Cost Comparison of R.C.C, Steel and Composite Structures

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Abstract— Reinforced concrete structures are mostly used in India since this is the most convenient & economic system for low-rise buildings. However, for medium to high-rise buildings this type of structure is no longer economic because of increased dead load, less stiffness, span restriction and hazardous formwork. So the Structural engineers are facing the challenge of striving for the most efficient and economical design solution. Also Wind & Earthquake engineering should be extended to the design of wind & earthquake sensitive tall buildings. Use of composite material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies. In India, many consulting engineers are reluctant to accept the use of composite steel-concrete structure because of its unfamiliarity and complexity in its analysis and design. But literature says that if properly configured, then composite steel-concrete system can provide extremely economical structural systems with high durability, rapid erection and superior seismic performance characteristics. This paper discusses comparison of cost effectiveness of steel-concrete composite frames over traditional R.C.C and steel frames for building structures by analysis and design of G+15 stories R.C.C., Steel and Composite Building under effect of wind and earthquake using STAAD PRO, it proves that steel-concrete composite building is better option.

Key words: Composite Structures, R.C.C

I. INTRODUCTION

An important and economic combination of construction materials is that of steel and concrete, with applications in medium to high-rise buildings as well as bridges. Steel concrete composite system has several advantages over traditional reinforced concrete or steel structures: these include high strength-to-weight ratios, structural integrity, durable finishes, dimensional stability and sound absorption. These advantages have led to a substantial increase in the use of composite construction all over the world in recent years. However, in a developing country like Bangladesh this innovative technology is not practiced widely. Most of the buildings constructed in Bangladesh so far are low rise structures which are not economically favourable for composite construction point of view. Due to increased land price and population growth medium to high-rise structures are gaining popularity and approvals from Government. In Bangladesh reinforced concrete members are mostly used in the framing system for most of the buildings since this is the most convenient & economic system for low-rise buildings. However, for medium to high-rise buildings this type of structure is no longer economic 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 the feasibility of composite construction in Bangladesh for medium to high-rise buildings.

A. Objective

The objectives of this study are,

1) To provide a brief description to various components of steel concrete framing system for buildings.
2) To investigate the cost effectiveness of steel-concrete composite frames over traditional reinforced concrete frames and steel frames for building structures.

II. COMPOSITE CONSTRUCTION

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.It can also be defined as the structures in which composite sections made up of two different types of materials such as steel and concrete are used for beams, and columns. Numbers of the studies are carried out on composite construction techniques by different researchers in different parts of the world and found it to be better earthquake resistant and more economical as compared to RCC construction.

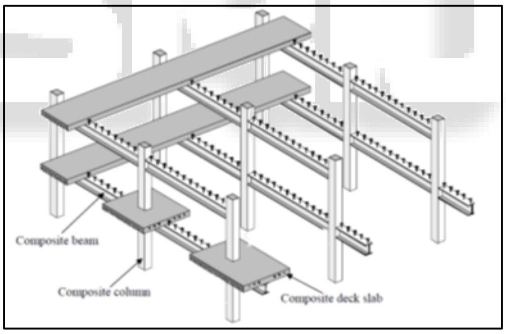

Fig. 1: Composite Structures

A. Elements of Composite Construction

The primary structural components use in composite construction consists of the following elements.

- Shear connector
- Composite slab
- Composite beam
- Composite column

1) Shear Connectors

The total shear force at the interface between concrete slab and steel beam is approximately eight times the total load carried by the beam. Therefore, mechanical shear connectors are required at the steel-concrete interface. These connectors are designed to (a) transmit longitudinal shear along the interface, and (b) Prevent separation of steel beam and concrete slab at the interface.

Following are the commonly used types of shear connectors as per IS: 11384-1985

- rigid shear connectors,

- flexible shear connectors
- anchorage shear connectors

2) Composite Slab

Traditional steel-concrete floors consist of rolled or built-up structural steel beams and cast in-situ concrete floors connected together using shear connectors in such a manner that they would act monolithically .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 girder.

