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Comparative study of RCC and Steel-Concrete composite structure under Time history Analysis

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Abstract

In Nepal, generally traditional RCC framed structure are preferred due to its familiarity. However, these structures are considered more suitable for the low rise building only and not suitable for the high-rise building due to its higher weight, restriction to maximum span, requirement of formwork and other reasons. During the "25th April 2015 Gorkha earthquake", it was observed that most of the high-rise building and apartments were highly affected. So for new construction of high-rise building and apartments, steel-concrete composite can be used to replace the traditional RCC section because of their excellent strength, ductility, better economy, better energy absorption capacity and performance during earthquake. Steel-concrete composite elements are widely used in the construction of building, bridges, offshore structure and other structures worldwide, however it is new concept for the construction industry in Nepal. A composite column is built by encasing the steel member by concrete or simply steel section is embedded in concrete section. This thesis work presents the comparative study of performance of building with RCC and steel-concrete structural system. It has been found that, steel-concrete composite structures will be relatively lighter, flexible with higher time periods and attracts considerably lesser horizontal seismic forces. Hence, construction with steel-concrete composite was found to be useful for the location with high seismicity like Nepal.

Keywords

Composite Structure, RCC Structure, Composite Column, Steel Beam, Shear Connector, time history analysis, ETAB software

1. Introduction

In Nepal reinforced concrete members are mostly used in the framing system for most of the building since this is the most convenient and economical system for low-rise buildings. However, there is need of vertical growth of building due to lack of land space and increase in population in urban area, so medium to high-rise building are becoming necessary for recent and upcoming scenario. For this composite construction gained several advantages in comparison to the conventional system construction. It is all because, for medium to high-rise building this RCC structures are no longer economic because of increased dead load, less stiffness, span restriction and hazardous formwork [1] . Steel concrete composite frame system can provide an effective and economic solution to most of these problems in medium to high-rise building. Moment resisting RCC structures are very common in Nepal for building construction. With time, the requirements for construction of high-rise buildings have increased with a challenge to resist high seismic loads. Hence, an economical construction technology with better structural performance has been investigated.

Structural members that are made up of two or more different materials are known as composite elements. Composite structure are more flexible than the RCC structure. The deformation of the structure is classified into three categories as overall building movements, story drift and other internal deformation and inelastic deformation for structural component and elements. These movements occurs due to rigid body displacement and shear deformations [2]. The main benefit of the composite elements that is the properties of each material can be combined to form a unit that perform better overall than its separate constituent parts. There are many type of composite elements like steel-timber, timber-concrete, plastic-concrete etc. but most common form of composite element in construction is a steel-concrete composite.

The steel and concrete are compatible and complementary to each other as steel is good in tension and concrete is good in compression and they have almost same thermal expansion coefficient. In addition, concrete cover and/or filler prevents the occurrence of local buckling; in turn, steel hollow section enhances the concrete confinement and fire and corrosion resistance [3]. The benefits of composite construction include speed of construction, performance and value. Steel framing for a structure can be erected quickly and the pre-fabricated steel floor decks can be put in place immediately. When cured, the concrete provides additional stiffness to the structure. Additionally, the concrete encasement protects the steel from buckling, corrosion and fire. Service integration within the channels on the composite decks is another advantage to composite construction. In the composite structure, the concrete act together with the steel to create a stiffer, lighter, less expensive structure. Material handling at site is less and has better ductility, hence superior lateral load behavior; better earthquake resistance. In addition, it has ability to cover large column free area in buildings.

1.1 Composite beam and slab

If the steel beams are connected to the concrete slab in such a way that they two act as single unit, the beam is called as composite beam. A composite beam consists of a steel beam, over which a reinforced concrete slab is cast. The composite interaction is achieved by the attachment of shear connectors to the top flange of the beam. The composite action reduces the overall beam depth by the effective composite action between steel beam and concrete slab. The principal merit of steel-concrete composite construction lies in the utilization of the compressive strength of concrete slabs in conjunction with steel beams, in order to enhance the strength and stiffness of the steel beam [4].

1.2 Composite Column

It is conventionally a compression member comprising either a concrete encased hot-rolled steel section or a concrete filled tabular steel section. Concrete filled steel tube (CFST) construction are lighter compared to RCC structure [5]. In composite column both steel and concrete, resist the loading by interacting together by bond and friction. The interactive and integral property of steel and concrete makes the composite column very stiff, more ductile, cost effective and structurally efficient member. The lighter weight and higher strength of steel permit the use of smaller section and light foundation and addition of concrete enables the structure to easily limit the sway and lateral deflections.

1.3 Shear Connectors

In order that the steel beam and slab act as a composite structure, the connectors must have adequate strength and stiffness. If there are no horizontal or vertical separations at the interface, the connectors are described as rigid; complete interaction can be said to exist under these idealized circumstances. However, all connectors are flexible to some extent, and therefore partial interaction always exists. For most connectors used in practice, failure by vertical separation is unlikely and any uplift would have only negligible effect on the behavior of the composite structure.

