COMPARATIVE STUDY OF TRADITIONAL TRUSSES AND CELLULAR BEAMS AND TAPERED BEAMS

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ABSTRACT

The traditional roof truss system takes a long time to construct and is challenging to maintain. Because of the truss geometry's large vertical void, utility services are also combusted. The use of castellated beams in a variety of structures is quickly becoming more popular. This is because they have a high strength to weight ratio, a deeper section without adding weight, and require less upkeep and painting. The main benefits of castellated beams are their increased vertical bending stiffness, ease of maintenance, and appealing look. The goal of the study is to determine which cellular beam system is more cost-effective and structurally appropriate when compared to the standard truss system. The primary goal of this study is economy. It compares various cellular beam systems which can be designed and analyzed using SAP2000 Software with the traditional Howe truss. The purpose of this study is to calculate the percentage weight and economy that the cellular beam system achieves over the traditional truss system. A 40-meter-long shed with 12-, 17-, and 22-meter spans has been taken for the analysis. The study reveals that the spine cellular beams are significantly better in economy as compared to conventional truss system.

Keyword: - Conventional truss, Castellated beam, Cellular beam, Economy, Spine cellular beam.

1. INTRODUCTION

An industrial building is any structure used by the industry to house raw materials or manufacture products for the industry. Normal type industrial buildings and Special type industrial buildings are two categories for industrial buildings. Cellular beam constructions or traditional truss structures may be used to build the industrial building. Trusses are triangle frame structures where an externally imposed load effectively subjects the members to axial forces. In order to withstand gravity loads, trusses are utilized in the roofs of multi-story buildings, long span floors, and single-story industrial buildings. Over time, it has been noted that the roof truss system takes a long time to install and is challenging to maintain. Additionally, the truss shape leaves a large amount of vertical space empty, which is problematic for utility services. As a result, a novel option that could replace the truss system is the use of tapered, castellated, and spine cellular beams. Cellular or castellated beams are those with holes in the web section of the beam. It is now considered a good engineering practice to provide beams with web apertures, as this reduces the chance that a service engineer will cut holes later on in the wrong place. The most recent advancement in conventional beam technology that satisfies the necessary criteria is the Castellated beam. More and more engineers are using castellated beams in their designs because of its advantages in both construction and design. Improved flexural stiffness (lateral section modulus) and decreased weight per unit length of the beam are two benefits of the design. One advantage of construction is that utilities can be run via the opening. The purpose of this study is to calculate the percentage weight and economy that the cellular beam system achieves over the traditional truss system.

2. LITERATURE REVIEW

A substantial research work has been done and is going on the analysis of trusses and cellular beams. The research work done by various researchers in discussed here in brief.

Nikos D. Lagaros, Lemonis D. Psarras, Manolis Papadrakakis, Yiannis Panagiotou.(2008) The goal of this effort is to construct 3D steel structures with perforated I-section beams as optimally as possible. The optimization problem is expressed as an optimization problem that combines topology, size, and shape. The sizing design factors for columns and beams are their cross-sectional dimensions, whereas the topology and shape design variables are the quantity and size of the beams' web apertures. Depending on the finite element discretization used to simulate the structural elements, two different formulations of the optimization issue are examined. The best designs obtained are compared between the two formulations, which correspond to beam and shell discretization. By permitting web apertures in the structure's beams, a measurable reduction in the structure's weight can be achieved without compromising structural strength or serviceability criteria, as demonstrated by a typical test example.

Saneebamol, Soni Syed (2014) Structural engineers are always experimenting to come up with better designs that force the required features onto the structure. As a result, engineers developed the concept of the castellated steel beam. As CSB has hollow sections, it is crucial to ensure both its strength and load-bearing capacity. The use of stiffeners is one way to enhance the characteristics. Stiffeners are inserted both inside the castellation and in conjunction with spacer plates to facilitate finite element analysis.

B. Anupriya, Dr. K. Jagadeesan.(2014) This research uses a comprehensive finite element analysis (FEA) to investigate the shear strength behavior of a castellated beam (ANYSIS14).Although castellated beams are commonly used in industrial buildings, power plants, and multi-story structures, their web opening causes stress concentration at load application points and throughout corners. Additionally, as the depth of the opening increases, the stiffness of the castellated beams decreases. Therefore, shear stiffeners are inserted along the web opening to raise the castellated beam's shear strength and decrease its deflection. Based on the ANYSIS results, it was determined that the deflection

Flavio Rodrigues, Pedro C. G. da S. Vellasco, Luciano R. O. de Lima, Sebastião A. L. de Andrade.(2014) Due to both practical and aesthetic concerns, multi-story buildings frequently have height restrictions. Large pipes and ducts typically need to pass through substantial areas beneath steel beams, which results in unfeasible floor heights. The most widely used remedy for this problem is to create the necessary service area by using steel beam web apertures. Depending on the adopted openings' shape, size, and location, the beam load carrying capacity may be significantly reduced as a result of these openings. The current investigation was prompted by these factors and was conducted using FE simulations calibrated against test and numerical data. The precision of the results allowed for a thorough parametric study of beams with web openings, with particular attention paid to the web opening's location and profile size. The effectiveness of longitudinal stiffeners welded at the opening region and the advantages of employing a suitable edge conformance radius in beams with rectangular and square openings were also examined in this study. The obtained results demonstrated that in order to maximize the ultimate load carrying capability of the beam, welded longitudinal stiffeners were required. The ultimate load of beams with square and rectangular aperture heights equal to 0.75 H, respectively, can be increased by twice or even three times with this adoption.

