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Sustainable Design of Cold-Formed Steel in The Context of Life Cycle Cost

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Abstract - The purpose of this paper is to emphasise the importance and necessity of implementing new sophisticated construction techniques in order to achieve rapid, sustainable and long-term growth in the construction sector Traditional methods such as concrete frame building and hot rolled steel erection are time-consuming, involve a lot of people and machinery, and have a high fabrication cost. Recent advancements in the subject have centered on achieving environmentally friendly, long-lasting, and cost-effective construction. CFS (Cold formed steel) system is one of those which is a dry construction and can be carried out in remote locations with greater feasibilities. CFS system is a construction technology which uses cold formed steel as the construction material, is made by compressing the steel at very cold temperatures and are made to thickness varying from 0.5-3 mm. Cold formed steel is one of the technologies which have very high potential for low rise residential and commercial buildings. This eliminates the massive reduction in construction time. Finally a comparative study is done by designing a industrial steel warehouse using conventional steel as well as cold formed steel by using a design software STAAD Pro and ETABS. This paper also compares industrial steel warehouse in terms of a life-cycle cost (LCC).

Keywords - ***CFS system, HRS system, Cost analysis, Sustainability, ETABS software, STAAD Pro Software.***

I. INTRODUCTION

In steel construction, there are two core families of structural members. One is the familiar group of hot-rolled steel shapes. The last, less familiar but of growing importance, is composed by cold-formed sections from sheets, strips, plates or flat bars in roll forming machines, by press-brake or bending brake operations. These are cold-formed steel structural members [1]. The thickness of steel sheets generally used in cold-formed steel structural members ranges from 0.5 to 3 mm for sheeting and from 1 to 8 mm for Profiles, respectively [2].

This technology is now stretching wide in India because of its flexibility and suitability for a variety of applications in lighter load bearing structures. This framing system is a full rival device that reduces the net worth and offers a significant reduction in construction time [3]. In addition to new construction, CFS system is also ideal for extending existing buildings. The system is based on the construction of a base structure by assembling a factory made cold formed galvanized steel parts and subsequently fixing paneling material to shape walls and floors with and without insulating material. For high wind zone regions, as well as seismic zones Cold formed steel framing systems is a perfect choice [4].

IS 801 (or) international code BS 5950 is used for the design of cold formed steel. The foundation for CFS is the same as for any type of construction, although the dead weight added would be much lower compared to traditional brick masonry and RCC construction. Therefore, a heavy foundation might not be required. The structure of the Cold formed steel frame is much lighter than the traditional material. Indicates that necessary foundation is therefore light. Construction is about 80% quicker. The structure has high and enhanced thermal and sound insulation and better resistance to disasters [1].

The well-designed structure ensures uniformity, long-term construction durability, and improved architectural beauty. It is environmentally friendly, as it uses totally recycled pre-engineered steel parts, and it speeds up the construction Process. These steel frame structures can be constructed in a short period of time. CFS rate analysis has been incorporated into the regular tariff plan by CPWD. BMPTC intends to establish and allow ecosystem for different streams of modern building technology with the help of the CPWD, Bureau of Indian Standards, and state

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governments. With more and more construction agencies equipping themselves with Production capabilities and improving their resilience, it is now up to the construction fraternity, especially public and private agencies, to accept these new systems for achieving, accommodating all goals, and building a more resilient India [5].

1.1 Cold formed steel characteristics

- It has consistent quality and strict requirements.
- Cold formed steel is light, robust, and easy to work with.
- It's galvanized (zinc-coated) for long-term use.
- It also has a lot of strength and stiffness to it.
- It won't shrink (or) creep as a result of moisture loss, -giving it a high-quality finish and preventing cracks.
- Noncombustible
- It's completely recyclable.

1.2 Steel building system

Steel building systems combine structural steel frames with cold formed steel secondary structural elements in cladding to create a type of structure that is structurally efficient, financially effective, and allows for a wide range of design options. The method is built around the assembly of custom formed cold forms galvanised light gauged steel structure, followed by the installation of panelling materials and a roof with (or without) insulation.