Various composite structure elements[6] are shown below:-

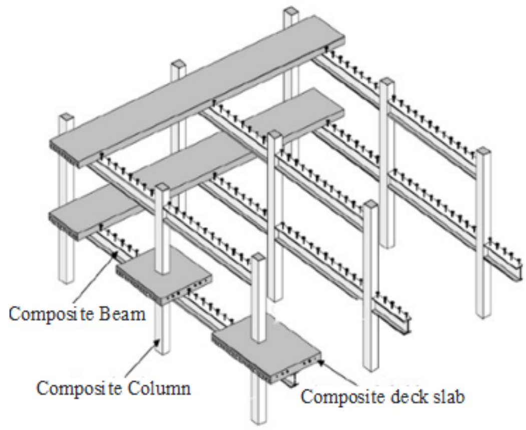

Figure 1: Composite Structure elememts

2. Objectives and Scope of Study

- To investigate major parameter like fundamental time period, storey drift, lateral joint displacements, bending moments and shear force in column.
- To find out best suited range for composite construction.
- To check the effectiveness of shear wall in RCC

versus composite Structure.

The scope of the present study aims at compare the performance of G+5, G+8, G+11, G+15,G+20, G+30 RCC and composite building frame situated in earthquake zone V. All frames are designed for same gravity loadings. RC frame designed as usual and steel concrete composite structure designed as steel section encased in concrete for columns and the concrete slab is connected to steel beam with the help of mechanical shear connectors so that they act as single unit. Time History method is used for seismic analysis. E-tab16 is use and results are compare for both of the cases for all stories building.

3. Methodology

Analysis of the building has been carried out by using ETAB 16.2. Here, the synthetic time history has been generated using three earthquakes namely Darfield (New Zealand), Imperial Valley (California, USA) and Kobe earthquake (Japan) with target spectrum taken as response spectrum given for the medium soil as per IS code 1893:2002. Here, the peak input acceleration of the Darfield, Imperial and Kobe earthquake before matching was 0.22g for time period of 5.667 sec, 0.26g for time period of 0.433 sec and 0.203g for time period of 3.04 sec whereas after matching the accelerograms with the target spectrum the peak input was found to be 0.38g for 5.655 sec, 0.40g for 1.03 sec and 0.38g for time period of 3.288 sec respectively. For response evaluation of all structures, selecting the best earthquake wave which gives maximum response by using linear time history analysis.

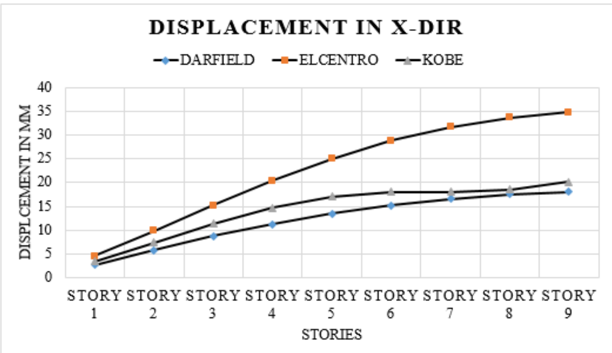

Figure 2: Displacements in x-direction due to various earthquake force in $G+8$ RCC

Step-wise procedure has been discussed below :

1. Based upon the literature review and general practice 20m x 12m plan is selected as building plan. Six models $G+5$, $G+8$, $G+11$, $G+15$, $G+20$ and $G+30$ story are created for both RCC and steel-concrete composite on the same plan.

2. Size of the members is selected as they meet both strength and serviceability criteria.

3. Define load pattern like a dead load, live load, Super dead load, EQx, EQy etc. and assign to the frame objects.

4. Based upon the model analysis, check whether members will passed or not strength and serviceability limit, if passed its ok otherwise repeat member size selection and analyze again.

5. Since the analysis of the RCC and composite building are to be formulated using the minimum of three earthquakes based upon the FEMA, firstly the three earthquakes data which are closed to the target response spectrum based upon the IS 1893:2002 was obtained from the Peer Barkley NGA west database site. Based upon the above procedure the three major earthquakes which are closer to the target response spectrum was found to be Kobe earthquake (Japan), Imperial Valley earthquake (California, US) and Darfield (New Zealand) respectively.

6. Define the target response spectrum function based upon the IS 1893:2002 from Define options.

7. Define the time history function of the respective earthquake by going to define > time history function> choose function type as from file > make necessary arrangement based upon the obtained notepad data obtained from the Peer Barkley.

8. Matching of the practical earthquake response with the target response spectrum as define > time history function > function type > matched to response spectrum. Here the matching has been carried out based upon the spectral matching with time domain type. As per ASCE 7-10, the target response spectrum was considered to matched with the reference acceleration time history if the match range is

within 0.2T to 1.5T where, T is the fundamental time period in seconds.