Pradeep V, Papa Rao G. (2014) In any kind of industrial construction, long span, column-free structures are crucial, and Pre Engineered Buildings (PEB) meet this need in addition to taking less time and money to construct than traditional structures. This methodology's versatility stems from its light weight and cost-effective construction, in addition to its excellent predesigning and prefabrication. The design and comparative analysis of traditional steel frames with concrete columns, steel columns, and pre-engineered buildings (PEB) are presented in this article. STAAD Pro V8i is used in this study to assess and design an industrial building that is 44 meters long and 20 meters wide, with a roofing system made up of pre-engineered steel trusses and ordinary steel trusses.

Jamadar A. M., Kumbhar P. D. (2015) Because castellated beams have so many beneficial structural uses, their use is becoming more and more common. Beams that feature apertures in the web section are known as cantillated beams. Hot rolled steel (HRS) I section webs are cut into zigzag patterns and then rejoined over one another to create castellated beams. Generally speaking, the holes created in the webs are square, diamond, round, or hexagonal in shape. The size and form of the apertures produced in the web are therefore always a significant factor to consider when evaluating the structural performance of the beam. There is a need to improve the beams with various shaped openings because a lot of research has been done on optimizing the diameters of castellated beams with hexagonal openings. While alternative shaped holes, such as circular or diamond shapes, can help reduce the local failure linked to the castellated beam. Thus, in order to maximize the size of the castellated beam, a parametric study of the beam with circular (cellular beam) and diamond-shaped openings has been conducted in this paper. This study takes into account the ratios of the overall depth of the castellated beam to the depth of the opening provided (D/Do) and the spacing of the opening to the depth of the opening (S/Do). Using Abaqus/CAE 6.13 software and adhering to Eurocode 3 guidelines, a finite element analysis (FEA) of the beam has been conducted for various opening sizes. The von-misses failure criteria is utilized to determine the beam's failure load, and experimentation is performed to evaluate the optimized beam's findings. According to the data, the beam performs better when it has a diamond-shaped opening with an opening size that is 0.67 times the beam's whole depth. Additionally, it has been noted that castellated beams typically fail in their local modes of failure.

Ajim S. Shaikh, Pankaj B. Autade (2016) The most significant factor influencing the sectional property of the section is its depth. The moment of inertia of an I-section is directly proportional to the third power of depth, and thus plays a significant influence in serviceability. Because cellular beams' constantly shifting section properties throughout the cell make them more difficult to study, there is comparatively little research and less development on cellular beams with circular web openings than on cellular beams.

is 9.75 mm in the absence of stiffeners, 7.85 mm in the presence of diagonal stiffeners, and 3.99 mm in the presence of vertical stiffeners in addition to diagonal stiffeners.

3. METHODS OF ANALYSIS:

3.1. Static analysis: An important technique in structural engineering is static analysis, which evaluates a structure's performance and stability under a range of circumstances and applied forces. Its main goal is to guarantee that structures can withstand external loads such as wind, gravity, seismic activity, and other factors without experiencing undue stress or deformation. This analysis is based on the principles of equilibrium, which indicate that in order to preserve static balance, the net total of the forces and moments acting on the structure must be zero. In order to calculate internal forces and structural deformations, static analysis also considers a variety of loads, including as dead loads, live loads, wind loads, seismic forces, and temperature-induced impacts.

3.2. Dynamic Analysis: Through linear dynamic analysis of buildings, it is possible to examine how structures react to dynamic forces such as earthquakes, wind pressures, or vibrations brought on by human activities. The aim is to assess the behavior of the structure concerning movements, accelerations, and internal stresses. Engineers use finite element analysis to create a mathematical model of the building that takes into account its dimensions, material properties, and limitations.

3.3. Loads on trusses: The Wind load is major load in case of shades having large span and covered with trusses. The trusses are analyzed for both direction of wind and also for the uplift due to wind. Wind load combinations are worst combination for which truss need to be design. In steel structure self-weight of structure is very less to overcome the lateral forces. Hence, structure need to design with proper system to resist those loads.

