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ANALYSIS AND DESIGN OF COMPOSITE STRUCTURES WITH STEEL CASTELLATED BEAMS

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Abstract: Steel-concrete composite construction has gained wide acceptance worldwide as an alternative to pure steel and pure concrete construction. Reinforced concrete members are used in the framing system for most of the buildings since this is the most convenient and economic system for low-rise buildings. However, for medium to high-rise buildings this type of structure is no longer economical because of increased dead load, less stiffness, span restriction and hazardous formwork. Steel-concrete composite frame system can provide an effective and economic solution to most of these problems in medium to high-rise buildings. An attempt has been made in this study to explore cost effectiveness of composite construction.

Steel–concrete composite construction with castellated steel beams for large span member is economical in construction, which also saves lot of time and money in construction, which will help the planners to meet the demand with minimum time. This technology provides more carpet area than any other type of construction. Composite construction also enhances life expectancy of structures.

Index Terms - R.C.C., Steel, Composite, E-tabs, Cost Analysis

I. INTRODUCTION

In India, most of the building structures fall under the category of low-rise buildings. So, for these structures reinforced concrete members are used widely because the construction becomes quite convenient and economical in nature. Structural engineers are facing the challenge of striving for the most efficient and economical design solution while ensuring that the final design of a building must be serviceable for its intended function, habitable for its occupants and safe over its design lifetime. As our country is one of the fastest growing country across the globe and need of shelter with higher land cost in major cities where further horizontal expansion is not much possible due to space shortage, we are left with the solution of vertical expansion. Steel-concrete composite construction has gained wide acceptance worldwide as an alternative to pure steel and pure concrete construction. Steel-concrete composite frame system can provide an effective and economic solution to most of these problems in medium to high-rise buildings and for buildings having longer spans. An attempt has been made in this study to explore the cost effectiveness of composite construction for high-rise buildings and for the long span composite system.

In due consideration of the above fact, this project has been envisaged which consists of analysis and design of composite structures with steel solid beams using Steel-Concrete composite option. The project also involves analysis and design of R.C.C structure, composite structure with steel beams so that a cost comparison can be made between a Reinforced concrete structures, Composite structures with steel solid beams.

- **Composite Structures**

Composite Steel-Concrete Structures are used widely in modern bridge and building construction. A composite member is formed when a steel component, such as an I beam is attached to a concrete component, such as a floor slab or bridge deck as shown in figure 1.1. Composite beams are similar to concrete T-beam where flange of the T-beam is made up of concrete and web of beam is made up of steel section. In such a composite T-beam, the comparatively high strength of the concrete in compression complements the high strength of the steel in tension. The fact that each material is used to the fullest advantage makes composite Steel-Concrete construction very efficient and economical. However, the real attraction of such construction is based on having an efficient connection of the Steel to the Concrete, and it is this connection that allows a transfer of forces and gives composite members their unique behavior.

Composite beam, Slab and Shear Connectors A steel concrete composite beam consists of a steel beam, over which a reinforced concrete slab is cast with shear connectors. The composite action reduces the beam depth. Rolled steel sections themselves are found adequate frequently for buildings and built up girders are generally unnecessary. The composite beam can also be constructed with profiled sheeting with concrete topping or with cast in place or precast reinforced concrete slab.

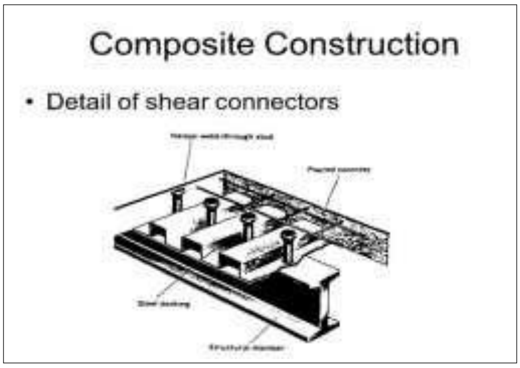

Chart -1: Composite beams

- **Need of steel in construction:**

In building construction, role of steel is same as that of bones in a living being. Steel is very advantageous because it:

- Offers considerable flexibility in design and is easy for fabrication.
- Facilities faster construction scheduling of projects.
- Enables easy construction scheduling even in congested sites.
- Permits large span construction repair/modification.
- Is an ideal material in earthquake prone locations due to high strength, Stiffness, ductility.
- Is environment friendly and fully recyclable on replacement.

