International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 15, Number 3 (2026) pp. 293-304
Research India Publications
https://www.ripublication.com

Green and Sustainability aspects of Steel Multi-storey Buildings made of Hollow Members SHS & RHS and Wide Flange Rolled Sections

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Abstract

The concept of Lightweight Sustainable Steel Green Multi-storey Building is an innovative and eco-friendly approach to modern urban construction. These buildings are designed using lightweight steel sections such as Square Hollow Sections (SHS), Rectangular Hollow Sections (RHS) and Parallel Flange Rolled sections which provide high strength-to-weight ratios, reducing the overall dead load on the structure. This reduction in mass is particularly beneficial in earthquake-prone regions, as it lowers seismic forces and enhances building safety. Additionally, the use of prefabricated steel components accelerates the construction process and ensures high precision and quality. To promote sustainability, these buildings integrate green materials and systems such as fly ash brick with glass partitions for walls, steel floors and energy-efficient features like natural lighting. In this paper two model buildings, one RCC and one Steel, have been analyzed for seismic zone III and zone IV as per Indian Standard. Purpose of the buildings are commercial type. Proper steel bracing systems are provided for stability of the steel structure. Comparing the two buildings' design it is observed that the steel building reduces carbon footprint and operational energy consumption. The materials used are often recyclable, durable and low in embodied energy, making the steel building more environmentally responsible throughout their lifecycle. Overall, steel building represents the future of smart construction, offering a balance between strength, speed, environmental consciousness and long-term performance.

Keywords: Lightweight multi-storey steel building, Sustainable construction, Green building materials, Seismic-resistant design

1 Introduction

The rapid growth of the construction industry has intensified the demand for sustainable, economical and structurally efficient building systems, especially in rapidly urbanizing developing countries. Conventional reinforced concrete (RCC) construction, though widely used, often leads to high dead loads, longer construction time and increased environmental impact. To address these issues, lightweight sustainable steel green multi-storey buildings have emerged as an efficient alternative that integrates structural performance with environmental responsibility.

Steel construction systems using Square Hollow Sections (SHS) and Rectangular Hollow Sections (RHS) and Parallel Flange Rolled sections offer advantages such as high strength – to - weight ratio, ductility, faster construction through prefabrication and reduced material usage. They are also recyclable and align with green building principles, while performing better under seismic loads due to flexibility and energy dissipation capabilities.

In earthquake-prone regions like Seismic Zones III and IV of India, selecting an appropriate structural system is crucial for safety and long-term sustainability. This study compares a G+10 storey steel green building with a conventional RCC building under these seismic conditions, analysing structural behaviour, material consumption, embodied energy and construction cost. Through this analysis, the research seeks to determine the most sustainable and cost-effective solution for multi-storey buildings in such regions.

2 Definition of Green Buildings and Materials

A green building is a structure that is environmentally responsible and resource efficient throughout its lifecycle from planning and design to construction, operation, maintenance, renovation and deconstruction.

2.1 Features of Green Buildings:

- Energy-efficient materials, lighting and appliances
- High-performance building envelope (insulated walls, double-glazed windows)
- Solar panels or other renewable energy sources
- Rainwater harvesting and greywater recycling
- Smart building management systems for energy and water monitoring
- Sustainable landscaping using native plants
- Natural ventilation and daylighting

2.2 Example Certifications:

- LEED (Leadership in Energy and Environmental Design)
- USGBC (U.S. Green Building Council)
- IGBC (Indian Green Building Council)
- GRIHA (Green Rating for Integrated Habitat Assessment)

3 Definition of Sustainability Engineering against Natural Hazards

Sustainability engineering against natural hazards like earthquake, wind, flood, fire etc. is the application of engineering principles to design resilient systems that mitigate hazard impacts while ensuring long-term environmental protection, social well-being and economic efficiency. In this paper, sustainability against seismic hazard is the main objective and development of better seismic resistant system i.e. steel building will be examined.