4. OBJECTIVES:

The primary goals of this project can be suitably outlined as follows:

- The comparison of the standard Howe truss with the Spine Cellular Beam, Spine Castellated Beam, and Tapered Cellular Beam is done in this work.
- The analysis is carried out for 12m, 17m and 22m respectively.
- The analysis is done for the Pune region.
- The analysis is carried out to obtain the structural performance under gravity and wind load. In this study three types of truss configuration is considered i.e Spine Cellular Beam, Spine Castellated Beam, Tapered Cellular Beam.
- For the analysis we considered three truss. Analysis is done in SAP2000 software

- Executing wind Analyzing and contrasting the configuration and design elements of the three truss types, as well as comprehending their positive and negative features, will help you design the structure properly for a range of truss spans.
- Comparative Study: Conduct a comparative study between the conventional truss with cellular beam Compare their structural behaviour, construction feasibility, material requirements, and cost implications. Analyse the advantages and disadvantages of each system to determine their suitability for the given project.
- Structural Performance Evaluation: Analyze the building's ability to withstand various loading scenarios, including seismic and gravity forces. Examine characteristics including story displacement, base shear, story drift, and bending moment to ensure compliance with code requirements and recommended performance standards.
- Comparison between conventional truss and respective cellular truss consideration for the results obtained.

4.1. Software's used in analysis:

SAP2000: With the new SAP2000, complete analysis and design for any size or kind of structure can be completed faster than ever. Use a physical model in SAP2000 that is immediately transformed into the analytical model for your structural study to streamline your BIM workflow. SAP2000 is frequently used by structural engineers in the assessment, design, and analysis of many building and structure types.

AutoCAD 2017: The computer-aided design (CAD) program AutoCAD 2017, created by Autodesk, is extensively utilized in many different sectors, including manufacturing, engineering, architecture, and construction. To increase design productivity and efficiency, it provides a number of new features and improvements. Many enhancements were made to AutoCAD 2017 to increase 2D drafting and documentation capabilities.

4.2. Types of truss configuration:

The different types of truss configuration is considered for this study is as follow.