- **Advantages of composite construction**

The most effective utilization of steel and concrete is achieved:

- Keeping the span and loading unaltered, a more economical steel section (in terms of depth and weight) is achievable in composite construction compared with conventional non-composite construction.
- As the depth of beam reduces, the construction depth reduces, resulting in enhanced headroom.
- Encased steel beam sections have improved fire resistance and corrosion.
- Considerable flexibility in design, pre-fabrication and construction scheduling in congested areas.

II. LITERATURE REVIEW

- Liu et al. (2003) have studied a comprehensive finite element investigation on steel beams with web openings of various shapes and sizes and the primary structural characteristics of those steel beams are examined in detail. It is found that all steel beams with large web openings of various shapes behave similarly under a wide range of applied moments and shear forces. The failure modes are common in all beams, and the yield patterns of those perforated sections at failure are also similar to each other.
- Lagaros et al. (2006) have considered characteristic test example and showed that a quantifiable reduction in the weight ofthe structure is accomplished by allowing web openings in the beams of the structure without reducing structural strengthor serviceability requirements.
- Koppad and Itti (2013) Studied steel concrete composite with Reinforced concrete option which is considered for comparative study of B+G+15 storey of residential building which is situated in earthquake zone 3 and for earthquake loading, the provisions of IS:1893(Part1)-2002 is considered. For modelling of composite and Reinforced concrete structures, STAAD-proV8i software is used.
- Shah and Pajgade (2013) discussed analysis and design of G+15 stories R.C.C. Steel and Composite Building under effect of wind and earthquake, it proves that steel-concrete composite building is better option and it is more economical.

III. METHODOLOGY

- METHODS OF ELASTIC ANALYSIS
  - Seismic Engineering is a sub discipline of the broader category of Structural engineering. Its main objectives are
  - To understand interaction of structures with the shaky ground.
  - To foresee the consequences of possible earthquakes.
  - To design, construct and maintain structures to perform at earthquake exposure up to the expectations and in completion with building codes.
- Structural analysis methods can be divided into the following categories:
  - Equivalent Static Analysis
  - Response Spectrum method
  - Time history method
  - Linear Dynamic Analysis

- Equivalent Static Method

Seismic analysis of most structures is still carried out on the assumption that the lateral (horizontal) force is equivalent to the actual (dynamic) loading. This method requires less effort because, except for the fundamental period, the periods and shapes of higher natural modes of vibration are not required. The base shear which is the total horizontal force on the structure is calculated on the basis of the structure ‘s mass, its fundamental period of vibration, and corresponding shape. The base shear is distributed along the height of the structure, in terms of lateral force, according to the code formula. Planar models appropriate for each of the two orthogonal lateral directions are analyzed separately, the results of the two analyses and the various effects, including those due to torsional motions of the structure, are combined. This method is usually conservative for low to medium-height buildings with a regular configuration.

IV. PROBLEM FORMULATION

The plan dimensions of buildings are shown in table below. The plan view of building, elevation of different frames is shown in figures below.

