c 2-legged

Details of RCS joint model

Reinforced concrete column and steel beam (RCS) composite joint is designed based on Indian code of practice and Guidelines given by American society of Civil Engineers. Height of the column is 3m and length of beam is 1.2m. Column and beams are designed under the guidelines of IS 456-2000 and IS 800-2007 while the joint between concrete column and steel beam is designed under the guidelines of ASCE. The overall geometrical configuration and description of RCS joint is given in table 2.

Table 2 Configuration of RCS model

Sr No.	Section	Reinforcement details
1	Column 450 X 450 mm	Longitudinal reinforcement 12- 20 mm ϕ
		Stirrups 8 mm ϕ @ 150 mm c/c 2-legged
2	Beam ISMB 500	D- 500 mm, $b_f = 180\ mm$, $t_f = 17.2\ mm$
		$t_w = 10.2mm$

Loading

Uniformly distributed load is used in present study of dissertation. Uniformly distributed load with intensity of 80 kN/m is applied on the beam. Both models are subjected to same loading.

5. FINITE ELEMENT MODELLING AND ANALYSIS OF RC AND RCS FRAME

The finite element method (FEM) is the most popular simulation method to predict the physical behaviour of system and structure. Since analytical solution are in general not available for most daily problems in engineering science, numerical method like FEM have been evolved to find a solution for the governing equations of the individual problem. Much research work has been done in the field of numerical modelling during the last thirty years which enable engineering today to perform simulation close to reality. Nonlinear phenomenon in structural

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mechanics such as nonlinear material behaviour larger deformation or contact problems have become standard modelling task. Because of rapid development in the hardware sector, resulting in more and more powerful processers together with costs of memory is decreased. Now-a-days, it is possible to perform simulation even for models with millions of degrees of freedoms. In a mathematical sense the finite element solution always just gives one and approximate numerical solution of the considered problem. If experimental analytical results are available it is easily possible to verify any finite element result. However, to predict any structural behaviour in reliable way without experiment, every user of finite element package should have a certain background about the finite element method in general. This section is intended to show a summary of ANSYS capabilities to obtain result of finite element analysis as accurate as possible. Many feature of ANSYS are shown and where it is possible, we show what is already implemented in ANSYS.16 Workbench.

ANSYS model

RC Joint model

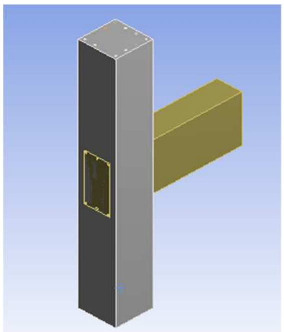

Fig. 5 RC joint

RCS joint model

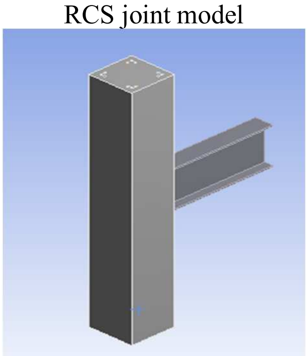

Fig. 6 RCS joint

6. RESULT AND DISCUSSION

Results

ANSYS models of both RC and RCS joint are developed. Both joint models are subjected to same loading. Fig 7 to Fig 12 present behaviour of ANSYS models under loading.