9. Define the static load case and set analysis type as time history > linear model.

10. Since the linear analysis is under the action no consideration of the geometric and material non-linearity is carried out i.e. no consideration of the hinge and P-delta effect.

11. Arrange the load case type to acceleration > load name as U1 and U2 > function as the matched time history type for the respective earthquakes > scale factor is considered as (IG/R) of EQx or EQy in case if the base shear of THx and THy are less than (IG/R) of EQx and EQy.

12. Analysis of the maximum responses regard to the both RCC and Composite buildings regard to the responses such as top displacement, inter story drift, base shear and overturning moment has been carried out.

13. The maximum responses of RCC and Composite building will then be compared with each other and check with the variation in the code limit if any.

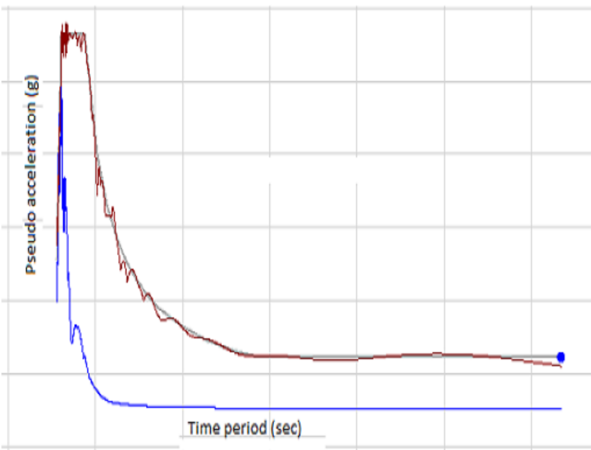

Figure 3: Response spectrum of original, matched and target spectrum for Imperial earthquake

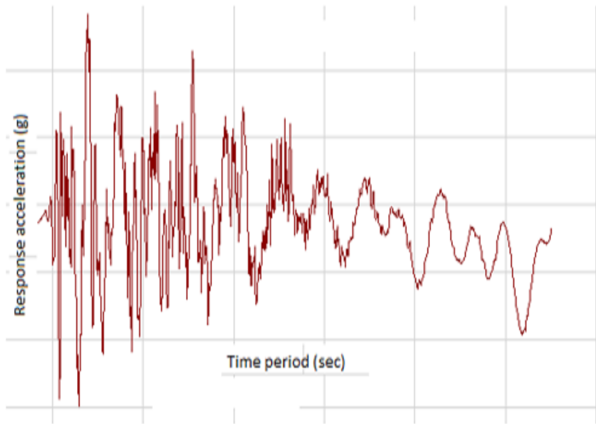

Figure 4: Synthetic time history of Imperial Valley EQ

4. Model Configuration

Table 1: Model Configuration

		Height	Area	Each story Height	Column	Beam	Slab
G+5	RCC	18.5 m	240 m^2	3m	0.3m x 0.4m	0.25m x 0.35m	125mm
	Composite	18.5 m	240 m^2	3m	0.35m x 0.35m (Encased ISHB 200-1)	ISMB 200 with shear Connector	125mm
G+8	RCC	27.5 m	240 m^2	3m	0.4m x 0.4m	0.3m x 0.35m	125mm
	Composite	27.5 m	240 m^2	3m	0.4m x 0.4m (Encased ISHB 200-1)	ISMB 200 with shear Connector	125mm
G+11	RCC	36.5 m	240 m^2	3m	0.4m x 0.5m	0.3m x 0.35m	125mm
	Composite	36.5 m	240 m^2	3m	0.4m x 0.4m (Encased ISHB 250-1)	ISMB 200 with shear Connector	125mm
G+15	RCC	48.5 m	240 m^2	3m	0.45m x 0.55m	0.3m x 0.4m	125mm
	Composite	48.5 m	240 m^2	3m	0.45m x 0.45m (Encased ISHB 300-1)	ISMB 250 with shear Connector	125mm
G+20	RCC	63.5 m	240 m^2	3m	0.5m x 0.6m	0.3m x 0.4m	125mm
	Composite	63.5 m	240 m^2	3m	0.5m x 0.5m (Encased ISHB 350-1)	ISMB 250 with shear Connector	125mm
G+30	RCC	93.5 m	240 m^2	3m	0.6m x 0.7m	0.3m x 0.6m	125mm
	Composite	93.5 m	240 m^2	3m	0.6m x 0.7m (Encased ISHB 400-1)	ISMB 350 with shear Connector	125mm