4 Present Case Study

Rapid urbanization and environmental concerns are driving the construction industry toward sustainable and cost-efficient building solutions. Although RCC buildings provide strength and durability, they involve high material consumption, longer construction periods and significant embodied energy and carbon emissions. In contrast, steel structures made of SHS & RHS and Parallel Flange Rolled Sections offer a lightweight, ductile and earthquake-resistant alternative solution for seismic-prone areas. Additionally, steel buildings enable faster construction, prefabrication, reduced maintenance problems and lower overall energy consumption.

This study includes design comparison of G+10 storey green and sustainable Steel building with conventional RCC building in Seismic Zone III and Zone IV (moderate to severe intensity) of India.

5 Method of Analysis and Design

The work is going to be carried out to a G+10 storey commercial Steel Building and also a conventional RCC building of identical configuration.

5.1 Structural Modelling

- Create two structural models: Model A: Conventional RCC Building. Model B: Steel Green Building mainly using SHS & RHS and Parallel Flange Rolled Section members.
- Using structural analysis software STAAD Pro.

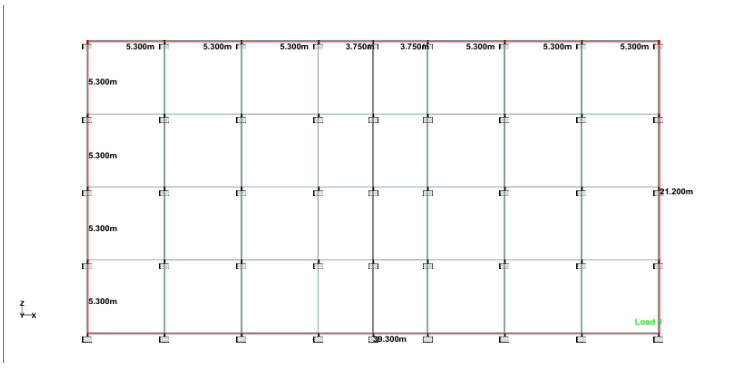
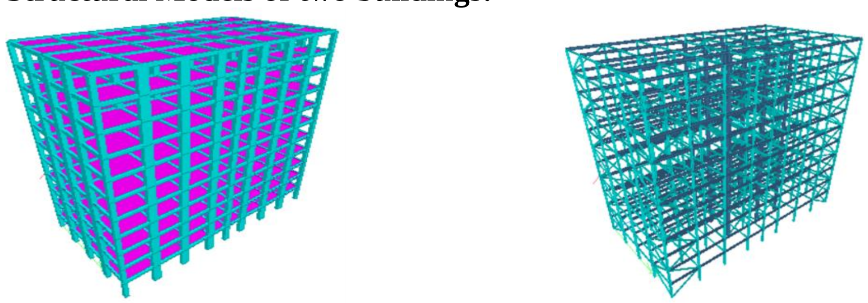


Fig. 1: Typical Floor Plan of two buildings

5.2 Structural Models of two buildings:



Model A: Conventional RCC Building **Model B:** Steel Green Building

Fig. 2: STAAD picture of G+10 storey RCC and Steel buildings

Model A: Conventional RCC Building in Seismic Zone III

- Defining concrete grade (M30), grade of reinforcement steel (Fe500) and other properties as per IS 456.
- Live Load considered 4 kN/m^2
- Considering Seismic zone III of India; Zone factor, Z = 0.16, Importance Factor, I = 1.50, Response Reduction Factor, R = 3.0 as per IS 1893:2016

Design

- Columns and Beams design calculation of RCC building done by STAAD Pro.
- Slab design done by Excel and get slab thickness 110mm.
- Design of Sub Structure done by Excel.
- Pile provided 550mm diameter of capacity 95 ton and 23m shaft length (2m cut-of length). After design we get,

Table - 1: Detail of Columns with HYSD rebars (in mm)

Floor	Intermediate Column Size	Peripheral Column Size	Main Reinforcement	Lateral Ties
Ground Floor to 5th Floor	1050 x 1050	-	20-25 □	8□ @ 150 c/c
From 6th Floor to Roof	750 x 750	-	16-20 □	8□ @ 150 c/c
Ground Floor to Roof	-	1200 x 600	28-20 □	8□ @ 150 c/c
	-	900 x 600	16-20 □	8□ @ 150 c/c
	-	600 x 600	12-20 □	8□ @ 150 c/c