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a) RC Model

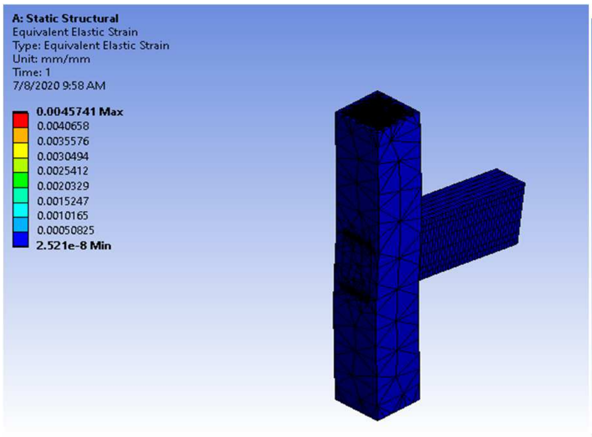

Fig. 7 Strain in RC joint

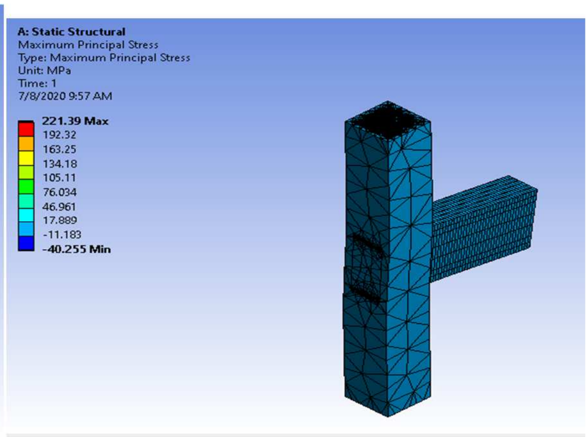

Fig. 8 Stress in RC joint

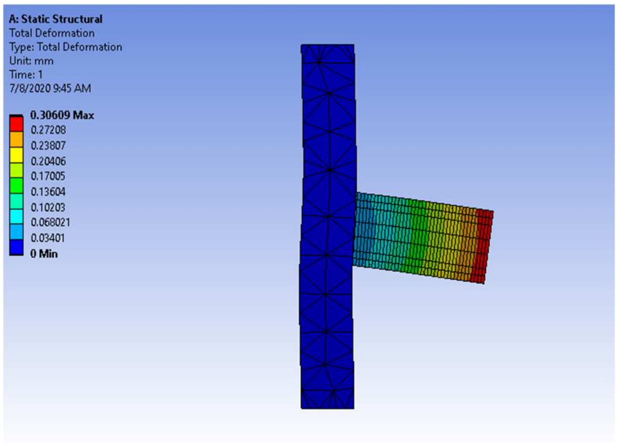

Fig. 9 Deformation of RC joint

b) RCS Model

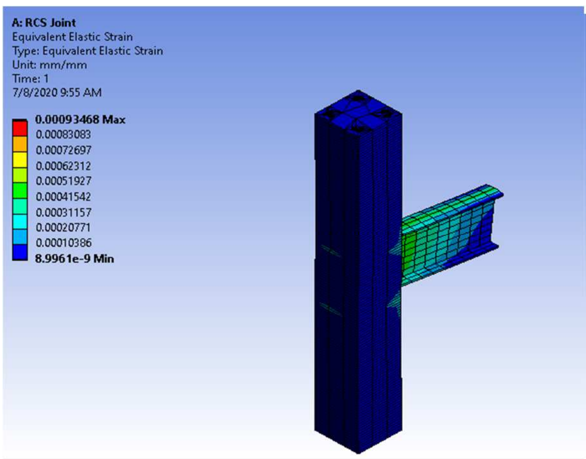

Fig. 10 Strain in RCS joint

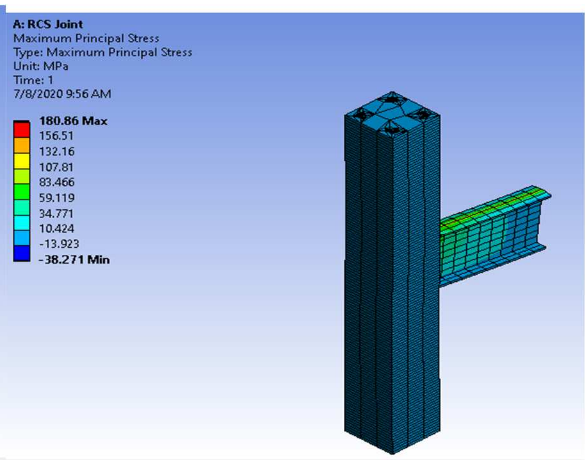

Fig. 11 Stress in RCS joint

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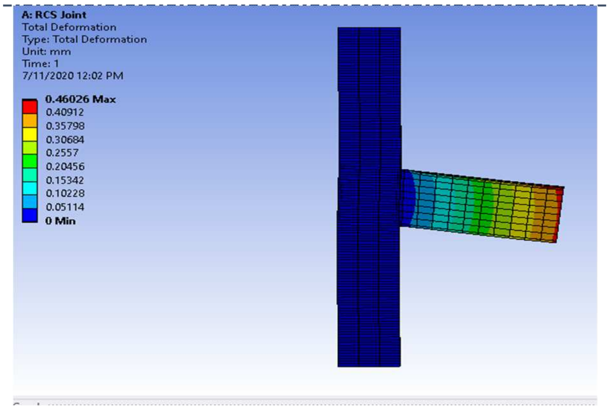

Fig. 12 Deformation of RCS joint

The maximum stress, strain and deformation predicted by ANSYS models of RC and RCS joints are presented as below.