1. Conventional truss.
2. Spine Cellular Beam.
3. Spine Castellated Beam.
4. Tapered Cellular Beam.

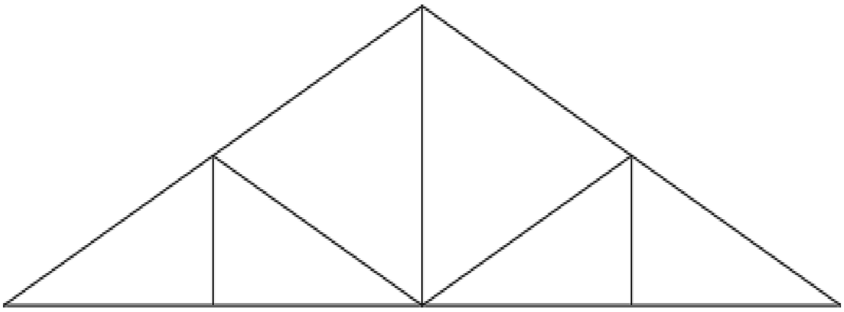

Figure 1 Conventional Howe Truss

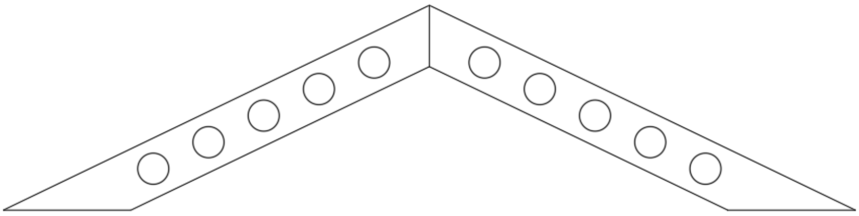

Figure 2 Spine Cellular Beam

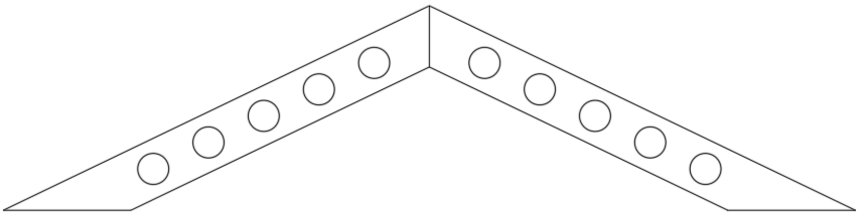

Figure 3 Spine Castellated Beam

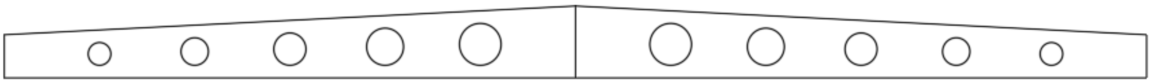

Figure 4 Tapered Cellular Beam

5. METHODOLOGY

5.1. **Pathway followed for the analysis**: Using the appropriate software, it is suggested to perform a gravity and wind study of a truss with prismatic sections, taking into account both wind and gravity forces. This will allow for the following results. SAP software is used in this study to analyze the construction utilizing finite elements. Using finite element analysis, this software provides the deflection, shear stresses, and bending stresses for the beams. After manually calculating the loading on the structure, SAP is used to define the structure. The traditional Howe truss system, spine cellular beam system, spine castellated beam system, and tapered cellular beam system have all been taken into consideration for the study's analysis for a 40-meter shed with spans of 12, 17, and 22 meters as well as an eaves height of 10m. In accordance with IS: 875-1897, the trusses have been examined for dead load, superimposed load, wind load, and combinations. The similar construction has been used for the cellular beam structure. Bay lengths are kept at 4-meter intervals along their length. In general, the roof's slope for this construction is calculated to be 25.64˚. The building's eaves height has been determined to be 10 meters. Welded connectors are the connection type offered. The usual Howe truss configuration and loading selection are displayed below.

Span of Truss in m	Dead Load In KN		live load in KN		Wind load In KN					
					Windward			Leeward		
	At Internal Node	At End Node	At Internal Node	At End Node	At Internal Node	At End Node	At Ridge node	At Internal	At End Node	At Ridge node
12m	4.53	2.876	5.86	3.72	15.185	9.65	7.6	14.39	9.137	7.195
17m	4.59	2.95	5.532	3.58	14.33	9.22	7.165	13.58	8.733	6.79
22m	3.71	2.54	4.29	2.89	10.25	7.014	5.125	9.37	6.413	4.685

Table-1 Load considered for analysis

Selection of configuration and loading for spine cellular beam, spine castellated beam, tapered cellular beam is shown below,

Span of Beam in m	Spine Cellular beam			Spine castellated Beam			Tapered Cellular Beam			
	Loading in KN/m2	Depth of beam in m	No of openings	Loading in KN/m2	Depth of beam in m	No of openings	Loading in KN/m2	Depth of beam in m		No of openings
								at End	at Center	
12m	46.22	250	10	46.22	250	10	46.22	250	450	10
17m	29.64	300	14	29.64	300	14	29.64	350	650	14
22m	29.64	400	18	29.64	400	18	29.64	500	750	18

Table-2 Truss configuration and loading.

6. RESULTS AND DISSCUSSION

The following findings have been drawn from the current study's analysis and comparison of the traditional Howe truss, spine cellular beam, spine castellated beam, and tapered cellular beam based on deflection, weight, and cost:

SPAN	**12m**	**17m**	**22m**
CONVENTIONAL TRUSS	3.15	11.03	21.92
SPINE CELLULAR BEAM	1.923	2.152	2.327
SPINE CASTELLATED BEAM	1.752	1.53	1.98
TAPERED CELLULAR BEAM	9.32	20.369	34.32

Table-3: Deflection (mm) Comparison of Howe Truss, Spine Cellular, Spine Castellated and Tapered Cellular Beams.

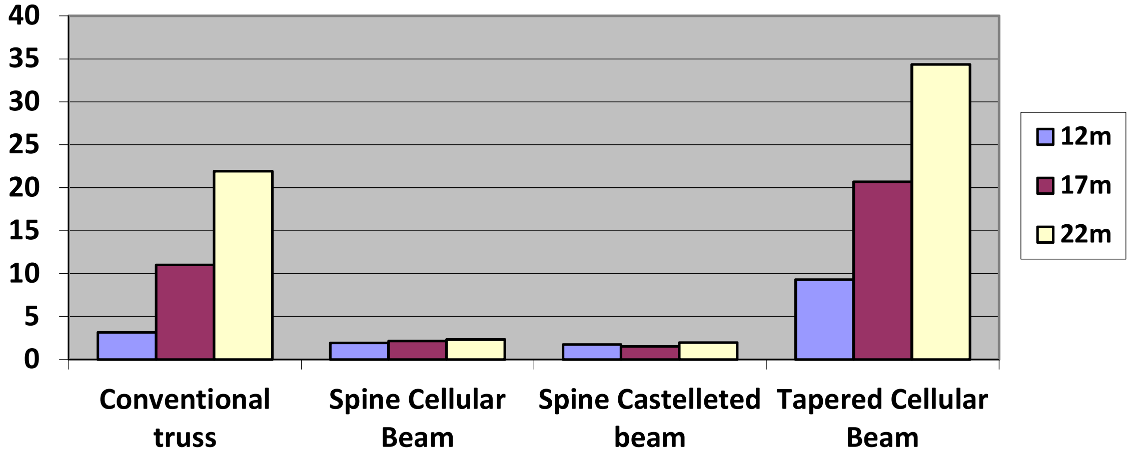

Chart -1: Deflection Comparison of Howe Truss, Spine Cellular, Spine Castellated and Tapered Cellular Beams.