Once the specification meets IS: 801 or BS:5950 international codes, construction will Proceed as follows: foundation laying, track installation, wall panel installation with bracing as needed, roof panel installation, decking sheets, electrical & plumbing services installation, walling materials installation, roof insulation installation [1].

II. OBJECTIVES

- The study's main goal is to design, analyse, and compare cold form steel systems to traditional construction methods such as structural steel frame systems.
- The flexibility, serviceability, and economic feasibility of the cold form system as an alternative to traditional systems were also addressed in the article.
- Make design advice for such structural elements to help designers make the best and safest selections possible.
- To compare the cold form system's sustainability to traditional systems in terms of life cycle cost (LCC).

III. SUSTAINABLE DESIGN OF COLD FORMED STEEL

Sustainable construction differs from traditional construction in that it aims to achieve integrated economic, social, and environmental objectives. Direct and indirect ecological consequences, such as reduced greenhouse gas emissions and reduced water usage, are summarized in the environmental concerns. Clean, comfortable air and the usage of natural light are all social factors that are intimately tied to a structure. Beyond the building, it would include things like increasing mass transit and urban densification. The influence of a building on resources and health is considered in sustainable building design. Its goal is to save natural resources while also creating healthy indoor and outdoor settings. The development of closed loop systems to reduce the consumption of primary resources or inputs, as well as waste creation or outputs, is a principle of sustainable designs. Its goal is to encourage people to reuse and recycle as much as possible.

3.1 Environmental choice label for steel

- It must contain at least 50% recycled content and at least 15% post-consumer waste.
- It must have a total harmful heavy metal content of less than 0.25 percent. It must be made using slabs made on site, not from other sources.
- It must have a gate-to-gate embodied energy of 7.5 MJ/kg or less in its hot band condition.
- It must have a gate-to-gate embodied energy of 11.5 MJ/kg in its completed steel roll state.
- Steel mills must adopt good environmental management.
- It must sort hazardous materials into categories and make plans for reuse, recycling, or suitable disposal.

3.2 Design of adaptability

Adaptability is aided by cold formed steel because it:

- Increasing the structural strength of a structure to allow for increasing loads.
- Attachments and additions to the existing structure, on plan or elevation, are made easier.
- Flexible cladding systems that adapt to change are available.
- Adding extra levels or lightweight mezzanine floors behind existing facades.
- Processes' harmful features are minimized.
- Minimizes the destructive aspects of Processes.
- Cold formed steel components were removed and reused in the deconstruction of some steel constructions.

IV. METHODOLOGY

Cold form steel sections are made by compressing steel at very low temperatures and then utilising a computerised automated equipment to bend to the desired shapes. Because the majority of the parts are automated, the modelling and design of the cold form steel structures must be done with extreme caution and precision to ensure good

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member attachment. The structural frame is built using channel sections with no lips as studs.

The structural frame is built using channel sections with no lips as studs. The same structure is modelled using hot rolled steel sections for comparison. The models are examined for the linear static case, deflection limits are confirmed according to codal regulations, and required revisions are made. After the structure's design is finished, the quantities are estimated for cost comparison. An industrial steel warehouse is chosen for the study [7].

V. ANALYSIS, MODELLING & DESIGN

Thin sheets of cold formed steel are moulded into appropriate Profiles. Buckling of the studs is a crucial criterion for failure as the thickness decreases. Local buckling, distortional buckling, and lateral torsional buckling are the three general buckling modes for cold formed Profiles.

5.1 Problem Statement

Design a Pratt type roof truss which is required for a industry building at Aurangabad with following details.