More recently, composite floors using profiled sheet decking have become very popular in the West for high rise office buildings. Composite deck slabs are particularly competitive where the concrete floor has to be completed quickly and where medium level of fire protection to steel work is sufficient. However, composite slabs wit profiled decking are unsuitable when there is heavy concentrated loading or dynamic loading in structures such as bridges. The alternative composite floor in such cases consists of reinforced or pre-stressed slab over steel beams connected together to act monolithically.

Advantages of using composite floors with profiled steel decking are

- Savings in steel weight are typically 30% to 50% over non-composite construction.
- Greater Stiffness of composite beams results in shallower depths for the same span. Hence lower storeys heights are adequate resulting in savings in cladding costs, reduction in wind loading and savings in foundation costs.
- Faster rate of construction.

3) Composite Beams

A steel concrete composite beam consists of a steel beam, over which a reinforced concrete slab is cast with shear connectors. In conventional composite construction, concrete slabs rest over steel beams and are supported by them. Under load these two components act independently and a relative slip occurs at the interface if there is no connection between them. With the help of a deliberate and appropriate connection provided between them can be eliminated.

4) Composite Column

A steel concrete composite column is a compression member, comprising either of a concrete encased hot rolled steel section or a concrete filled hollow section of hot rolled steel. It is generally used as a load bearing member in a composite framed structure. Composite columns with fully and partially concrete encased steel sections concrete filled tubular section are generally used in composite construction.

III. BUILDING DETAILS

The building considered here is a commercial building. The plan dimension is 25.61mx15.92m. The study is carried out on the same building plan for both R.C.C and Composite construction. The basic loading on both types of structures are kept same.

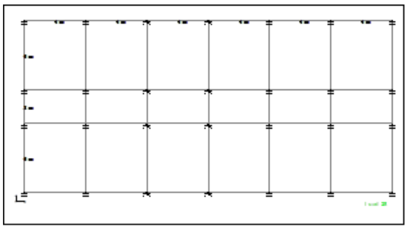

Fig. 1: Building Plans

Plan dimension	25.61mx15.92m
Total height of building.	56.5m.
Height of each storey	3.35m
Height of parapet	1.0m
Depth of foundation	2.9m
Size of beams 6.0m span	300x650
Size of beams 3.0m span	300x450
Size of beams 4.0m span	230x500
Size of outer columns	450x850
Size of internal columns	450x1100
Thickness of slab	140mm
Thickness of internal & external walls	230mm
Seismic zone	IV
Wind speed	39 m/s
Soil condition	hard soil
Importance factor	1.0
Zone factor	0.24
Floor finish	1.0 kN/m^2
Live load at all floors	4.0 kN/m^2
Grade of concrete	M30
Grade of reinforcing steel	Fe415
Density of concrete	25 kN/m^3
Density of brick	20 kN/m^3
Damping ratio	5%

Table 1: Data for Analysis of R.C.C. Structure

Plan dimension	25.61mx15.92m
Total height of building.	56.5m.
Height of each storey	3.35m
Height of parapet	1.0m
Depth of foundation	2.9m
Size of beams 6.0m span	W24x76
Size of beams 4.0m span	W21x48
Size of beams 3.0m span	W24x76
Size of columns upto 10th floor	W21x248
Size of columns for remaining floor	W18x158
Thickness of slab	140mm
Thickness of internal & external walls	230mm
Seismic zone	IV
Wind speed	39 m/s
Soil condition	hard soil
Importance factor	1.0
Zone factor	0.24
Floor finish	1.0 kN/m^2
Live load at all floors	4.0 kN/m^2
Grade of concrete	M30
Grade of reinforcing steel	Fe415
Density of steel	7850 kg/m^3
Density of brick	25 kN/m^3
Damping ratio	5%

Table 2: Data for Analysis of Steel Structure

Plan dimension	25.61mx15.92m
Total height of building.	56.5m.
Height of each storey	3.35m

Height of parapet	1.0m
Depth of foundation	2.9m
Size of beams 6.0m span	ISMB 450
Size of beams 4.0m span	ISMB 300
Size of beams 3.0m span	ISMB 200
Size of outer columns	320X580(ISMB 400)
Size of internal columns	330X630(ISMB 450)
Thickness of slab	140mm
Thickness of all walls	230mm
Seismic zone	IV
Wind speed	39 m/s
Soil condition	hard soil
Importance factor	1.0
Zone factor	0.24
Floor finish	1.0 kN/m^2
Live load at all floors	4.0 kN/m^2
Grade of concrete	M30
Grade of reinforcing steel	Fe415
Density of concrete	25 kN/m^3
Density of brick	20 kN/m^3
Damping ratio	5%