Table 3 Maximum principal stress

Sr. No.	Content	Maximum principal stress (MPa)
1	RC frame	221.39
2	RCS frame	180.86

Table 3 shows results of Maximum principal stress for the RC joint and RCS joint. It is concluded that Maximum principal stress for the RSC joint is less than RC joint by 18.30 %.

Table 4 Equivalent elastic strain

Sr. No.	Content	Equivalent elastic strain
1	RC frame	0.004574
2	RCS frame	0.000934

Table 4 shows results of Equivalent Stress for the RC joint and RSC joint. It is concluded that Equivalent strain for the RCS joint is less than RC joint by 78 %.

Table 5 Joint Deformation

Sr. No.	Content	Deformation
1	RC frame	0.30
2	RCS frame	0.46

From Table 5 shows results of Deformation for the RC joint and RSC joint. It is concluded that Deformation for the RCS joint is more than RC joint by 34.78 %.

7. SEISMIC PERFORMANCE OF RC AND RCS (G+13) STOREY FRAME

This article includes study of seismic performance of RC and RCS composite frames. Response spectrum analysis of both frames are carried out in ETABS software. Details buildings, methodology of analysis and modelling details have been presented in this article.

Geometrical configuration

The table number 6 below shows the details of structural configuration. Plan and elevation of both frames are shown in table 6.

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Table 6 Details of RC and RCS frames

Content	RC frame description	RCS frame description
Plan dimension	20 m X 20 m	20 m X 20 m
Number of stories	14	14
Story height	3.2 m	3.2 m
thickness of slab/deck	150 mm	150 mm
Beam size	300 mm X 600 mm	ISMB 450
Column size	450 mm X 450 mm	450 mm X 450 mm

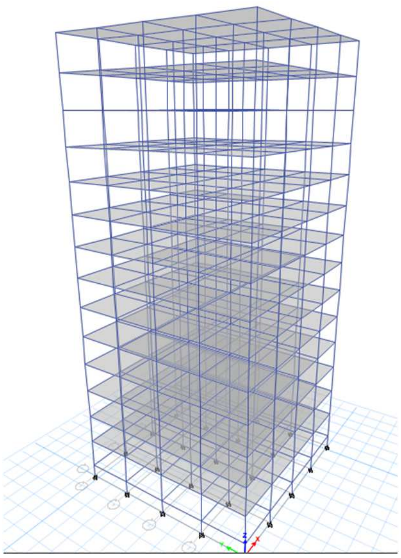

Fig. 16 3D model of building

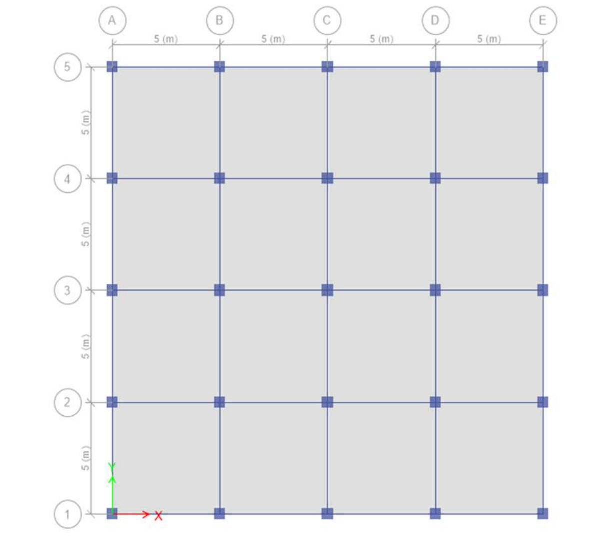

Fig. 17 Plan of building

Details of material properties

Details of material properties and seismic parameters used in analysis are shown in table 7 and table 8 below.