Table - 2: Detail of Beams with HYSD rebars (in mm)

Floor	**Beam Size**	**Reinforcement**				
		Top Bar		**Bottom Bar**		**Stirrups**
	W x D	**At Supp.**	**At Span**	**At Supp.**	**At Span**	
Ground Floor	300 x 550	6-20 □	4-20 □	4-20 □	6-20 □	2L-8□ @ 150c/c
Intermediate Floors	300 x 550	6-25 □	4-25 □	4-25 □	6-25 □	2L-8□ @ 150c/c
Roof	300 x 550	3-20 □	3-20 □	3-20 □	3-20 □	2L-8□ @ 150c/c

Table - 3: Detail of Pile Caps with HYSD rebars (in mm)

Pile Cap	No of Piles in each Pile cap	Total Number of Pile caps	Size	Depth of cap	Reinforcement
PC-1 (4 Pile cap grp.)	4	6	2500 x 2500	1000	□□□ bar @ 100mm c/c B/W
PC-2 (6 Pile cap grp.)	6	21	4000 x 2500	1800	□□□ bar @ 100mm c/c B/W
PC-3 (8 Pile cap grp.)	8	18	4000 x 4000	1800	□□□ bar @ 100mm c/c B/W

Estimation of Material Quantities:

1) **For RCC Building -** Calculating quantity of concrete and HYSD reinforcement steel

Pile and Pile Cap :

Total number of Piles (550 diameter) = 295.00 Nos.
Total volume of Concrete required for Piles & Pile Caps = 2687.00 m^3
Rebar Steel required for Piles & Pile Caps (110.00 kg/m^3) = 296.00 ton

Secondary Beam (250 x 425):

Volume of Concrete required for Secondary beam = 104.00 m^3
Rebar Steel required for Secondary beam (196 kg/m^3) = 20.40 ton

Staircase:

Volume of Concrete required for Staircase = 34.00 m^3
Rebar Steel required for Staircase (90 kg/m^3) = 3.10 ton

Slab (110 mm thickness):

Rebar Steel required for Slab (90 kg/m^3) = 90.00 ton

Data from STAAD Pro. Output File :

Volume of Concrete (including Slabs, Beams and Columns) = 1987.60 m^3
Rebar Steel (including Beams and Columns) = 184.20 ton
Total weight of Rebar Steel = **595.00 ton**
Total volume of Concrete (M30) = **4815.00 m^3**
Using Cement Content(M30) = **400.00 kg/m^3**
Total Cement required = **1926.00 ton**

5.3 Model B: Steel Green Building in **Seismic Zone III**

- Defining steel hollow sections (SHS/RHS) as per TATA Structura, Parallel Flange Beam sections (NPB) as per Jindal Steel, Indian Standard Medium Weight Beam (ISMB) as per SP 6 and concrete grade(M25) for sub structure and roof slab.

- Live Load considered 4 kN/m^2.
- Considering Seismic zone III of India; Zone factor, Z = 0.16, Importance Factor, I = 1.50, Response Reduction Factor, R = 4.0 as per IS 1893:2016.

Design

- Member Design calculations of Steel building done by Excel
- Chequered plate of thickness 3mm @ 350mm c/c is provided at every intermediate floor with supporting member 50 x 25 x 2 RHS as stiffeners
- Provide Secondary beam 220 x 140 x 5 RHS
- Roof slab is made of concrete (thickness = 100 mm)
- Design of Sub Structure is done by Excel.