The following conclusions can be drawn from Table 3 and Chart 1 of the Deflection Comparison: Deflection of the Spine Cellular Beam and Spine Castellated Beam are almost equal.

Comparing the Spine Cellular beam to the Conventional Howe truss, the deflection is reduced by 38.95% for a 12 m span, 80.49% for a 17 m span, and 89.38% for a 22 m span.

Comparing the Spine Castellated beam to the Conventional Howe truss, the deflection is reduced by 44.38% for a 12 m span, 86.12% for a 17 m span, and 90.96% for a 22 m span.

Comparing the Tapered Cellular beam to the Conventional Howe truss, the deflection is increased by 66.20% for a 12 m span, 45.85% for a 17 m span, and 36.13% for a 22 m span.

SPAN	12m	17m	22m
CONVENTIONAL TRUSS	260.26	815.4	1707.41
SPINE CELLULAR BEAM	235.42	792.125	1492.629
SPINE CASTELLATED BEAM	239.36	736.16	1463.54
TAPERED CELLULAR BEAM	392.6	936.325	1893.6

Table-4: Weight (Kg) Comparison of Howe Truss, Spine Cellular, Spine Castellated and Tapered Cellular Beams.

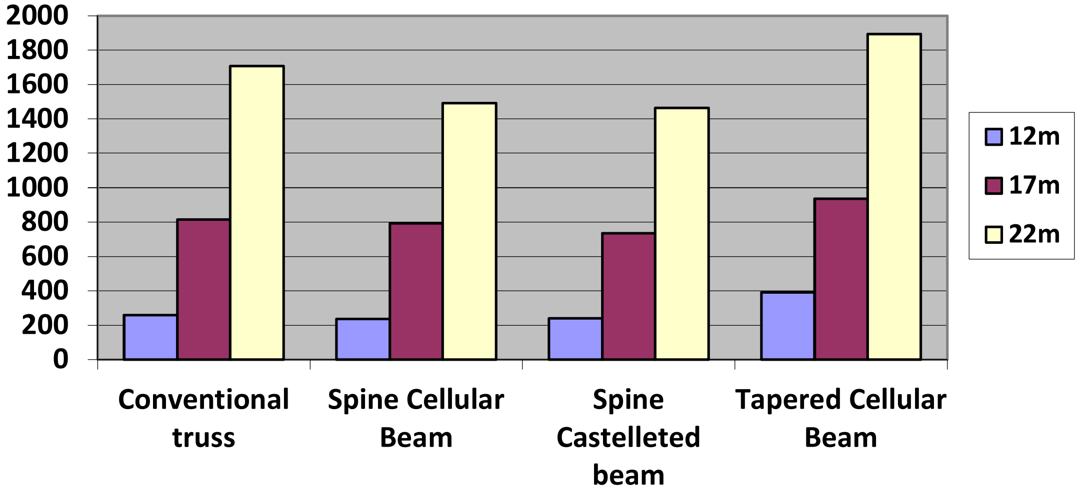

Chart -2: Weight Comparison of Howe Truss, Spine Cellular, Spine Castellated and Tapered Cellular Beams.

The following observations are drawn from Table 4 and Chart 2 of the weight comparison: as we used the identical sections for the spine cellular beam and the spine castellated beam, both beams have the same weight.
In comparison to the conventional Howe Truss, the weight of the Spine Cellular and Spine Castellated beams is reduced by 8.73% for a 12 m span, 10.76% for a 17 m span, and 16.66% for a 22 m span.
In comparison to Tapered Cellular beam, the weight of Spine Cellular and Spine Castellated beams is reduced by 66.76% for 12 m span, 27.19% for 17 m span, and 29.38% for 22 m span.