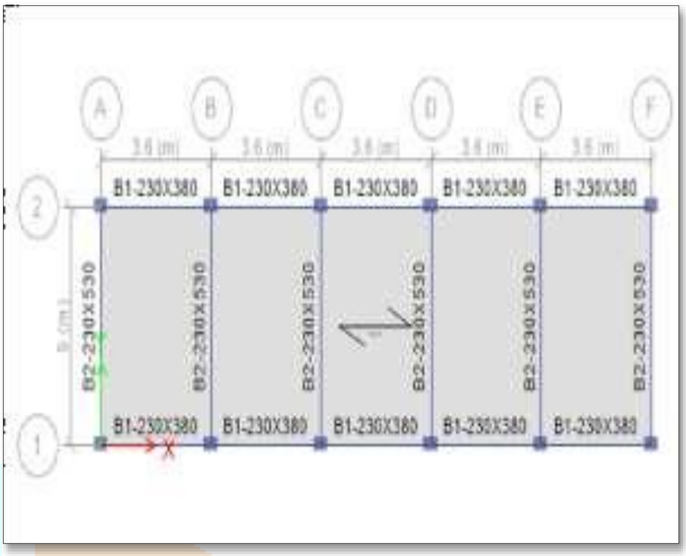

Chart -2: Plan of Building

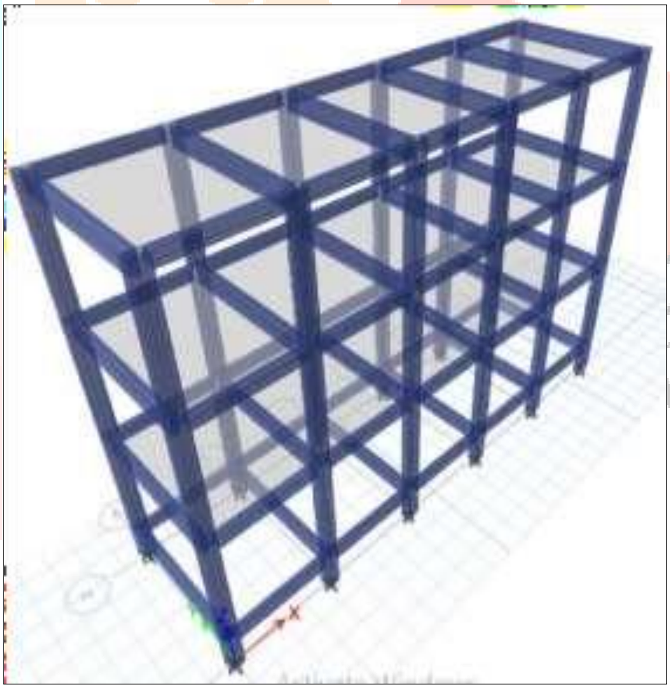

Chart -3: 3D View of Building

Table-1: Detail Features of Building

Sr. No.	Parameters	Values
1	Material used	Concrete-M20 Reinforcement Fe-500 Structural Steel Fy-250MPa
2	Plan Dimension	Y = 5m Y = 7.5m Y = 10m Y = 12.5m Y = 15m
3	Height of each Storey	4m
4	Density of concrete	$25kN/m^3$
5	Poisson Ratio	0.2-concrete 0.3-steel
6	Density of masonry	$20kN/m^3$
7	Damping	5%-R.C.C. 2%-Steel 2%-Composite
8	Seismic zone	III
9	Importance Factor	1
10	Response Reduction Factor	5
11	Foundation soil	Medium
12	Slab thickness	130mm
13	Wall thickness	230mm
14	Floor Finish	$1kN/m^2$
15	Live load	$3\ kN/m^2$
16	Earthquake load	As per IS 1893-2002

V. RESULT AND CONCLUSION

- BASE SHEAR (kN):

It is the total design lateral force at the base of the structure. Variation of Base Shear in X and Y direction has been studied. Variation of base shear in X-direction and Y -direction for Reinforced concrete structures, composite structures without opening and composite structures with opening are shown in Table-2

Table-2: Variation of Base Shear (KN) in X-Direction and Y-Direction

Trials	Direction	R.C.C. Structure	Composite Structure Without opening	Composite Structure With opening
Trial 1 (Y = 5m)	EQx	142.06	89.54 (-36.97%)	109.08 (-23.21%)
	EQy	120.37	62.93 (-47.71%)	72.60 (-39.67%)
Trial 2 (Y = 7.5m)	EQx	217.41	141.64 (-34.85%)	130.39 (-40.02%)
	EQy	181.61	134.98 (-25.61%)	128.30 (-29.35%)
Trial 3 (Y = 10m)	EQx	232.50	161.76 (-30.42%)	168.39 (-27.57%)
	EQy	241.89	194.81 (-19.46%)	197.46 (-18.36%)
Trial 4 (Y = 12.5m)	EQx	256.77	215.42 (-16.10%)	197.85 (-22.94%)
	EQy	270.47	251.81 (-6.89%)	234.61 (-13.25%)
Trial 5 (Y = 15m)	EQx	313.43	264.78 (-15.52%)	243.31 (-22.37%)
	EQy	330.62	303.97 (-8.06%)	285.01 (-13.79%)