Table 3: Data for Analysis of Composite Structure

IV. ANALYSIS

The explained 3D building model is analyzed using Equivalent Static Method. The building models are then analyzed by the software Staad Pro. Different parameters such as deflection, shear force & bending moment are studied for the models. Seismic codes are unique to a particular region of country. In India, Indian standard criteria for earthquake resistant design of structures IS 1893 (PART-1): 2002 is the main code that provides outline for calculating seismic design force. Wind forces are calculated using code IS-875 (PART-3) & SP64.

A. Comparison of Cost for Steel, Composite & R.C.C. Structure

1) Cost for Steel Structure:

Steel Take-Off

PROFILE	LENGTH (m)
WEIGHT (KN)	
W21X48	1632.00
1140.455	
W24X76	1784.99
1981.642	
W21X248	925.40
3338.872	
W18X158	656.60
1506.679	

TOTAL	= 7967.649

Total Structural Steel = 7967.694(796.76ton)
Rate os Structural Steel = 58000/ton
Cost of Steel = 796.76x58000 = <u>Rs.46212080</u>/-
a) Cost of Slab:
Quantity of slab (140mm thk.) = 15.92x25.61x0.14x16 = 913.27 cu.mt
Assuming the rate of M30 concrete = Rs. 5000/cu.mt.
Cost of concrete = 913.27x5000 = Rs.4566350/-
Reinforcing steel in slab (assuming 70kg/m^3) = 913.27x70 =63929 kg (63.92 T.)
Rates of Reinforcing steel = Rs. 50000/M.T.
Cost of reinforcing steel = 63.92x50000 = Rs. 3196000/-
Total cost of steel structure = Rs.46212080+ Rs.4566350+ Rs. 3196000 = Rs. 53974430/-

2) Cost of R.C.C. Structure

Volume of concrete of columns & beams (from staad take off results) =1183.03 cu.mt.
Quantity of slab (140mm thk) = 15.92x25.61x0.14x16 = 913.27 cu.mt
Assuming the rate of M30 concrete = Rs. 5000/cu.mt.
Cost of concrete = (1183.03 + 913.27) x 5000 = Rs.104815000/-
Reinforcing steel of columns & beams (from staad take off results)=825.4kN (82.54 T.)
Reinforcing steel in slab (assuming 70kg/m^3)
= 913.27x70 = 63.92 kg (63.92 T.)
Rates of Reinforcing steel = Rs. 50000/M.T.
Cost of reinforcing steel = (82.54+63.92)x50000
= Rs. 7323000/-
Total cost in R.C.C. structure = Rs. 104815000+Rs. 7323000 = <u>Rs. 17804500/-</u>

3) Cost of Composite Structure

Quantity of column =
10X0.33X0.63X56.5 = 117.46
18X0.32X0.58X56.5 = <u>188.75</u>
Total = 306.21 cu.mt.
Assuming the rate of M30 concrete for columns = Rs. 5000/cu.mt.
Cost of concrete = 306.21x5000 = Rs.1531050/-
Quantity of slab (125mm thk.) = 15.92x25.61x0.125x16 = 815.42 cu.mt.
Assuming the rate of M30 concrete for slab (as no form work is required)= Rs. 4000/cu.mt.
Cost of concrete = 815.42x4000 = Rs.3261680/-
Reinforcing steel of column: (4-25ϕ)
4x3.86x28x56.5 = 24426 kg
Stirrups = 8000 kg
Total = 32426 kg (32.426 T.)
Reinforcing steel of slab: (assuming 30kg/m^3 as profile sheet will act as tension steel)
Quantity = 815.42x30 = 24462.6kg. (24.46 T.)
Cost of reinforcing steel = (32.426+24.46) x50000
= Rs. 2844300/-
a) Structural Steel
ISMB 450 (Encased Column) – 10X56.5X0.724 = 409.06 kN
ISMB 400 (Encased Column) – 18X56.5X0.615 = 625.45 kN
ISMB 450 (Main Beam) – 1428X0.724= 1033.87 kN
ISMB 300 (Main Beam) – 1632X0.46 = 750.72 kN
ISMB 200 (Main Beam) – 357X0.242= 86.39 kN
ISMB 200 (Secondary Beams @ 2.0m. spacing)
24X0.242X4X16 = 371.71 kN
Total = 3277.2 kN = 327.72 T
Cost of structural steel = 327.72x58000= Rs. 19007760/-

