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Life Cycle Cost Assessment of Multistory Steel Concrete Composite Building

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Abstract- The present work deals with the analysis of G+26 multi-story unsymmetrical building using the Staad Pro V8i. Software with the different load combination as recommended by IS Code have been taken into consideration. Identification of maximum bending moment at beam and column are evaluated. Based on the output of the analysis further design part related to building has been performed. Further the study and design of same building with the same load combinations were conducted based on Steel- Concrete Composite Structure manually. The results of both types of framed structure were studies conducted theoretically and compared.

It has been observed the Steel – Concrete Composite Structure is found to be more economical as compared to regular conventional RCC structure during Costing. But While after performing the Life cycle cost analysis it has been found that the Composite Structure is 13.70% cheaper than RCC Structure while assessment done at the discount rate of 8% for 30 yrs, 100 yrs @ 8% it is , 13.90 %, 30 yrs @ 12% it is 13.10% and for 100 yrs @12% the same reduces to 13.15%.

Keywords—Composite Structure, Composite beam, Composite slab, Life Cycle Cost, Multi-storey, Seismic and Wind load.

I. INTRODUCTION

In the past, for the design of a building, the choice was normally between a traditional concrete structure and a masonry structure [4]. Failures of many multi-storied Reinforced cement concrete structures and masonry buildings due to lateral forces enhance structural engineers to find out the best practical alternative method of construction [4]. Steel structures are then comes as solution but it found comparative costlier further from the economical point of view an alternate solution of composite structure for high rise has been investigated.

Composite structures are focused to new innovational approach due to its manufacturing and performance. The composite materials are those which rare composed of more than one material so that the properties of composite material are different from those of individual constituents.

Steel possess high tensile strength and ductility whereas concrete having high compressive strength and corrosion resistance, a member constructed while combining these two materials provides positive features of both the material to the structure. Building of Composite structural members provide a cost-effective alternative to traditional structural steel or reinforced concrete beams, slabs, columns, and walls. This work investigates the behavior and life cost analysis of multi-storied unsymmetrical composite building consisting composite columns, beams comparison to the equivalent RCC structure subjected to the lateral forces also.

With the view to finding out the effectiveness of steel – Concrete Composite structure option vis-a-vis RCC [22] alternative this project has carried out study to compare analysis and design part of both steel- concrete composite and an equivalent RCC structure.

• To fix the preliminary dimension of components for RCC and Steel – Concrete Composite Structure by using STAAD – Pro V8i software.
• To determine deflection, axial force, shear force, bending moment all and design the members.
• To compare the various parameters to design the components and find the quantities of both composite and RCC structure.
• To perform and compare life cycle cost assessment of both RCC and steel concrete composite structure.
• The design selection based on the low cost of construction without compromising quality and serviceability function.

II. COMPOSITE STRUCTURE

Structural steel has high strength, ductility, and is fast to erect. Reinforced concrete provides high rigidity and is economical, fire resistant, and durable. In steel and concrete composite construction, the two materials are combined together so strongly that they act as a single unit to from a structural point of view when this occurs it is termed as composite action [14]
A composite member is consisting rolled up or built up structural steel shapes like I section, T Section etc. i.e., filled with concrete, encased by reinforced concrete or structurally connected reinforced concrete slab. It is constructed such that the structural steel shapes and concrete act together to resist axial and bending moment.

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

1. Shear connector
2. Composite beam
3. Composite column
4. Composite Slab

Figure 1. Steel-concrete composite frame [35]

Composite Steel-Concrete beam:- A concrete beam is formed when a concrete slab which is casted in-situ conditions is placed over an I-section or steel beam. Under the influence of loading both these elements tend to behave in an independent way and there is a relative slippage between them. If there is a proper connection such that there is no relative slip between them, then an I-section steel beam with a concrete slab will behave like a monolithic beam as shown in the figure 2. In our present study, the beam is composite of concrete and steel and behaves like a monolithic beam. Concrete is very weak in tension and relatively stronger in tension whereas steel is prone to buckling under the influence of compression. Hence, both of them are provided in a composite such they use their attributes to their maximum advantage. A composite beam can also be made by making connections between a steel I-section with a precast reinforced concrete slab. Keeping the load and the span of the beam constant, we get a more economic cross section for the composite beam than for the non-composite tradition beam. Composite beams have lesser values of deflection than the steel beams owing to its larger value of stiffness. Moreover, steel beam sections are also used in buildings prone to fire as they increase resistance to fire and corrosion.