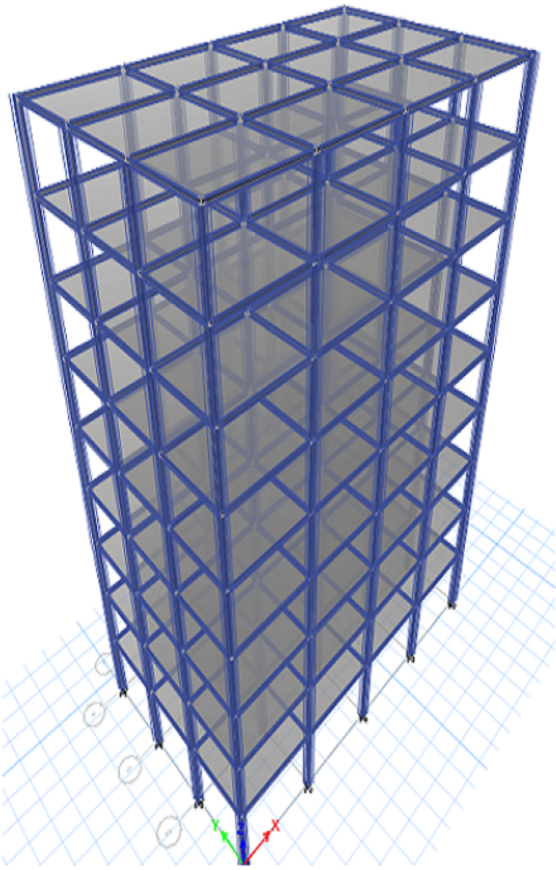

Figure 5: 3D view G+8 Model

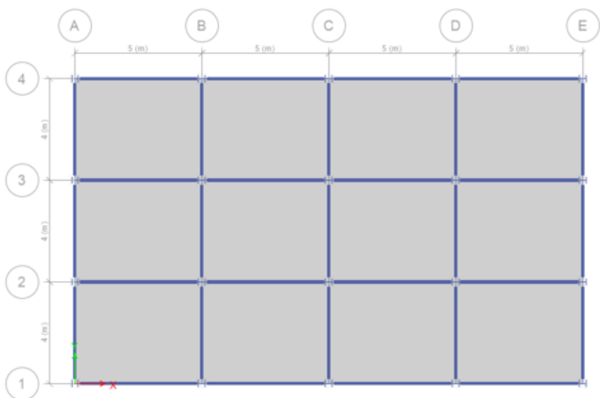

Figure 6: Plan area for all models

4.1 Material Properties

Concrete properties:[7]

- Characteristic strength of concrete(fck)=30Mpa and 25Mpa
- Modulus of elasticity (Ec)=5000 sqrt fck Mpa
- Density of concrete = 25 KN/m3
- Poisson's Ratio (u) = 0.2

Reinforcement properties:

- Minimum Yield Strength(Fy)= 500 MPa
- Modulus of elasticity (Es)=200,000 Mpa
- Density of steel = 7850 KN/m3
- Poisson's Ratio (u) = 0.3

Steel properties:[8]

- Minimum Yield Strength(Fy)= 250 MPa
- Modulus of elasticity (Es)=210,000 Mpa
- Density of steel = 7850 KN/m3
- Poisson's Ratio (u) = 0.3

4.2 Seismic Parameter: [9]

- Zone factor, Z = 0.36 (Zone V)
- Importance Factor I = 1.0
- Response Reduction factor, R = 5
- Soil type = Medium Soil
- Damping Coefficient = 0.05

5. Result and Discussion

5.1 Dead Load

Table 2: Dead Load

S.N.	Buildings	RCC (KN)	Composite (KN)	Change in percentage
1	G+5	16302.28	14914.888	9%
2	G+8	25461.02	22867.8008	10%
3	G+11	34614.09	30541.937	12%
4	G+15	47968.4	42017.8584	12%
5	G+20	64507.95	56699.3758	12%
6	G+30	106079.5	92227.9116	13%

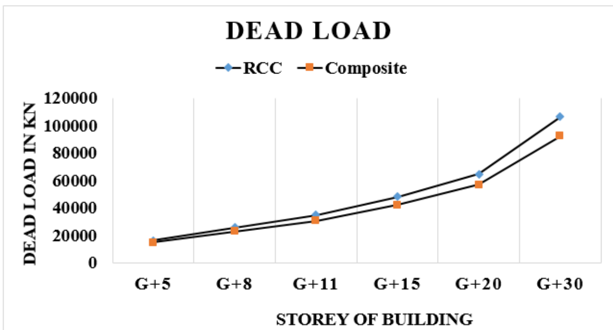

Figure 7: Dead load comparison between RCC and composite

5.2 Time Period

Table 3: Time Period

Time Period (Sec)		X- direction		Y- direction	
S.N.	Building	RCC	Composite	RCC	Composite
1	G+5	1.395	2.043	1.522	1.96
2	G+8	1.918	3.001	1.837	2.842
3	G+11	2.372	4.047	2.393	3.847
4	G+15	2.762	4.375	2.787	4.208
5	G+20	3.603	5.747	3.622	5.531
6	G+30	3.717	6.099	4.131	6.106

