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DESIGN AND PERFORMANCE EVALUATION OF CURVED STRUCTURES USING STAAD.PRO

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Abstract — This study involves the structural analysis and design of curved structures, such as roofs and bridges, utilizing STAAD Pro software to evaluate their performance under various load conditions, including wind and gravity loads. This design mainly stimulates from the design on CAD designs.

The process entails creating a 3D model, defining geometric properties and structural loads, and conducting ananalysis to determine internal forces like bending moments and shear forces. The results then inform the design of members to meet strength and serviceability requirements, often comparing curved structures to their straight counterparts and highlighting STAAD Pro efficiency for complex geometries and large-span projects.

These projects are mainly used for different types of structures in the construction field. It also proves that these types of designs give different type of view for the buildings and in their architecture point of view.

Index Terms — Curved structures, STAAD.Pro, Aesthetic and Structural Efficiency, Modelling Curved Elements, Load Considerations, Comparison with Straight Structures, Performance Evaluation.

I. INTRODUCTION

Curved structures represent one of the most elegant and efficient forms in structural engineering. Unlike straight members, curved beams, arches, domes, and shells distribute loads more naturally, often reducing bending stresses and enhancing stability. Their geometry allows architects and engineers to achieve both aesthetic appeal and structural economy, making them popular in bridges, stadium roofs, auditoriums, and modern architectural landmarks.

STAAD Pro, as a versatile structural analysis and design software, provides the computational power to handle these complex geometries. By using its finite element modeling capabilities, engineers can simulate how curved members respond to different loads : dead, live, wind, or seismic and evaluate stresses, deflections, and stability. The software integrates international design codes, enabling engineers to check compliance automatically and optimize sections for safety and cost-effectiveness.

When analyzing curved structures in STAAD Pro, the focus is not on linear step-by-step commands but on understanding the behavior of curved geometry under loads. Curved beams experience combined bending and axial forces, arches rely on compression for strength, and shells distribute loads across their surfaces. STAAD Pro’s ability to model these behaviors in three dimensions makes it invaluable for engineers working on projects where precision and efficiency are critical.

II. LITERATURE REVIEW

A. Shaowei Xu (2024) Research on Topology Optimization Design of Truss Structure This study uses topology optimization to improve truss designs, reducing material usage while ensuring load bearing efficiency. It focuses on achieving sustainable and cost-effective structural solutions. Simulations demonstrate the advantages of optimized trusses for complex load distributions.

B. Singh, Roy (2023) Effects of Roof Slope and Wind Direction on Wind Pressure in Low-Rise Buildings This research explores how roof angles and wind directions affect wind pressure distribution. Pitched roofs experience higher uplift forces, requiring special design considerations. The study offers valuable insights for improving roof stability under strong winds.

C. Watane, Dahat (2023) Comparative Study on Pratt and Howe Trusses Using STAAD Pro This paper evaluates Pratt and Howe trusses using STAAD Pro, finding that Howe trusses are more stable for longer spans. Pratt trusses perform better for shorter spans. The results guide efficient truss selection for various structural needs.

D. Parthasaarathi R., Kabilan G., Karthick V., Chandru D., Dhamotharan K. (2022) Comparative Study on Analysis and

Design of Structural Steel Elements with Indian and American Codes This paper compares steel structures designed with Indian (IS 800) and American (AISC 360) codes

using STAAD.Pro. It highlights differences in stress ratios, deflection, and bending moments, showing that AISC designs often provide higher strength. The study aids in selecting standards for safe and economical structures.

E. Peng et al. (2022) Reliability Analysis of Large Curved Roofs Under Wind and Snow This study evaluates curved roofs under combined wind and snow loads using computational models. The findings reveal high- risk scenarios, prompting design improvements. The research enhances roof resilience to extremeweather.

F. Prabhodana (2020) Design and Analysis of Industrial Warehouse This paper uses STAADPro to design industrial warehouses, ensuring efficient load management and compliance with IS codes. The results demonstrate cost-effective and safe designs. It highlights STAAD.Pro's capabilities for large industrial structures.

G. Bhattacharyya, Dutta (2019) Comparative Analysis of Pratt and Howe Trusses This research compares Pratt and Howe trusses, showing Howe trusses are better for longer spans. Pratt trusses are more suitable for shorter spans. The study helps in selecting trusses for different structural needs.