Figure 2. Steel-concrete composite beam

Steel-Concrete Composite Column is a compression member comprising of a concrete filled tubular section of hot-rolled steel or a concrete encased hot-rolled steel section (figure.3). In a composite column, both the concrete and the steel interact together by friction and bond. Therefore, they resist external loading. Generally, in the composite construction, the initial construction loads are beared and supported by bare steel columns. Concrete is filled on later inside the tubular steel sections or is later casted around the I section. The combination of both steel and concrete is in such a way that both of the materials use their attributes in the most effective way. Due to the lighter weight and higher strength of steel, smaller and lighter foundations can be used. The concrete which is casted around the steel sections at later stages in construction helps in limiting away the lateral deflections, sway and bucking of the column. It is very convenient and efficient to erect very high rise buildings if we use steel-concrete composite frames along with composite decks and beams. The time taken for erection is also less due to which speedy construction is achieved along better results.

A composite member subjected mainly to compression and bending is called as composite column (Figure 3).

\[
P_p = A_p P_y + A_s P_{ck} + A_S P_{sk}
\]

Where,

\[
P_y = 0.8 f_y
\]
\[
P_{ck} = 0.4(f_{ck})_{cu}
\]
\[
P_{sk} = 0.67 f_y
\]
Shear Connector- Composite construction consists of providing monolithic action between prefabricated units like steel beams or pre-cast reinforced concrete or pre-stressed concrete beams and cast-in-situ concrete, so that they will act as one unit. Although there is bound to be a certain amount of natural bond between concrete and steel at least at the initial stages, this bond cannot be relied upon as the same is likely to be deteriorate due to use and over load. Mechanical shear connectors are therefore provided to help the steel and concrete element to act in a composite manner ignoring the contribution made by the inherent natural bond towards this effect. 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. Commonly used types of shear connectors as per IS: 11384-1985 [35]. There are three main types of shear connectors; rigid shear connectors, flexible shear connectors and anchorage shear connectors.

Rigid Type:
These connectors as the name implies, are designed to be bent proof with little inherent power of deformation. These types of shear connectors could be of various shapes, but the most common types are short length of bars, angles or tees welded on to the steel girder in manners

Flexible Type:
Flexible type connectors such as studs, channels welded to the structural beams derive their resistance essentially through the bending of the connectors and normally failure occurs when the yield stress in the connector is exceeded resulting in slip between the structural beam and the concrete slab.

Bond / Anchorage Type:
These connectors derive their resistance through bond and/or anchorage action.
These normally consist of inclined bars with one end welded to the flange of the steel unit and the other suitably bent. M.S. bar welded to the flange of the steel unit in the form of helical stirrups.[35]

III. LIFE CYCLE COST ASSESSMENT

Life cycle cost is the total discounted rupee cost of owning, operating maintaining and disposing of the building or a building system over a period of time. It is an economical evaluation technique that determines the total owning and operating a facility over a stipulated time.

The usefulness of life cycle analysis is not only to determine the total cost of the project but it also helps to compare the alternatives of the project and determines the best economical alternative to spend the money [21]. It also includes the time value of money. It can be understand by as more quickly the project finished, the more saving in project cost both in terms of cost overrun and time value of money since the usage of building start as soon as the project finished.

LCC can be breakdown in the following variables,
1) The pertinent cost of ownership
2) The period of time over which the costs are incurred
3) The discounted rate that applied to the future costs to equate them with the present day costs.[21,22]

STEPS IN COMPLETION OF LCCA OF A PROJECT:

Step 1- Initial Investment Costs are the cost that will be incurred prior to the occupation of the building should be commensurate with the level of project detail.
Construction cost can be derived from the historical cost of the similar projects executed elsewhere regularly published construction cost literature, quotations of contractors who have already executed similar type of projects, or professional cost consultants.

Step 2- Operating Cost is annual cost excluding maintenance and repair costs, involved in the operation of the facility.
All the operational costs are discounted to their present value prior to addition to the LCCA total. Operational costs that are directly not related to the building should usually be executed from the LCCA.