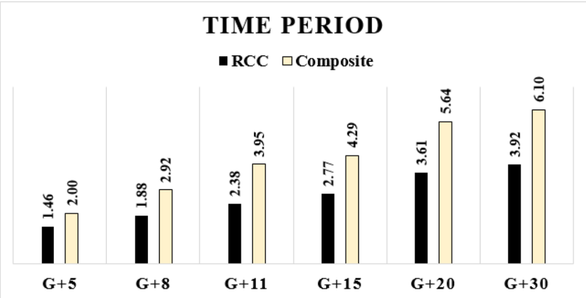

Figure 8: Time period

5.3 Base shear

Table 4: Base Shear

		X- dir		Y- dir		X- dir	Y- dir	Avg.
S.N.	Building	RCC	Composite	RCC	Composite	% Change		% Change
1	G+5	606.1889	380.54965	555.8476	396.6322	37%	29%	33%
2	G+8	684.4781	397.01	714.1514	419.27	42%	41%	42%
3	G+11	754.9313	398.23	748.5964	414.14	47%	45%	46%
4	G+15	897.5577	547.2164	889.3076	547.2164	39%	38%	39%
5	G+20	924.4193	737.4013	919.5375	737.4013	20%	20%	20%
6	G+30	1465.775	1192.4547	1362.2154	1192.4547	19%	12%	16%

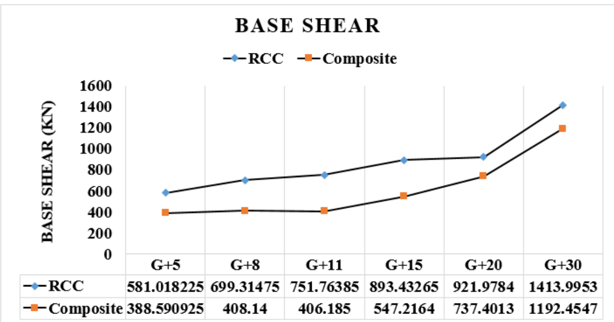

Figure 9: Base Shear comparison between RCC and composite

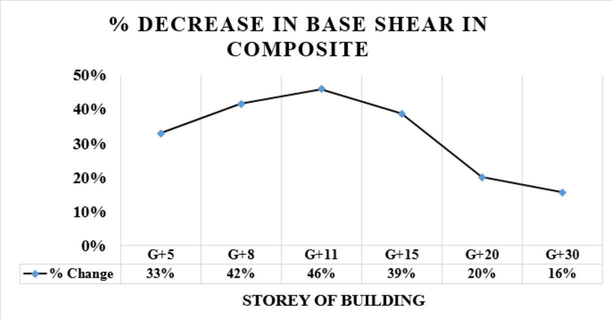

Figure 10: percentage of Base shear variation

5.4 Max. Story displacement

Table 5: Max. Story displacement

		X- dir		Y- dir		X- dir	Y-dir	Avg.
S.N.	Building	RCC	Composite	RCC	Composite	% Change		% Change
1	G+5	24.698	37.44	22.048	35.009	52%	59%	55%
2	G+8	34.709	51.7	30.974	55.696	49%	80%	64%
3	G+11	40.551	65.744	40.842	68.443	62%	68%	65%
4	G+15	48.261	74.835	52.202	79.069	55%	51%	53%
5	G+20	68.561	119.457	67.977	136.679	74%	101%	88%
6	G+30	70.432	128.203	70.888	147.256	82%	108%	95%