- Site Location – Aurangabad
- Building Size – 30x60 m
- Type of Truss – Pratt Truss
- Height – 8m

5.2 Design parameters

The following mechanical Properties are used for the steel cold formed sections

- Young's Modulus of Elasticity *(E)* = 2.05×10^5 N/mm^2
- Shear Modulus *(G)* = 0.79×10^5 N/mm^2
- Density *(q)* = 7.85×10^3 Kg/m^3
- Poisson's Ratio *(m)* = 0.3
- Thermal Expansion Coefficient *(a)* = 1.2×10^5 N/mm^2
- Cold form steel *(Fy)* = 550 MPa
- Hot Rolled Steel *(Fy)* = 250 MPa

5.3 Summary of Dead load, live load and wind load per panel point are

Loads	Load on each intermediate panel point	Load at end point
Dead load (DL)	2.40 kN	1.20 kN
Live load (LL)	2.85 kN	1.42 kN
Wind load (WL)	10.42 kN	5.21 kN

Table.1 – Summary of Dead, Live and Wind Load Per Panel Points

5.4 Load Combinations

From IS 800-2007, we find load factor is 1.5 for case (i) whereas for load case (ii) it is 1.2 for DL, LL and WL and 0.9 for DL and 1.5 for WL.

i. 1.5 (DL + LL)
ii. 1.2 (DL + LL + WL) (Table 4, IS 800:2007)
iii. 0.9 DL + 1.5 WL

Figure 1, 2, & 3 Shows the Dead Load, Live Load & Wind Load Per Panel Points.

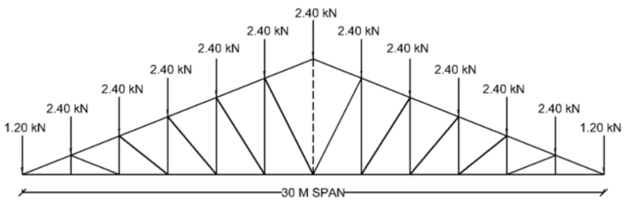

Figure.1 - Dead Load per panel point

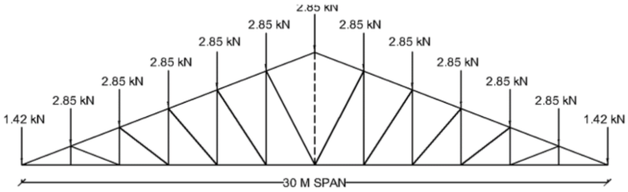

Figure.2 - Live Load per panel point

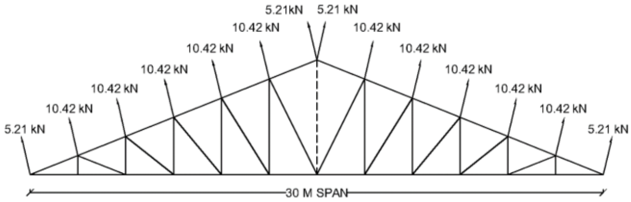

Figure.3 - Wind Load per panel point

5.5 Experimental Procedure

The entire design done in STAAD Pro V8i Series 6 and ETABS 2018.

I. Experimental Procedure in STAAD Pro.

- Open STAAD PRO. Software-File-New-Click on Space-Write the File Name and select Location-Length Units = Meter, Force Units = Kilo Newton-Next-Open structure wizard-Finish.
- Now select Prototype model-Model type-Truss models-Pratt truss-Length 30m-Height 5m-No of bays along length 12-Apply-Ok
- Then go to file-merge selected model with STAAD PRO model-yes.
- Property: Section Database-Indian-ISA100X100X8, ISA65X65X10, ISA110X110X8, ISMC300, ISMC350, ISMC400, ISLC40-Material = STEEL-Add-Close then for Assign, select the Property and click on Assign to selected beams-Assign-Yes.
- Support: Create-Fixed-Add-Now for Assign click on the Support type-Select the Support point in Truss-Assign to Selected Nodes-Assign-Yes.
- Translational Repeat: Now Select the whole structure (in View window) by using beam cursor, Translational Repeat-Global Direction =Z-No. of Steps = 10-Spacing= 6-Click on Link Steps-OK.
- Load & Definitions: Load Cases Details-Add-Loading Type = Dead-Title = Dead Load or DL-Add-Loading Type = Live-Title = Live Load or LL-Add -Close.-DL-Add-Self weight-Direction = Y, Factor = -1-Add-Close. Then SELFWEIGHT Y-1-Assign To View-Assign-Yes.-For Given loads: Again Dead Load or DL-Add-Nodal Load-