Pile provided 500mm diameter of capacity 85 ton and 23m shaft length (2m cut-of length). After design we get,

Table - 4: Detail of Member Properties (in mm)

Member	**Member Properties**			
	TATA Structura		Jindal Steel	ISMB
Column	250x250x10 SHS, 220X220X8 SHS, 220X220X6 SHS, 180X180X6 SHS,		NPB 600X220X154.5, NPB 500X200X90.7	
Beam		200X100X6 RHS		ISMB 350
Bracing	132x132x5.4 SHS, 113.5x113.5x5.4 SHS			

Table - 5: Detail of Pile Caps with HYSD rebars (in mm)

Pile Cap	**Nos of Pile in each Pile cap**	**Total Numbers of Pile cap**	**Size**	**Depth of cap**	**Reinforcement**
PC-1 (3 Pile cap grp.)	3	35	3800 x 1650	1500	20□ bar @ 100 c/c B/W
PC-2 (4 Pile cap grp.)	4	4	2500 x 2500	1000	20□ bar @ 100 c/c B/W
PC-3 (5 Pile cap grp.)	5	4	3000 x 3000	1000	20□ bar @ 100 c/c B/W
PC-4 (8 Pile cap grp.)	8	2	3800 x 3800	1400	20□ bar @ 100 c/c B/W

Estimation of Material Quantities:

For Steel Building - Calculating steel tonnage for beams, columns, bracings, SHS/RHS profiles and flooring system.

Pile and Pile Cap:

Total numbers of Pile (500 diameter) = 157 Nos.

Total volume of Concrete required for Piles & Pile Caps = 1202.00 m^3

Rebar Steel required for Piles & Pile Caps (110 kg/m^3) = 133.00 ton

Roof Slab (100 mm thickness):

Volume of Concrete required for roof slab = 84.00 m^3

Rebar Steel required for roof slab (90 kg/m^3) = 7.00 ton

Checkered plates and Supporting members:

Total weight of Checkered plates and Supporting members = 250.00 ton

Secondary Beam (220 x 140 x 5 RHS):

Total weight of Secondary beam = 151.00 ton

Data from STAAD Pro. Output File

Weight of Structural Steel = 297.50 ton

Total weight of Structural Steel = **699.00 ton**

Total weight of Rebar Steel = **140.00 ton**

Total volume of R.C. Concrete (M25) = **1286.00 m^3**

Use Cement Content (in M25) = 375.00 kg/m^3

Total weight of Cement (in M25) = **485.00 ton**

6 Result Analysis and Discussion for Seismic Zone III

Embodied Energy Calculation - Using embodied energy factors for each material from published databases:

For RCC Building

Considering-

Embodied Energy of Rebar Steel = 20.00 GJ/ton

Embodied Energy of M30 grade concrete including all = 3.25 GJ/m^3

Embodied Energy of Rebar Steel as calculated = 11900.00 GJ

Embodied Energy of Concrete (M30) as calculated = 15649.00 GJ

Total Embodied Energy of R.C.C. Building = 27549.00 GJ

Total Embodied Energy = 31681.35 GJ

(considering 15% extra for detailing and wastage) say **31685.00 GJ**

For Steel Building

Considering-

Embodied Energy of Cement (OPC) = 5.50 GJ/ton

Embodied Energy of Structural Steel = 20.00 GJ/ton

Embodied Energy of Rebar Steel = 20.00 GJ/ton

Embodied Energy of Steel as calculated = 16780.00 GJ

Embodied Energy of Cement (OPC) as calculated = 2668.00 GJ

Total Embodied Energy of Steel Building = 19448.00 GJ

Total Embodied Energy (considering 5% wastage) **= 20421.00 GJ**

Therefore, Embodied Energy approximately 1.55 times less in Steel Green building compare to conventional R.C.C. building.

Emission of CO2 Calculation - Producing one ton of cement releases approximately 0.90 ton of CO_2 and that for steel is 2 tons due to one ton of steel production.

For RCC Building

Total Cement required = 1926.00 ton
CO_2 emissions = 1734.00 ton
Total Steel required = 595.00 ton
CO_2 emissions = 1190.00 ton
Total CO_2 emissions = **3363.00 ton**
(15% extra for detailing and wastage)

For Steel Building

Total Cement required = 485.00 ton
CO_2 emissions = 437.00 ton
Total Steel required = 839.00 ton
CO_2 emissions = 1678.00 ton
Total CO_2 emissions (5% extra for wastage) = **2221.00 ton**

Therefore, CO2 emissions approximately 1.5 times less in Steel Green building compare to Conventional R.C.C. building.