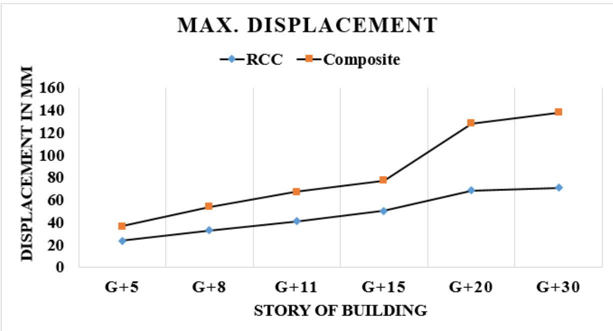

Figure 11: Max Displacements of buildings

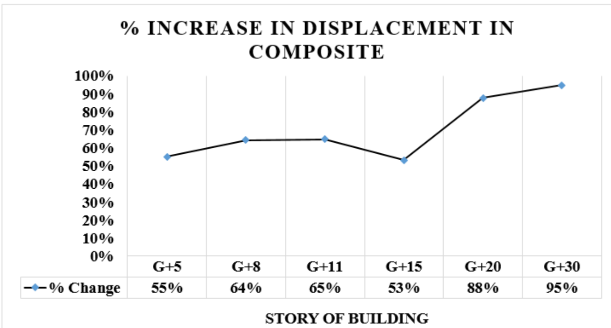

Figure 12: percentage of displacement variation

5.5 Max. Story drift

Table 6: Max. Story drift

		X- dir		Y- dir		X- dir	Y-dir	Avg.
S.N.	Building	RCC	Composite	RCC	Composite	% Change		% Change
1	G+5	5.646	8.154	5.831	8.463	44%	45%	45%
2	G+8	5.445	7.506	5.412	8.658	38%	60%	49%
3	G+11	4.974	8.109	4.992	7.695	63%	54%	59%
4	G+15	4.206	6.963	4.755	7.092	66%	49%	57%
5	G+20	4.515	11.031	4.326	9.588	144%	122%	133%
6	G+30	3.159	8.982	3.252	6.525	184%	101%	142%

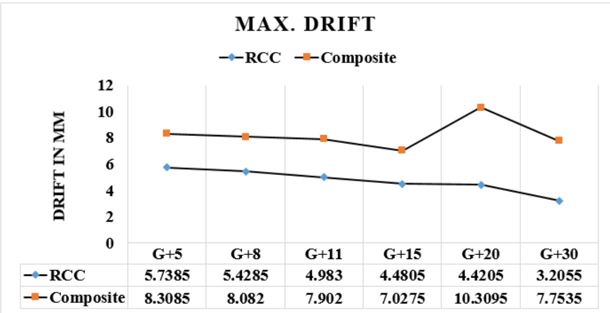

Figure 13: Max Drift of buildings

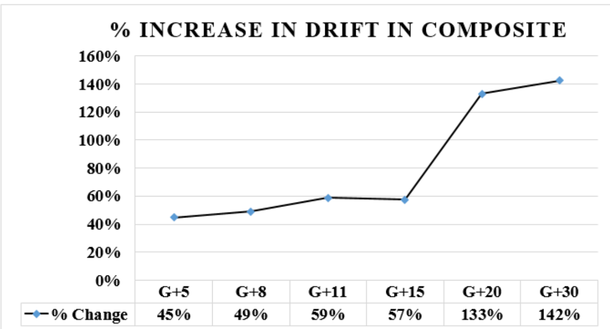

Figure 14: percentage of drift variation

5.6 Overturning Moment

Table 7: Max. Overturning Moment

		X- dir		Y- dir		X- dir	Y-dir	Avg.
S.N.	Building	RCC	Composite	RCC	Composite	% Change		% Change
1	G+5	5853.175	4835.9575	6883.804	6201.302	17%	10%	14%
2	G+8	12256.41	7762.4106	16421.82	6729.2028	37%	59%	48%
3	G+11	16198.81	8909.8235	21917.13	7398.4453	45%	66%	56%
4	G+15	26908.98	15539.076	31021.9	11827.8663	42%	62%	52%
5	G+20	34333.02	27509.83	32993.63	21185.2317	20%	36%	28%
6	G+30	55450.6	54123.086	72936.94	45829.7183	2%	37%	20%

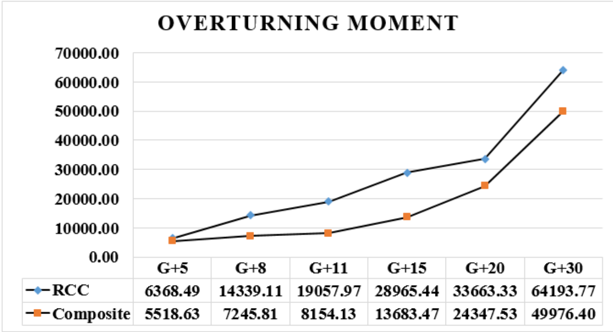

Figure 15: Overturning Moment of various buildings

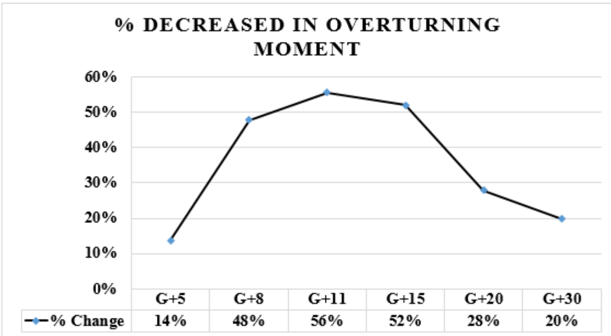

Figure 16: percentage of overturning moment variation

5.7 Axial Force in Column

Table 8: Axial Force in Column

	G+5	G+8	G+11	G+15	G+20	G+30
RCC (KN)	105.114	295.235	386.004	524.33	613.292	1309.75
Composite (KN)	90.3313	129.8	149.915	253.222	516.22	1279.28