Table 7 Material Properties

Content	Description
Characteristics compressive strength of concrete	M30
Rebar grade	HYSD 500
Steel grade	Fe 250

Table 8 Seismic Parameters

Content	Description
Seismic zone	IV (Z = 0.24)
Soil type	II
Importance factor	1
SMRF Frame	5

Methodology

RC and RCS composite frame models are analyzed by using linear dynamic method. For analysis of both the frames, ETABS 2016 software has been used. Different parameters such as base shear, story displacement and story drift have been compared. Design seismic force is calculated by using Indian standards criteria for earthquake resistant design of structures IS 1893 (PART-1): 2002.

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8. RESULT AND DISCUSSION

After analysis of RCS and RC frame structure by using ETABS software, the results are obtained and compared in terms of different parameters such as base shear, maximum story drift and story displacement. Comparative results are listed in tables and figures below.

8.4.1 Story Shear

After analysis of RCS and RC frames, obtained story shear of each story are listed in the table 9.

Table 9 Comparison of RCS and RC building for story shear

Story Level	Story shear	
	RCS frame	RC frame
Base	797.77	846.97
Ground floor	787.88	834.42
Story 1	754.39	797.16
Story 2	717.34	758.48
Story 3	683.86	724.38
Story 4	652.42	691.32
Story 5	619.50	655.74
Story 6	583.19	617.03
Story 7	543.44	575.58
Story 8	500.98	531.09
Story 9	456.46	483.34
Story 10	408.86	432.22
Story 11	352.77	374.05
Story 12	276.51	296.61
Story 13	163.71	179.33

Base shear of RCS composite frame is 5.8% less than that of RC frame. Maximum base shear is observed in RC frame structure. From this it is noticed that RCS frame structure is safer than RC frame structure.

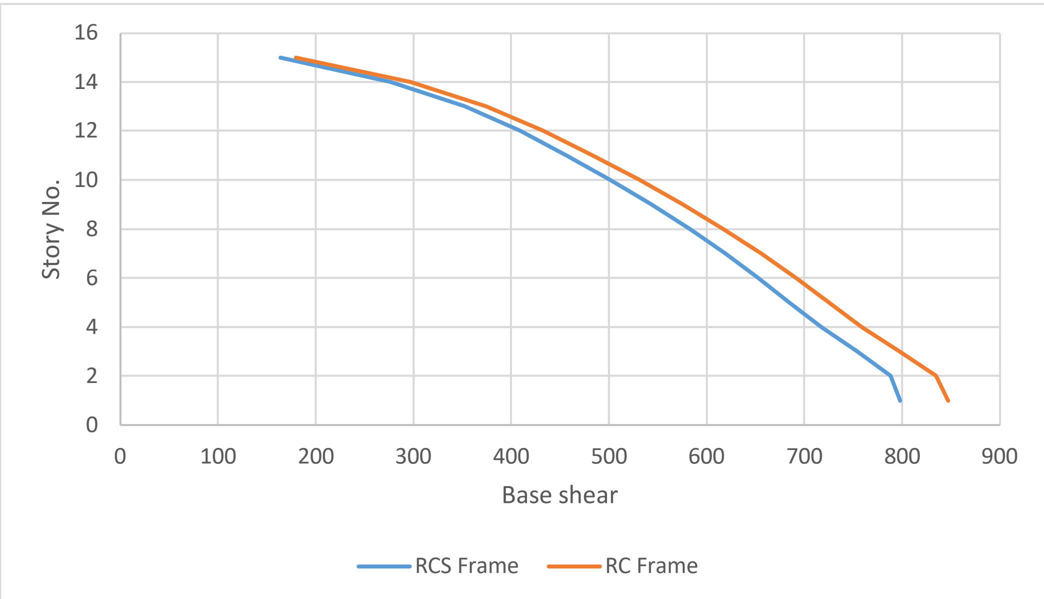

Fig. 18 Comparison of RCS and RC building for base shear

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8.4.2 Story drift

After analysis of RCS and RC frames, story drifts are listed in the table 10.

Table 10 Comparison of RCS and RC building for story drifts.