- COLUMN AXIAL FORCES FOR 1.5 (DL+LL)

Table-3: Variation of Intermediate Column Axial Forces (kN)for 1.5 (DL+LL)

Trials	Floor	R.C.C. structure	Composite structure without opening	Composite structure with opening
1 (Y=5m)	G.F.	526.82	455.28 (-13.57%)	574.67 (+8.30%)
	F.F.	394.98	296.16 (-25.01%)	424.76 (+7%)
	S.F.	162.55	137.03 (-15.69%)	175.08 (+7.11%)
2 (Y=7.5m)	G.F.	737.21	636.41 (-13.67%)	601.38 (-18.42%)
	F.F.	489.71	389.81 (-20.39%)	367.64 (-24.93%)
	S.F.	241.63	143.11 (-40.77%)	133.78 (-44.63%)
3 (Y=10m)	G.F.	1014.25	806.77 (-20.45%)	634.42 (-37.44%)
	F.F.	673.96	496.75 (-26.17%)	385.95 (-42.54%)

	S.F.	333.18	186.63 (-43.98%)	137.54 (-58.71%)
4 (Y=12.5m)	G.F.	1099.71	978.37 (-11.03%)	944.81 (-14.08%)
	F.F.	689.69	601.86 (-12.73%)	584.86 (-15.19%)
	S.F.	279.29	233.62 (-16.35%)	224.72 (-19.55%)
5 (Y=15m)	G.F.	1318.57	1189.22 (-9.80%)	1120.16 (-15.04%)
	F.F.	830.68	737.55 (-11.21%)	696.2 (-16.19%)
	S.F.	342.44	285.68 (-16.52%)	272.05 (-20.55%)

- Column Axial Forces for 1.2 (DL+LL+EQy)

Table-4: Variation of Intermediate Column Axial Forces (kN)For 1.2 (DL+LL+EQy)

Trials	Floor	R.C.C. structure	Composite structure without opening	Composite structure with opening
1 (Y=5m)	G.F.	522.60	385.07 (-26.3%)	535.85 (+3%)
	F.F.	332.05	248.34 (-25.2%)	342.95 (+3.5%)
	S.F.	134.86	113.48 (-15.85%)	141.23 (+4.5%)
2 (Y=7.5m)	G.F.	561.38	482.86 (-14.01%)	456.00 (-18.77%)
	F.F.	376.33	298.10 (-20.78%)	281.19 (-25.28%)
	S.F.	188.31	110.28 (-41.43%)	103.24 (-46.73%)
3 (Y=10m)	G.F.	690.68	616.99 (-10.66%)	483.64 (-30.04%)
	F.F.	435.48	382.22 (-12.23%)	296.46 (-31.92%)
	S.F.	176.03	144.49 (-17.91%)	106.33 (-39.59%)
4 (Y=12.5m)	G.F.	847.06	753.01 (-11.10%)	728.02 (-14.05%)
	F.F.	534.43	465.75 (-12.85%)	453.14 (-15.21%)
	S.F.	218.11	181.75 (-16.67%)	175.20 (-19.67%)
5 (Y=15m)	G.F.	1021.53	921.62 (-9.78%)	867.95 (-15.03%)
	F.F.	646.72	574.23 (-11.20%)	541.86 (-16.21%)
	S.F.	268.34	223.62 (-16.66%)	212.84 (-20.68%)

➢ COST ANALYSIS FOR R.C.C., COMPOSITE STRUCTURE WITH AND WITHOUT WEB OPENING:

Table-5: Variation of cost for R.C.C. Structures

Trials	Beams				Columns				Total cost		Total Cost
	Vol. of concrete (m^3)	Cost of concrete (Rs.)	Wt. of steel (Kg)	Cost of steel (Rs.)	Vol. of concrete (m^3)	Cost of concrete (Rs.)	Wt. of steel (Kg)	Cost of steel (Rs.)	Cost of concrete (Rs.)	Cost of steel (Rs.)	
1 (Y=5m)	21	73500	1855	92750	22	77000	2836	141800	150500	234550	**385050**
2 (Y=7.5m)	38	133000	3800	190000	26	91000	4900	245000	224000	435000	**659000**
3 (Y=10m)	73	255500	5960	298000	42	147000	5800	290000	402500	588000	**990500**
4 (Y=12.5m)	94	329000	9900	495000	46	161000	11200	560000	490000	1055000	**1545000**
5 (Y=15m)	121	423500	16565	828250	58	203000	14880	744000	626500	1572250	**2198750**

Table-6: Variation of Cost for Composite Structure with Solid Web Steel Beam

Trials	Beam		Columns				Total cost		Total Cost
	Wt. of steel (Kg)	Cost of steel (Rs.)	Vol. of concrete (m3)	Cost of concrete (Rs.)	Wt. of steel (Kg)	Cost of steel (Rs.)	Cost of concrete (Rs.)	Cost of steel (Rs.)	
1 (Y=5m)	6840	342000	21	73500	5000	250000	73500	592000	**665500**
2 (Y=7.5m)	10570.8	528540	25	87500	5600	280000	87500	808540	**896040**
3 (Y=10m)	15164.5	758225	40	140000	5600	280000	140000	1038225	**1178225**
4 (Y=12.5m)	18624.8	931240	40	140000	8700	435000	140000	1366240	**1506240**
5 (Y=15m)	23776.8	1188840	58	203000	12297	614850	203000	1803690	**2006690**

Table-7: Variation of Cost for Composite Structure with Castellated Steel Beam

Trials	Beam		Columns				Total cost		Total Cost
	Wt. of steel (Kg)	Cost of steel (Rs.)	Vol. of concrete (m^3)	Cost of concrete (Rs.)	Wt. of steel (Kg)	Cost of steel (Rs.)	Cost of concrete (Rs.)	Cost of steel (Rs.)	
1 (Y=5m)	4673.6	233680	21	73500	5000	250000	73500	483680	**557180**
2 (Y=7.5m)	7353.6	367680	25	87500	5600	280000	87500	647680	**735180**
3 (Y=10m)	10609.6	530480	40	140000	5600	280000	140000	810480	**950480**
4 (Y=12.5m)	14027.6	701380	40	140000	8700	435000	140000	1136380	**1276380**
5 (Y=15m)	18369.6	918480	58	203000	12297	614850	203000	1533330	**1736330**

Table-8: Variation in cost of Structures

Trials	R.C.C. structure	Composite structure with solid sections	Composite structure with web openings
	(Lakhs)	(Lakhs)	(Lakhs)
Trial 1 (Y=5m)	3.85	6.65	5.57
Trial 2 (Y=7.5m)	6.59	8.96	7.35
Trial 3 (Y=10m)	9.90	11.78	9.50
Trial 4 (Y=12.5m)	15.45	15.06	12.76
Trial 5 (Y=15m)	21.98	20.06	17.36