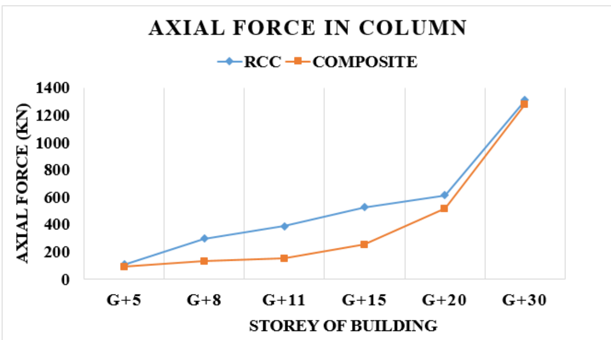

Figure 17: Axial force in columns

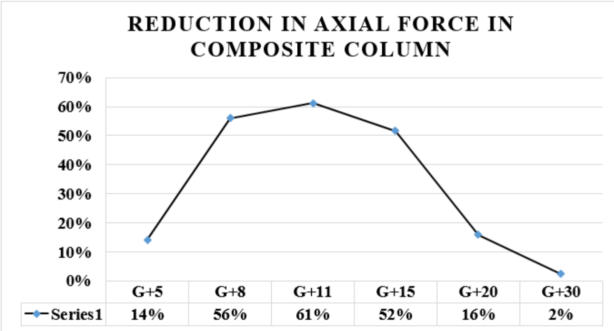

Figure 18: percentage of Axial force variation

5.8 Shear Force in Column

Table 9: Shear Force in Column

	G+5	G+8	G+11	G+15	G+20	G+30
RCC (KN)	33.8922	38.2419	38.1705	50.3974	49.2205	77.1801
Composite (KN)	20.0464	20.401	18.6046	29.3318	39.8457	64.421

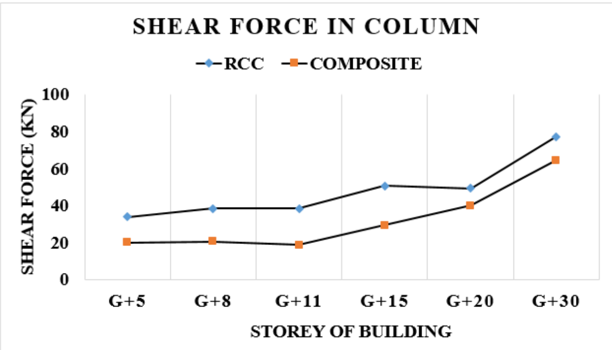

Figure 19: Axial force in columns

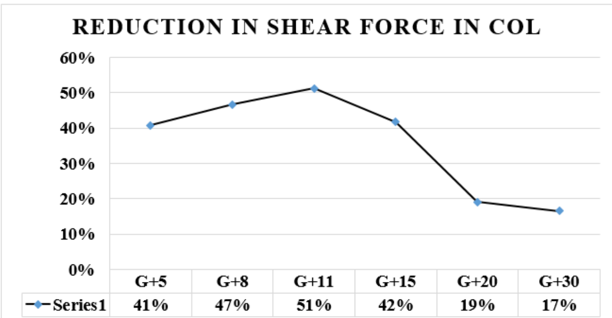

Figure 20: percentage of shear force variation

5.9 Bending Moment in Column

Table 10: Bending Moment in Column

	G+5	G+8	G+11	G+15	G+20	G+30
RCC (KNm)	74.409	86.6848	101.725	137.667	155.91	216.616
Composite (KNm)	58.8568	68.8072	66.5284	105.305	165.534	313.693