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Fy = -2.40 kN on intermediate panel points and -1.20 kN on end panel points- then Add-Live Load or LL-Add-Nodal Load -Fy = -2.85 kN on intermediate panel points and -1.42 kN on end panel points- then Add-Wind Load or WL-Add-Nodal Load-Fy = -10.42 kN on intermediate panel points and -5.21 kN on end panel points Add-Close, then click on defined force and select the required Nodes-Assign to selected Nodes-Assign-Yes.

- Load Combination: Load Cases Details-Add-Auto load Combinations –select steel load combination code-Indian-steel load combination category-general structure-add-close.
- Analysis and Result: From left side click on Analysis/Print-Static Check or All-Add-Close. At Menu bar-Analyze-Run Analysis-Go to post Processing mode-Done-Selected load cases-Apply-OK. For Support Reactions use node cursor and double click on the support point-Reactions. Then get the Table for all Support Reactions. For Beam Forces: From left side click on Beam-Graphs the find out Shear force and bending moment values.

II. Experimental Procedure in ETABS.

- After software has opened click on New Model - Opens Model Initialization dialogue box Enter Units, Concrete, steel code details- Ok
- Now give Grid Dimensions and storey Dimensions of building.
- Go to Define-Select Material Properties-Add Steel Grade (Fe550).
- Go to Define-Select Section Properties-Frame Sections- Add new-Auto selection list-Property name (beam & column) - ISA100X100X8, ISA65X65X10, ISA110X110X8, ISMC300, ISMC350, ISMC400, ISLC40 & Shift-Ok.
- Select Quick draw Beam-Draw beams as per industrial steel warehouses with given dimensions.
- Select the entire warehouses-Edit-Replicate (dx, dy, numbers)
- For bracing go to edit-Edit frames-Divide frames-Apply.
- Draw-Beam/Col/bracing-Quick draw braces-Go to Elevation view-Draw.
- Select Assign-Joints-Restraints (fixed for cold form) (hinged for hot steel)-Assign.
- Define-Section Properties-Slab sections-Add new Property- Property name : roof (thickness)-Ok
- Define-Load patterns-Add new load-Dead, Live, Wind-Ok.
- Assign-Joint Loads-Force-Dead Load (2.40 kN on intermediate panel point and 1.20 kN on end panel points)-Direction: Gravity-Ok
- Assign-Joint Loads-Force-Live Load (2.85 kN on end panel points and 1.42 on end panel points)-direction: Gravity-Ok
- Assign-Frame Loads-Point-wind load (10.42 kN on intermediate panel points and 5.21 kN on end panel points)-Direction: Local 2-Ok
- Define-Load combinations-Add default design combination- Steel frame design-Ok.
- Analyze-Check model-No warnings should be generated. (If any warnings are generated again repeat the Process)
- Analyze-Run Analysis.
- Start steel design-View/ preferences-Start design.
- Results- See Plan, 3D view, Shear Force & Bending Moment.

The sectional Property obtained from the design of Hot rolled steel and Cold formed steel by using STAAD Pro & ETABS software shown in Table 2, 3, 4 & 5, and 3D view of HRS & CFS structure in STAAD Pro & ETABS Are shown in Figure 4(a), 4(b), 5(a), 5(b).

Table 2. Weights of hot rolled steel (Software used- STAAD Pro)

Section Property	Weight (kN)	Total Weight (kN)
ISA 100X100X8	160.382	911.301
ISMC 300	97.810	
ISMC 400	26.956	
ISMC 350	167.337	
ISLC 400	236.469	
ISA 110X110X8	189.160	
ISA 65X65X10	33.186	

Table 3. Weights of hot rolled steel (Software used- ETABS)

Story	Weight (kN)	Total Weight (kN)
Story 2	23.63	1036.33
Story 1	803.11	
Base	209.59	

Table 4. Weights of cold formed steel (Software used- STAAD Pro)

Section Property	Weight (kN)	Total Weight (kN)
250CU80X5	522.029	522.029

Table 5. Weights of cold formed steel (Software used- ETABS)

Story	Weight (kN)	Total Weight (kN)
Story 2	17.09	516.19
Story 1	452.1	
Base	47	

Figure.4. (a) 3D view of 30 m span of HRS structure in STAAD Pro.