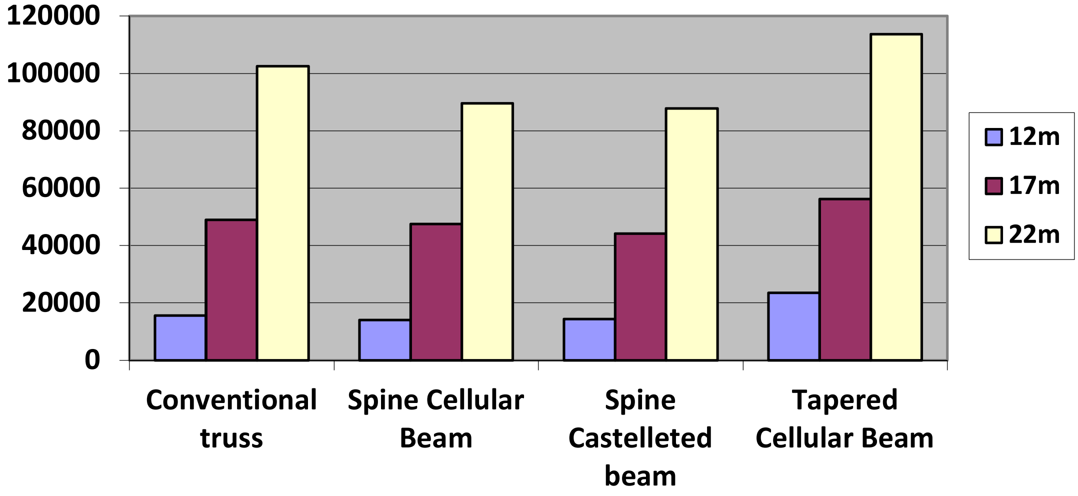

Chart -3: Cost Comparison of Conventional Howe Truss, Spine Cellular Beam, Spine Castellated beam, Tapered Cellular Beam

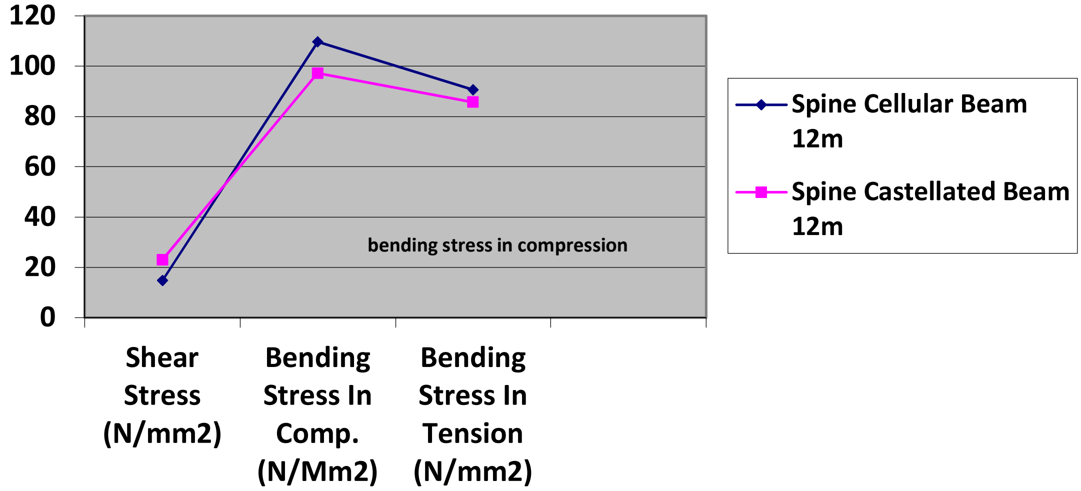

Chart -4: Shear and Bending stress comparison of Spine Cellular beam and spine castellated beam for 12m span.

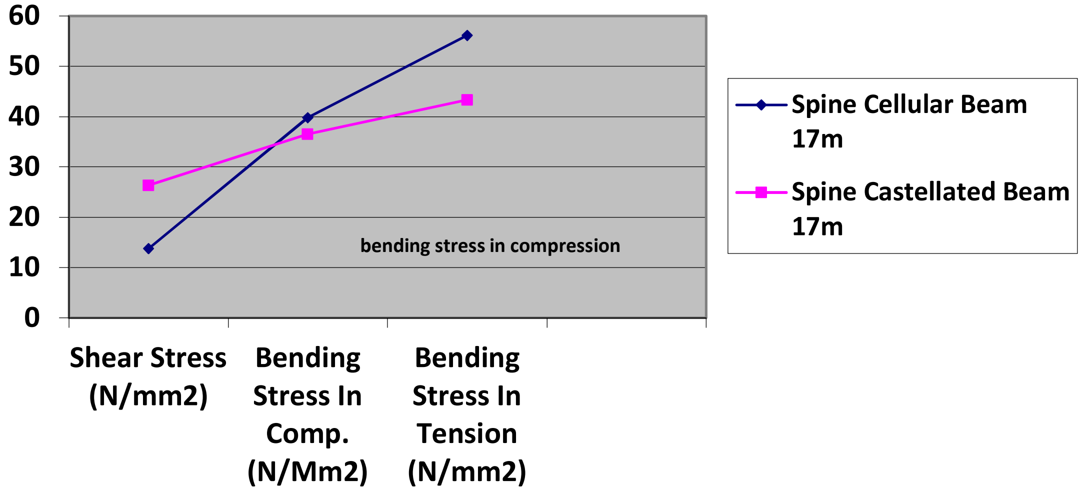

Chart -5: Shear and Bending stress comparison of Spine Cellular beam and spine castellated beam for 17m span.