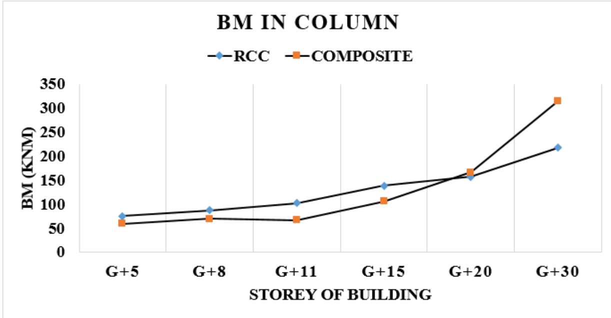

Figure 21: Bending Moment in columns

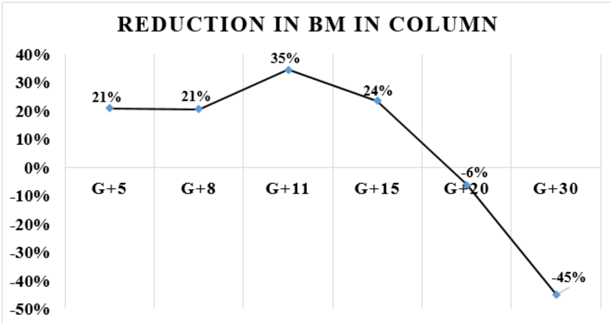

Figure 22: percentage of BM variation

5.10 Reduction in displacement due to shear wall

Table 11: Variation in displacement due shear wall

		Without Shear Wall				With Shear Wall			
		X- dir		Y- dir		X- dir		Y- dir	
S.N.	**Building**	**RCC**	**Composite**	**RCC**	**Composite**	**RCC'**	**Composite'**	**RCC'**	**Composite'**
1	G+5	24.698	37.44	22.048	35.009	14.187	15.17	14.666	16.111
2	G+8	34.709	51.7	30.974	55.696	22.351	26.006	35.14	46.681
3	G+11	40.551	65.744	40.842	68.443	29.608	32.637	33.726	54.216
4	G+15	48.261	74.835	52.202	79.069	31.961	35.524	41.355	54.578
5	G+20	68.561	119.457	67.977	136.679	41.164	57.413	60.385	63.132
6	G+30	70.432	128.203	70.888	147.256	67.58	104.376	66.667	112.247

RCC (% change)		Composite (% change)		RCC	Composite
X- dir	**Y-dir**	**X- dir**	**Y-dir**	**Average**	**Average**
43%	33%	59%	54%	38%	57%
36%	-13%	50%	16%	11%	33%
27%	17%	50%	21%	22%	36%
34%	21%	53%	31%	27%	42%
40%	11%	52%	54%	26%	53%
4%	6%	19%	24%	5%	21%

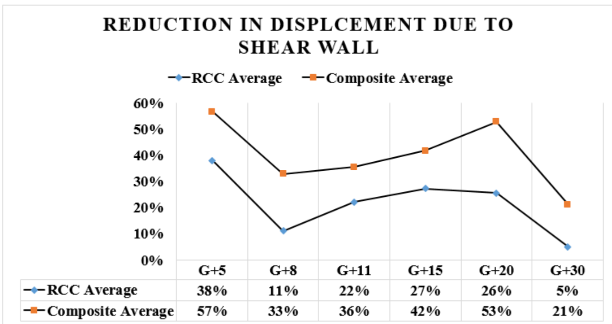

Figure 23: Reduction in displacement due to shear wall

6. Discussion

1. The dead load of the RCC structure is more than the composite structure. And percentage of the dead load decreases in composite structure (than RCC structure)is increases with height of building.

2. The time period for RCC building is less than Composite building. It is because RCC has more weight and less ductile than composite building.

3. The base shear of RCC structure has more than the composite structure. It is because RCC structure has more weight and less flexible than the composite structure and the base shear is directly proportional to the weight of the structure. The percentage of decrease in base shear in composite structure is vary with height of the structure. Based on this G+11-story range is best suited for composite structure.

4. Displacement in composite structure is more as compared to RCC Structure. This is because; composite structure is more flexible as compared to RCC structure. The variation of displacement in RCC and composite building is smooth up to the G+15 story building. After that, variation is increased enormously in composite building.

5. Drift of composite structure is more than RCC one. Also, drift increased in composite up to G+15 story is smooth after that it is enormously increased. It shows the necessity of shear wall especially in composite structure after G+15-story building.

6. Overturning moment of composite structure is less as compared to RCC Structure. This is because; composite structure have less base shear as compared to RCC structure. The percentage of increase in overturning moment in composite structure is vary with height of the structure. Based on this G+ 11-story range is best suited for composite structure.

7. Axial force in composite column is less than the rcc one which shows effectiveness of composite column. But for G+5 and G+30 it is not so effective as axial force is nearly same for both rcc and composite column. from this point of view composite structure neither suitable for low-rise building nor for very high-rise building until varying the section size. Based on this G+ 11-story range is best suited for composite structure.

8. Shear force for the composite column is less than the rcc column and G+11-story range is best suited for composite structure.

9. Bending moment in column up to G+15 story is lead by rcc but after that it is lead by composite column. On this basis it seen that up to G+15 story only composite column is effective than rcc one.

10. After introducing the shear wall in both rcc and composite structure, effectiveness of shear wall in composite structure is 15 to 25 percent more as compare to shear wall in RCC structure.

7. Conclusion

1. Total weight of the composite framed structure is less than RCC frame structure, it is subjected to less amount of forces induced due to the earthquake. As the dead weight of a composite structure is less compared to RCC structure, it helps in reducing foundation cost.

2. For the low-rise building (below $G+5$) and high-rise building (above $G+20$) composite structure is not so much suitable. The best-suited range for the composite structure is found to be $G+8$ to $G+15$.

3. The node displacement and deflection in composite structure is more compared to RCC structure but the deflection is within permissible limit.

4. As for same axial forces, shear forces, bending moments up to certain limit for composite structure having same specification and loading, we designed smaller section for same loading in beam and column.

5. Effectiveness of shear wall in composite structure found to be more than RCC structure.

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