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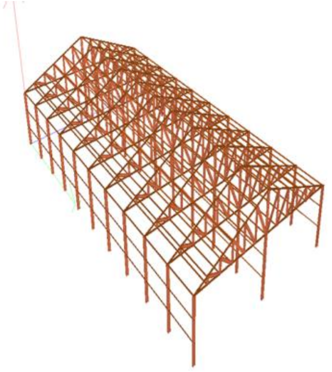


Figure.4 (b) 3D view of 30 m span of CFS structure in STAAD Pro.

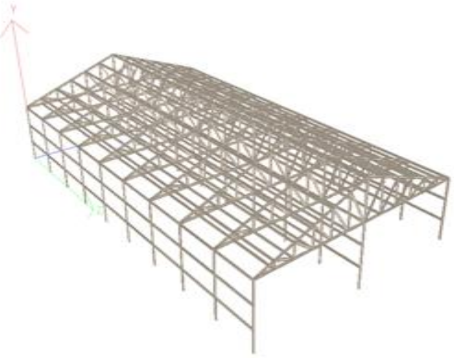


Figure.5 (a) 3D view of 30 m span of HRS structure in ETABs.

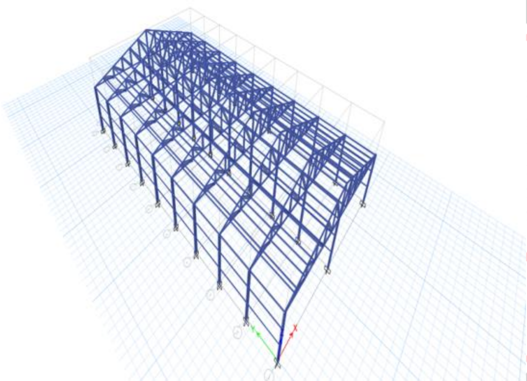
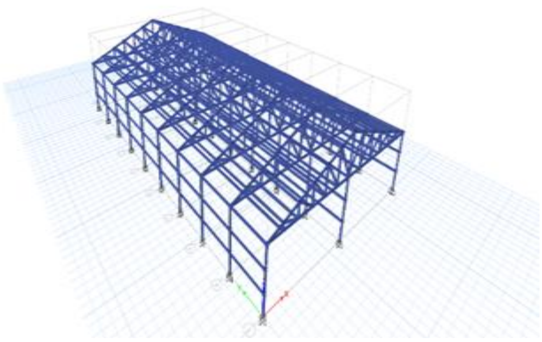


Figure.5 (b) 3D view of 30 m span of CFS structure in ETABs.



VI. CONCLUSION

The design study of a cold form steel structure is presented in this paper, along with a comparison to structural steel. For the comparison, an industrial warehouse roof truss is used. The paper outlines the overall construction Process, Weight comparison, Cost comparison as well as the need for and importance of using cold form technologies to replace traditional structural systems.

The structure's cost and time are compared, and the following conclusions are derived.

- The results prove that the Structural weight of the CFS system is 50.37 % less than that of HRS systems.
- When compared to the HRS system, the CFS system has a lower material cost, which extends its advantages in terms of manpower, labour cost, and building time. CFS systems are reported to be 55.31 % less expensive than HRS.
- For midrise structures, the CFS method appears to be the greatest alternative, sustainable construction technique to traditional construction systems.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Akash D. Kumbhar : Visualization, Conceptualization, Methodology, Supervision, Writing - review & editing.
Sachin B. Salve : Conceptualization, Methodology, Supervision, Writing - review & editing.
Dr. G.R. Gandhe : Supervision.

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