4) Cost of profiled sheets

Weight of profiled sheet from table 1 = 0.082kN/m^2
Total weight of profiled sheet = 15.92x25.6x16x0.082 = 535 kN.(53500kg)

Assuming the rates of sheet & it's Labour as Rs. 75 + Rs. 10 = Rs. 85/kg
Cost of sheet = 53500x85 =Rs. 4547500/-
Total cost in Composite Structure = 1531050+3261680+2844300+19007760+4547500 = Rs. 31192290/-
Total cost difference in construction of R.C.C. & Composite Structure
= 31192290-17804500 = 13387790/-

B. Comparison of Saleable Area Saving In Composite Structure & It's Cost Effectiveness:

Carpet area covered by R.C.C. column:-
10x0.45x1.1 = 4.95 sq.mt.
18x.45x.85 = 6.885 sq.mt.
Total area = 11.835 x 16 floors = 189.36sq.mt.
Carpet area covered by Composite column:-
10x0.33x0.63 = 2.08sq.mt.
18x0.32x0.58 = 3.34sq.mt.
Total area = 5.42x16 floors = 86.72sq.mt.
Total area difference =189.36- 86.72 = 102.64sq.mt.
If assuming the minimum market area rates as Rs.5000/sq.ft.
The cost of carpet area saving
= 102.64x10.764x5000 = 5524085/-
Maximum depth of beam in R.C.C. structure is 650mm
While Maximum depth of beam in Composite structure is 450mm
If we reduce the storey height by 200mm
The total reduction in height of building is = 16x0.2 = 3.2mt. (Almost one floor height)
So we can increase one floor keeping same height as R.C.C. building.
Increase in saleable area of extra floor
= 12x4x6x1.2 = 345.6sq.mt. (built up area of 12 offices)
Saleable cost of extra floor = 345.6x10.764x5000
= Rs.18600192/-
Total cost saving = 5524085+18600192
= Rs.24124277/-
Saving in terms of carpet area & extra floor
= Rs.24124277/-
Difference of cost for composite construction = Rs. 13387790/-
Net saving in composite construction = Rs. 10736487/-
The above results show that the composite construction is economical.

V. Further Discussion

Assuming that construction of R.C.C. building will take nearly 24 months to complete.

The composite construction is speedy, no form work is required for slab so no wastage of stripping time, at the same time work can be carried out at different levels simultaneously i.e. erection & concreting work may go on simultaneously at different levels, assuming the saving in time nearly 9 months.

The earning in terms of rent of offices (assuming Rs. 323/sq.mt. i.e. Rs.30/sq. ft.)
Rent = 12x4x6x10.764x30x15x9 = Rs. 12555130/-
Which is a considerable amount.

(For example, at the time the steel-framed Empire State Building (381m.) was completed, the tallest reinforced concrete building, the exchange building in Seattle, had attained a height of only 23 storeys.)

VI. Conclusion

The cost comparison reveals hat Steel-Concrete composite design structure is more costly, reduction in direct costs of steel-composite structure resulting from speedy erection will make Steel-concrete Composite structure economically viable. Further, under earthquake considerations because of the inherent ductility characteristics, Steel-Concrete structure will perform better than a conventional R.C.C. and Steel structure, because of

1) Weight of composite structure is quite low as compared to RCC structure which helps in reducing the foundation cost.
2) Composite structures are more economical than that of R.C.C. structure as shown in earlier chapter.
3) Speedy construction facilitates quicker return on the invested capital & benefit in terms of rent.
4) Weight of composite structure is quite low as compared to R.C.C. structure which helps in reducing the foundation cost.
5) Composite structures are the best solution for high rise structure.

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