Cost Estimate - Prepare Cost estimates for both building types using market prices for steel, concrete and reinforcement, including fabrication, transportation, erection (for steel) and formwork/shuttering (for RCC) all complete.

For RCC Building (in Rs.)

Considering - Cost of Rebar Steel = 76,000.00 /- per ton
Cost of RMC M30 grade concrete = 6,250.00 /- per m^3 of concrete
Total Cost of R.C.C. Building Structure = **8,66,10,815.00 /- INR**
(15% extra for detailing and wastage)

For Steel Building (in Rs.)

Considering - Cost of Structural Steel = 65,000.00 /- per ton
Cost of Rebar Steel = 65,000.00 /- per ton
Cost of RMC M25 grade concrete = 4,800.00 /- per m^3 of concrete
Total Cost of Steel Building Structure = **6,37,43,250.00 /- INR**
(5% extra for wastage)

Therefore, Total Cost of Building structure approximately 1.36 times less in Steel Green building compare to Conventional R.C.C. building.

7 Method of Analysis and Design in Seismic Zone IV

7.1 Model A: Conventional RCC Building

- Considering Seismic zone IV of India; Zone factor, Z = 0.24 as per IS 1893:2016
- Others configurations as per seismic zone IV.

Design - All designs are done as per seismic zone IV, after design we get,

Table - 6: Detail of Columns with HYSD rebars (in mm)

Floor	Intermediate Column Size	Peripheral Column Size	Main Reinforce ment	Lateral Ties
Ground Floor to 5th Floor	1050 x 1050	-	32-28 □	8□ @ 150 c/c
From 6th Floor to Roof	750 x 750	-	16-20 □	8□ @ 150 c/c
Ground Floor to Roof	-	1200 x 600	28-25 □	8□ @ 150 c/c
	-	900 x 600	16-20 □	8□ @ 150 c/c
	-	600 x 600	20-20 □	8□ @ 150 c/c

Table - 7: Detail of Beams with HYSD rebars (in mm)

Floor	Beam Size	Reinforcement				
		Top Bar		Bottom Bar		
	W x D	At Supp.	At Span	At Sup p.	At Span	Stirrups
Ground Floor	300 x 550	6-25 □	4-25 □	4-25 □	6-25 □	2L-8□ @ 150c/c
Intermediate Floors	300 x 550	6-28 □	4-28 □	4-28 □	6-28 □	2L-8□ @ 150c/c
Roof	300 x 550	3-25 □	3-25 □	3-25 □	3-25 □	2L-8□ @ 150c/c

Table - 8: Detail of Pile Caps with HYSD rebars (in mm)

Pile Cap	No of Piles in each Pile cap	Total Number of Pile caps	Size	Depth of cap	Reinforcement
PC-1 (4 Pile cap grp.)	4	4	2500 x 2500	1200	□□□ bar @ 100mm c/c B/W
PC-2 (6 Pile cap grp.)	6	5	4200 x 2500	1800	□□□ bar @ 100mm c/c B/W
PC-3 (8 Pile cap grp.)	8	36	4200 x 4200	1800	□□□ bar @ 100mm c/c B/W

Estimation of Material Quantities for RCC Building:

Total weight of Rebar Steel = **702.00 ton**

Total volume of Concrete (M30) = **5380.00 m^3**
Using Cement Content (M30) = **400.00 kg/m^3**
Total Cement required **= 2152.00 ton**

7.2 Model B: Steel Green Building

- Considering Seismic zone IV of India; Zone factor, Z = 0.24, as per IS 1893:2016.
- Others configurations as per seismic zone IV.
- All designs are done as per seismic zone IV Limit State Method, after design we get,

Table - 9: Detail of Member Properties (in mm)

Member	**Member Properties**			
	TATA Structura		**Jindal Steel**	
Beam		200X100X6 RHS		UB356X171 X 45
Column	250x250x12 SHS, 220X220X8 SHS		UC305X305X283, UC305X305X198, UC305X305X158, UC305X305X137, UC 254X254X89,	
Bracing	220x220x8 SHS, 180x180x6 SHS			

Table - 10: Detail of Pile Caps with HYSD rebars (in mm)