Story Level	Story drifts along X direction	
	RCS frame	RC frame
Base	0	0
Ground floor	0.00033	0.000346
Story 1	0.000979	0.000518
Story 2	0.001172	0.000655
Story 3	0.001167	0.000761
Story 4	0.001127	0.000852
Story 5	0.001082	0.000933
Story 6	0.001033	0.001007
Story 7	0.000978	0.001074
Story 8	0.000917	0.001135
Story 9	0.000849	0.00119
Story 10	0.000776	0.00124
Story 11	0.000695	0.001281
Story 12	0.000598	0.001284
Story 13	0.00047	0.001068

Story drift along X direction is maximum in 2nd floor of RCS frame structure. In RC frame structure maximum story drift in X direction is observed at 12th floor. Compared to RCS frame in RC frame story drifts are more.

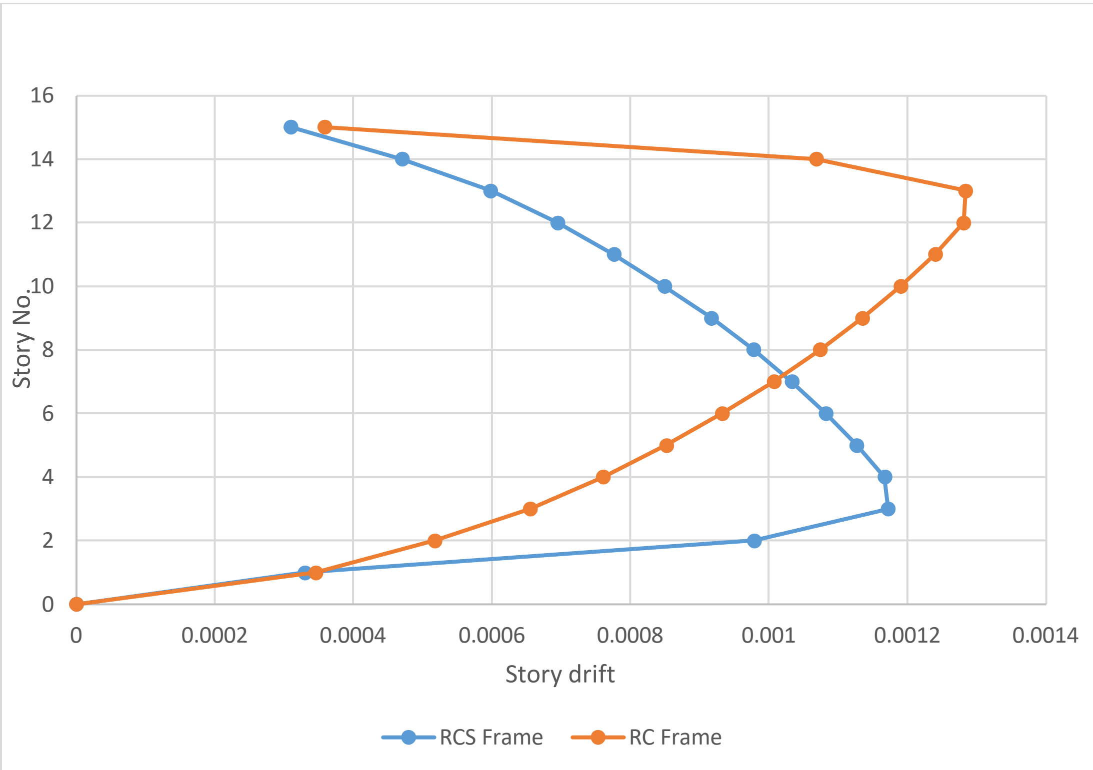

Fig. 19 Comparison of RCS and RC building for story drift

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8.4.3 Story displacement

After analysis of RCS and RC frames, obtained story displacement of each story are listed in the table 11.

Table 11 Comparison of RCS and RC building for story displacement

Story Level	Story displacement	
	RCS frame	RC frame
Base	0	0
Ground floor	0.764	0.817
Story 1	5.439	5.932
Story 2	11.043	12.067
Story 3	16.565	18.122
Story 4	21.809	23.88
Story 5	26.742	29.302
Story 6	31.353	34.37
Story 7	35.624	39.063
Story 8	39.529	43.353
Story 9	43.041	47.208
Story 10	46.127	50.596
Story 11	48.756	53.478
Story 12	50.889	55.813
Story 13	52.479	57.552

Comparatively, the RCS frame structure has less story displacement than RC frame structure.