Step 3 Maintenance Cost are the scheduled cost associated with the upkeep of the facility.
Repair costs are the unanticipated expenditures that are required to prolong the life of the building system without replacing the system. Some Maintenance costs are incurred annually or and other less frequently. Repair costs are unforeseen, impossible to predict when they occur. Thus all the maintenance and repair costs should be treated as annual costs and to be discounted to their present value prior to additional to the LCCA total. Facility location, age of the building system and the variation in the exterior envelope area are just a few factors that should be considered when estimating maintenance and repair costs for projects alternatives.

Step -4 Replacement Costs are anticipated expenditures to major building system components that are required to maintain the operation of facility. Replacement cost is typically generated by the replacement of a building system or a component that has reached the end of its useful life. The cost of replace a building component in the future will be same as the current cost of the building component in additional to the demolition cost and can be derived from historical cost of similar projects executed elsewhere, regularly published construction cost literature, or professional cost consultants.

Step -5 Residual Values is defined as net worth of the building or building alternative system at the end of LCCA study period. The residual cost of facility or building system is especially important when evaluating project alternatives that have different life expectancies.

Step-6 Final Shape of Life Cycle Cost Analysis – All pertinent cost have been established and discounted to their present value and the costs are summed up to generate the total life cycle cost of the project alternative.[21,22]

It is anticipated that the project option with the lowest overall life cycle cost will be the project option considered.

IV. BUILDING DETAILS

The building considered here is an residential building having G+26 storied located in Seismic Zone 4 & Wind Velocity 47m/s. the plan of building is shown in fig. 4. the building is planned to facilitate the basic requirements of an office building. The plan of building is kept symmetric about both the axes. Separate provisions are made for car parking, lift, staircase and other utilities; however they are excluded from scope of work. The plan dimension of the building for both types of structures other relevant data is tabulated in table I & II. The basic loading on both types of structures are kept same.

| TABLE I |
|-----------------|-----------------|
| **DATA FOR ANALYSIS OF RCC STRUCTURE : AS PER IS 456:2000**[23] |

<table>
<thead>
<tr>
<th>Parameters</th>
<th>RCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>6 mts below GL</td>
</tr>
<tr>
<td>No of Stories</td>
<td>G+26 stories</td>
</tr>
<tr>
<td>Walls</td>
<td>9” thick wall</td>
</tr>
<tr>
<td>Floor to Soffit height</td>
<td>3.2 mts</td>
</tr>
<tr>
<td>Height of Parapet</td>
<td>1.0 Mts</td>
</tr>
<tr>
<td>Parking Storey</td>
<td>Ground</td>
</tr>
<tr>
<td>Size of columns C1</td>
<td>1200mmX600mm</td>
</tr>
<tr>
<td>C2</td>
<td>600mmX1200mm</td>
</tr>
<tr>
<td>Sizes of Beams B1</td>
<td>450mmX600mm</td>
</tr>
<tr>
<td>Thickness of Slab</td>
<td>200mm</td>
</tr>
<tr>
<td>Thickness of internal and external walls</td>
<td>230mm</td>
</tr>
<tr>
<td>Seismic Zone</td>
<td>IV</td>
</tr>
<tr>
<td>Basic Wind Speed</td>
<td>47m/sec</td>
</tr>
<tr>
<td>Soil Condition</td>
<td>Hard</td>
</tr>
<tr>
<td>Importance factor</td>
<td>1.0</td>
</tr>
<tr>
<td>Zone factor</td>
<td>0.24</td>
</tr>
<tr>
<td>Floor finish</td>
<td>1.0 kN/m2</td>
</tr>
<tr>
<td>Live load at all floors</td>
<td>4.0 kN/m2</td>
</tr>
<tr>
<td>Grade of concrete</td>
<td>M30</td>
</tr>
<tr>
<td>Grade of Reinforcing steel</td>
<td>Fe415</td>
</tr>
<tr>
<td>Density of Concrete</td>
<td>25 kN/m 3</td>
</tr>
<tr>
<td>Density of Brick</td>
<td>18 kN/m 3</td>
</tr>
<tr>
<td>Damping Ratio</td>
<td>5%</td>
</tr>
</tbody>
</table>