Pile Cap	**Nos of Pile in each Pile cap**	**Total Numbers of Pile cap**	**Size**	**Depth of cap**	**Reinforcement**
PC-1 (3 Pile cap grp.)	3	23	3800 x 1750	1500	20□ bar @ 100 c/c B/W
PC-2 (4 Pile cap grp.)	4	6	2500 x 2500	1000	20□ bar @ 100 c/c B/W
PC-3 (5 Pile cap grp.)	5	10	3000 x 3000	1000	20□ bar @ 100 c/c B/W
PC-4 (6 Pile cap grp.)	6	6	4000 x 2500	1500	20□ bar @ 100 c/c B/W
PC-5 (9 Pile cap grp.)	9	2	4000 x 4000	1500	20□ bar @ 100 c/c B/W

Estimation of Material Quantities for Steel Building:

Total weight of Structural Steel = **784.00 ton**
Total weight of Rebar Steel = **162.00 ton**
Total volume of R.C. Concrete (M25) = **1486.00 m^3**
Use Cement Content (in M25) = **375.00 kg/m^3**
Total weight of Cement (in M25) = 558.00 ton

8 Result Analysis and Discussion for **Seismic Zone IV**

Embodied Energy Calculation - Calculation procedure as per seismic zone IV.

For RCC Building

Total Embodied Energy
(considering 15% extra for detailing and wastage) = **36255.00 GJ**

For Steel Building

Total Embodied Energy (considering 5% wastage) **= 23302.00 GJ**

Therefore, Embodied Energy approximately 1.56 times less in Steel Green building compare to conventional R.C.C. building.

Emission of CO_2 Calculation - Calculation procedure as per seismic zone IV.

For RCC Building

Total CO_2 emissions (15% extra for detailing and wastage) = **3843.00 ton**

For Steel Building

Total CO_2 emissions (5% extra for detailing and wastage) = **2428.00 ton**

Therefore, CO2 emissions approximately 1.58 times less in Steel Green building compare to Conventional R.C.C. building.

Cost Estimate - Cost estimate for both building types done as per the rates for zone III.

For RCC Building (in Rs.)

Total Cost of R.C.C. Building Structure = **10,00,23,550.00 /- INR**
(15% extra for detailing and wastage)

For Steel Building (in Rs.)

Total Cost of Steel Building Structure = 7**,20,54,000.00 /- INR**
(5% extra for wastage)

Therefore, Total Cost of Building structure approximately 1.39 times less in Steel Green building compare to Conventional R.C.C. building.

The above discussion compares Steel green buildings and conventional RCC buildings in Seismic Zones III and IV of India, highlights key differences in energy use, cost, seismic performance and sustainability. Steel buildings have lower embodied energy due to their lightweight nature and reduced material requirements, while RCC structures are heavier and consume more resources. Steel SHS/RHS and Wide Flange Rolled Section systems enable faster construction with less labour, making them more cost-effective, whereas RCC involves time-consuming processes like formwork, casting and curing. In terms of seismic performance, steel buildings perform better because of their ductility and energy dissipation capacity, while RCC structures are more brittle and require additional reinforcement. The advantages of steel structures become more significant in higher seismic zones. From sustainability and environmental perspective, steel buildings offer lower carbon emissions, support modular construction and integrate well with green technologies, whereas RCC buildings have higher lifecycle energy consumption and lower adaptability to sustainable systems.

9 Conclusion

The study evaluates and compares G+10 storey Steel green building constructed with steel SHS/RHS and Wide Flange Rolled sections mainly and conventional RCC system in seismic zone III and zone IV of India, considering structural behavior, energy demand, cost and sustainability. Results show that steel building performs better under seismic forces due to higher ductility, lower storey drift and reduced lateral displacement, while RCC building generates higher mass and base shear. Steel structure also require less embodied energy and produce lower carbon emissions because of efficient material use and recyclability. Additionally, steel construction proves more economical, with low construction cost. Overall, Steel Green Buildings offer a safer, more sustainable and cost-effective alternative to conventional RCC Buildings for earthquake-resistant urban construction.

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