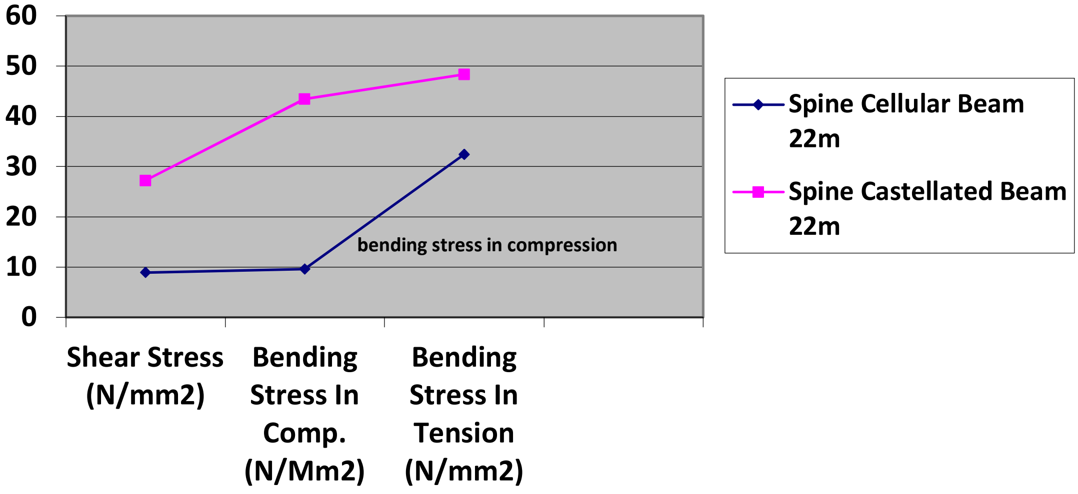

Chart -6: Shear and Bending stress comparison of Spine Cellular beam and spine castellated beam for 22m span.

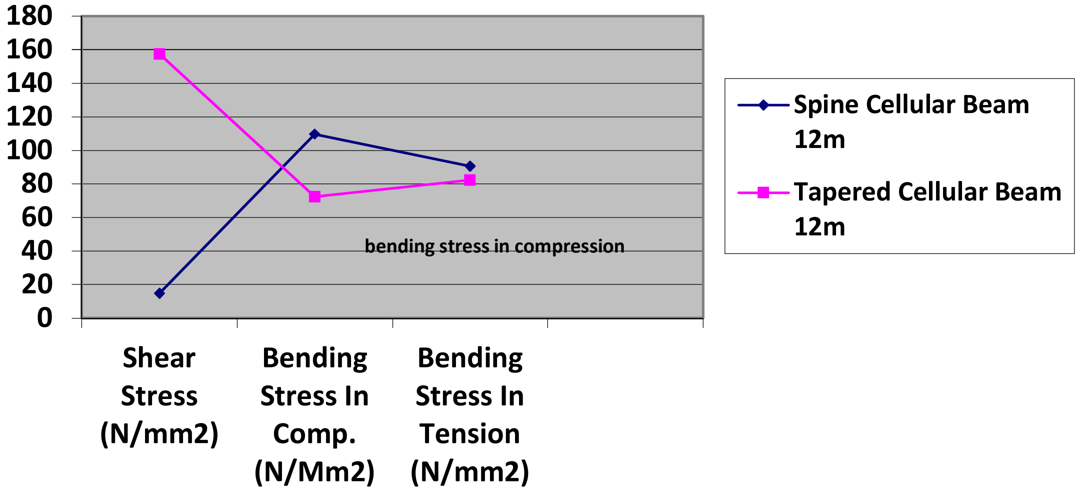

Chart -7: Shear and Bending stress comparison of Spine Cellular beam and Tapered cellular beam for 12m span.

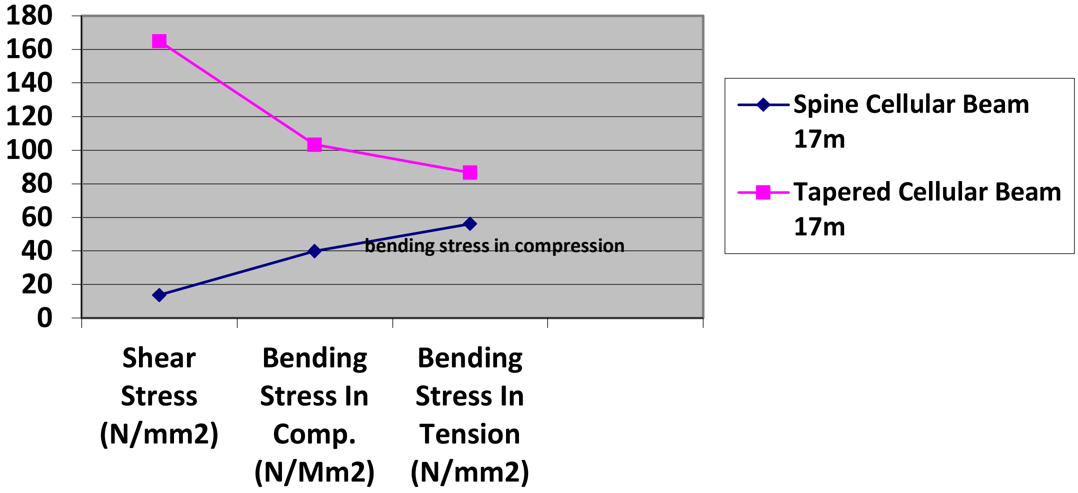

Chart -8: Shear and Bending stress comparison of Spine Cellular beam and Tapered cellular beam for 17m span.