Fig 4. Plan Shows Typical Floor Of Building
TABLE II
DATA FOR ANALYSIS OF STEEL–CONCRETE COMPOSITE STRUCTURE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>6 mts below GL</td>
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<tr>
<td>No of Stories</td>
<td>G+26 stories</td>
</tr>
<tr>
<td>Walls</td>
<td>9&quot; thick wall</td>
</tr>
<tr>
<td>Floor to Soffit height</td>
<td>3.2 mts</td>
</tr>
<tr>
<td>Height of Parapet</td>
<td>1.0 Mts</td>
</tr>
<tr>
<td>Parking Storey</td>
<td>Ground</td>
</tr>
<tr>
<td>Size of columns</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>1000mmX350mm (ISMB 600)</td>
</tr>
<tr>
<td>C2</td>
<td>350mmX1000mm (ISMB 600)</td>
</tr>
<tr>
<td>Sizes of Beams</td>
<td>ISMB-225</td>
</tr>
<tr>
<td>Thickness of Slab</td>
<td>150mm</td>
</tr>
<tr>
<td>Thickness of internal and external walls</td>
<td>230mm</td>
</tr>
<tr>
<td>Seismic Zone</td>
<td>IV</td>
</tr>
<tr>
<td>Basic Wind Speed</td>
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<td>Soil Condition</td>
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</tr>
<tr>
<td>Damping Ratio</td>
<td>5%</td>
</tr>
</tbody>
</table>

V. ANALYSIS

The explained 3D building model is analyzed using Equivalent Static Method. The building models are then analyzed by the software Staad Pro.V8i. Different parameters such as deflection, shear force & bending moment are studied for the models. In India, Indian standard criteria for earthquake resistant design of structures IS 1893 (PART-1): 2005 [29] is the main code that provides outline for calculating seismic design force. Wind forces are calculated using code IS-875 (PART-3) & SP64.

VI. RESULT AND DISCUSSION

Deflection :-

![Figure 5 Variation in Deflection.](image)

The deflection in composite structure is nearly double than that of R.C.C. structure but the deflection is within the permissible limit (Figure.5)

Bending Moment :-

![Figure 6 Variation in Bending Moment - X Direction](image)

Figure 6 & 7 bending moment in X and Z direction for composite structural system is less as compared to RCC Structure.
Figure 7 Variation in Bending Moment Z Direction

Axial Forces:

Figure 8 Variations in Axial Forces

Figure 8 Axial Forces for composite structural system is less as compared to RCC Structure.

Shear Forces:

Figure 9 Variation in Shear Force in X direction

The Figure 9 shows that the Shear force in R.C.C structure is on higher side than that of composite structure.

Cost Estimate:

Figure 10 Cost Variations in RCC & Composite Structure

Figure 10 shows the Composite Structure is comparative cheaper than the RCC structure.

Life Cycle Cost Estimate:

Figure 11 Comparative of Life Cycle Cost Assessment

Figure 11 shows Life Cycle Cost for 30 yrs and 100 yrs for 8% and 12% discount rate shows cost of Composite structure is lesser than RCC Structure.

VII. Conclusion

a. On analysis and study RCC column axial forces are 20% less as compared to Composite Structure.
b. Composite beam though posses heavy self weight but its moment carrying capacity is 3 times more than the RCC structure.
c. Percentage of steel is within the permissible limit of concrete, it indicates practically no shear as compared to RCC structure.
d. The cost comparison reveals that steel-concrete composite design structure is 22% economical in case of high rise buildings than the RCC building.
REFERENCES


[22] BS 5950-2000 Part -1 Code of Practice for Design –Rolled and Welded sections

[23] BS 5950-2000 Part -3 Code of Practice for design of Simple and continuous composite beams.


[26] www.academia.edu/756102/Lecture_Note_31_Introduction_to_Steel-Concrete_Composite_Building

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e. Analysis of Life cycle cost shows that the Composite Structure is 13.7% cheaper in while assessment done at the discount rate of 8% for 30 yrs , 13.90% for 100 yrs @ 8%, 13.10% for 30 yrs @ 12% and for 100 yrs @12% found to be 13.15%.