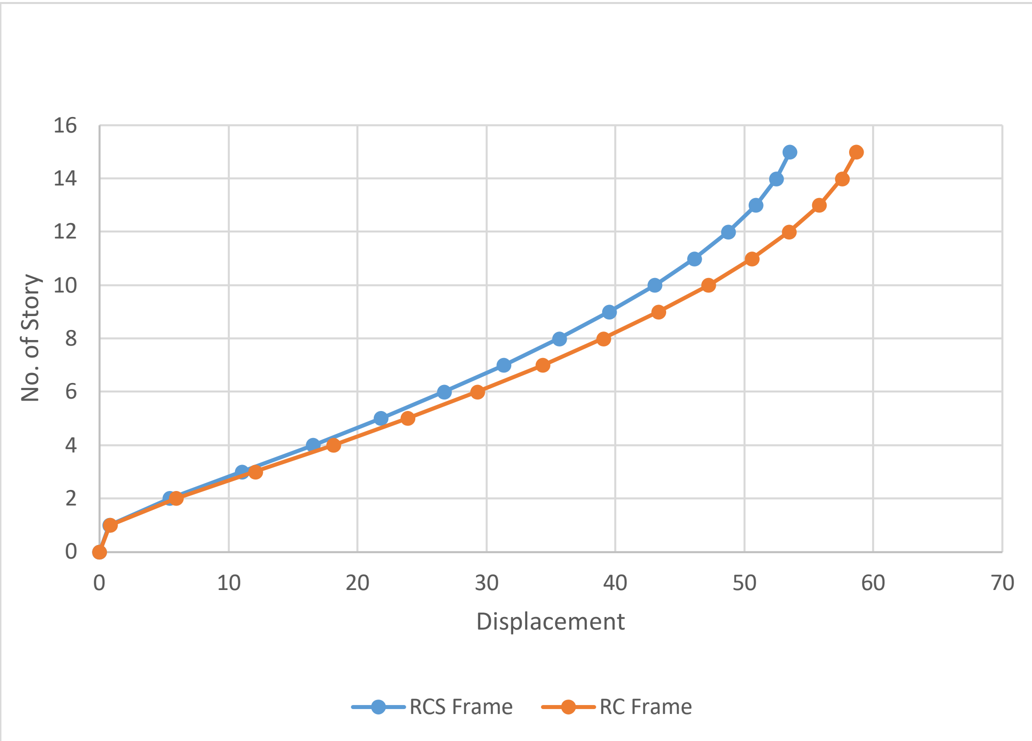

Fig. 20 Comparison of RCS and RC building for story displacement

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9. CONCLUSIONS

The present study shows modelling and analysis of RC and RCS joint in ANSYS software. It also presents modelling and analysis of G+13 story frame in ETABS software. Some critical elements from the ETABS model are analyzed in ANSYS software. After analysis of both models, it is concluded that RCS Joint has favorable results than RC joint with respect to equivalent elastic strain, maximum principal stress, base shear, story drift and displacement. Its conclusion can be drawn out as follows.

- Base shear of RCS composite frame is 5.8% less than that of RC frame. Maximum base shear is observed in RC frame structure. From this it is noticed that RCS frame structure is safer than RC frame structure.
- Story drift along X direction is maximum in 2nd floor of RCS frame structure. In RC frame structure maximum story drift in X direction is observed at 12th floor. In RC frame maximum story drift is observed.
- Comparatively, the RCS frame structure has less displacement than RC frame structure.
- Maximum principal stress for the RC joint and RSC joint is observed. As a result, it is concluded that Maximum principal stress for the RSC joint is less than RC joint by 15-20%.
- Equivalent Stress for the RC joint and RSC joint is observed. From the figure, it is concluded that Equivalent Stress for the RSC joint is less than RC joint by 25-35%.
- Total deformation for the RC joint and RSC joint is observed. From the figure, it is concluded that deformation for the RSC joint is more than RC joint by 30-35%.
- From above results of RCS and RC joint, it is observed that under same loading, RCS joint experiences less stress as well as less strain than RC joint. It also shows that the deflection of both the beam is within permissible limit. However deflection of RCS joint beam is found more than RC joint beam.

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