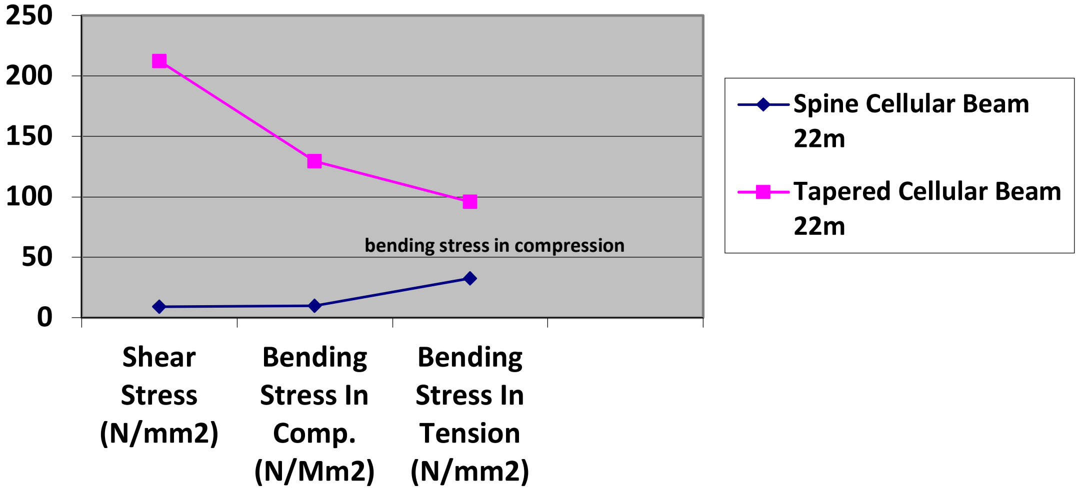

Chart -9: Shear and Bending stress comparison of Spine Cellular beam and Tapered cellular beam for 22m span.

7. CONCLUSIONS

All the work done in this dissertation work is concluded in this chapter. Also the future scope of the study has been given at the end of this chapter.

After comparison of results obtained from all the analysis, it is concluded that,

- The advantages of the spine cellular beam and spine castellated beam over the traditional Howe truss are better in terms of deflection, weight, and cost, all of which are broken down into percentages below.
- For spans of 12 m, 17 m, and 22 m, the percentage weight and cost saved by spine cellular beam and spine castellated beam over traditional Howe truss are 8.73%, 10.76%, and 16.66%, respectively.

- For spans of 12 m, 17 m, and 22 m, the percentage weight and cost attained by spine cellular beam and spine castellated beam over tapered cellular beam are 66.76%, 27.19%, and 29.38%, respectively.
- The next section compares the % deflection of a spine cellular beam, spine castellated beam, and tapered cellular beam to a standard Howe truss.
- When compared to a traditional Howe truss, the deflection of the spine cellular beam is reduced by 38.95% for a 12 m span, 80.49% for a 17 m span, and 89.38% for a 22 m span.
- When compared to a traditional Howe truss, the deflection of a spine castellated beam is reduced by 44.38% for a 12 m span, 86.12% for a 17 m span, and 90.96% for a 22 m span.
- Compared to a traditional Howe truss, the deflection of a tapered cellular beam is greater by 66.20% for a 12-meter span, 45.85% for a 17-meter span, and 36.13% for a 22-meter span.
- When compared to a spine castellated beam, the shear stress concentration in a spine cellular beam is lower by 35.89% for a 12-meter span, 47.70% for a 17-meter bridge, and 67.21% for a 22-meter span.
- In comparison to a spine castellated beam, the bending stress in compression for a spine cellular beam is more by 11.35% for a 12-meter span, 8.28% for a 17-meter span, and less by 77.86% for a 22-meter span.
- In comparison to a spine castellated beam, the bending stress in tension for a spine cellular beam is more by 7.58% for a 10-meter span, 26.78% for a 15-meter bridge, and less by 28.42% for a 20-meter span.
- From the above conclusions it is clear that the Spine Cellular beam system is better for use as well as economical as compared to Conventional Howe truss system and Tapered Cellular beam system.

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9. AUTHORS CONTRIBUTION

The author[1] has done research on the project and have written the research paper under the guidance of author[2] and reviewed by author[2].

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11. DECLARATION

Conflict of interest: All authors made equally significant contributions to the work, at least according to the author's understanding. We can confidently assert that the authors have no conflicts of interest.

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