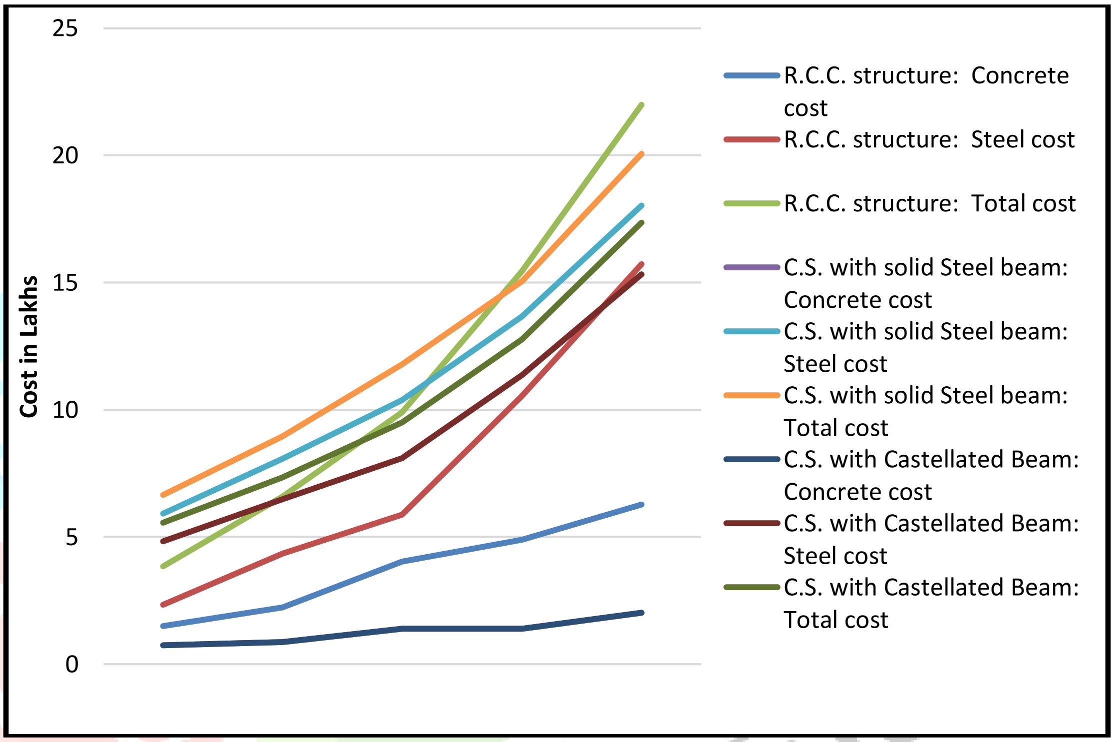

Chart -4: Cost Comparison of Various Types of Structures

➢ FINAL OBSERVATIONS

- R.C.C. structures give more base shear than the Composite Structures due to more mass of R.C.C. beams as Compared to Steel beams. The percentage difference in X-direction base shear is around 35% for smaller span and it is around 15% for larger span. Similarly, for Y-direction these percentage differences in base shear are around 45% for smaller span and 30% for larger span respectively.
- For medium spans (7.5m) and for large span (≥10m) the beam moments in Structures having steel beams are reduced compared to R.C.C. Structures. It is primarily due to drastic reduction in self weight of steel beams as compared to R.C.C. beams. The percentage reduction of support moment is in the range of 10%-16% and that of moment at centre is 8%-14% for solid web steel beams. These percentage difference are 2%-22% at support and 20%-34% at centre for castellated beams.
- Beam shear forces in composite structure with and without opening have reduced for composite structure as compared to that of reinforced concrete structure mainly because of the size and weight of R.C.C. section as compared to steel beams. The reduction in Shear Force is 8%-15% for solid web steel beams and 12%-25% for Castellated beams as compared to R.C.C. Structure. This percentage reduction is similar to percentage reduction in support moments.
- Column forces for both Composite structure without opening and composite structure with opening are reduced due to reduction in the sizes and weight of the beams and columns compared to that of reinforced concrete structure.The percentage reduction is 10%-20% for ground floor and first floor columns and 15%-40% for top floor column for solid web beams. These percentages are 14%-37% for ground floor and first floor columns and 20%-60% for top floor columns for castellated beams.
- Column moments for both Composite structure without opening and composite structure with opening are reduced due to reduction in the sizes of the beams and columns compared to that of reinforced concrete structures. However, the percentage reduction in moments is less as compared to the reduction in axial forces. These percentage reductions are 1%-5% for ground floor columns, 2%-8% for first floor and 12%-30% for second floor

columns for solid web beams. These percentages are 2%-7%, 5%-9% and 12%-30% respectively for frames with castellated members.

- R.C.C. Structures are economical up to moderate spans i.e. 7.5m. Steel Beams with Solid Webs are economical for large spans i.e. 10m and above as compared to R.C.C. beams. However, from 10m span Steel Beams with perforations are more economical as compared to R.C.C. structure as well as Steel beams with solid web.

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