H. Babu et al. (2019) Design of Curved Arch Truss for Auditorium Hall This study optimized curved truss designs, finding pipe sections more stable and economical than tube sections. STAAD.Pro analysis demonstrated improved efficiency. The findings aid in cost-effective auditorium roof design.

I. Baby et al. (2019) Space Truss Design Using STAAD.Pro This research designed space trusses for large open spans, ensuring durability and material efficiency. STAAD.Pro was effective in modeling these structures. The results support space trusses for arenas and exhibition halls

III OBJECTIVES

1. Generation of structural framing plan.
2. Creation of model of structure in STAAD PRO
3. Application of various load combinations on the member.
4. Analysis of the structure.
5. Design of the structure.
6. Useful for the high-end structure.
7. It is a more efficient way of building the structure.
8. It shows us different ways structure and its application.

IV. METHODOLOGY

✓ *STRUCTURE*

ASTRUCTURE can be defined as an assemblage of elements. STAAD is capable of analyzing and designing structures consisting of both frame and Finite elements. Almost any type of structure can be analyzed by STAAD.

Frame elements Beam elements – 2 nodes Finite elements

1) Plate -3 or 4 nodes
2) Solid – 4 to 8 nodes

In case of STAAD:

Nodes becomes Joint (it has a number and xyz coordinates) Beam

Becomes Member (it has a number and nodes at its ends) Plate Becomes Element (it has a number and node at its corners)

✓ *TYPES OF STRUCTURE*

A TRUSS structure consists of truss members which can have only axial member forces and no bending in the members.

A PLANE structure is bound by a global X-Y coordinate system with loads in the... (The sentence is incomplete in the extracted text).

Additional context from the AI-Enhanced Description:

The presentation's content description indicates that the slides (5-6) on "Understanding Structures" cover:

Definition of structures and classification into truss, plane, space, and floor types.

✓ *COMMANDS USED IN STAAD.PRO:*

1. Snap Node/Beam
2. Nodes cursor
3. Plates cursor
4. Add beam
5. Add 4 node plates
6. Add surface
7. Insert node and its application
8. Shift+ B - shows the number of beams
9. Shift+ N - shows the number of nodes
10. Translational Repeat-This command is usually used to repeat the element in liner direction
11. Circular Repeat-This command is usually used to repeat the element in radial direction
12. Member Load – It is adopted only on horizontal members and vertical members

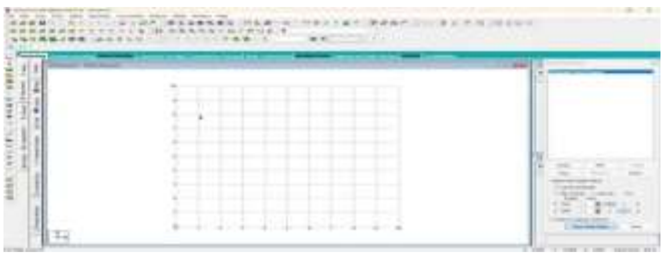
Open page of the STAAD.Pro

✓ *COMMANDS USED IN CURVED STRUCTURE:*

1. GEOMETREY

2. TRANSLATIONAL REPEAT
3. CUT SECTION
4. CREATE RENDERING VIEW
5. ADD PROPERTIES
6. SUPPORTS
7. LOAD CASES DETAILS
8. SELECT PARAMETERS
9. DEFINE PARAMETERS
10. DESIGN COMMANDS
11. ANALYSIS AND PRINT
12. CIRCULAR REPEAT

Interface of the STAAD.Pro



Points to be remember while designing:

- First draw the structure to be designed using nodes, beams, plates and surfaces.
- While drawing important thing to be considered is first complete the small element of the portion then repeat that for a whole structure.
- Then assume the material, properties, dimensions of the elements.
- Then define various loading conditions.
- At last, analyze the structure.

TOOLS USED

All these options is used to see the view of structure from various side

Rotation can be done by rotating the options

To zoom the structure and return of previous these are required

If you want to return the whole structure use this

To see the 3D render view use option

3D Modeling

The process begins by creating a detailed 3D model. A key technique is to simulate the curve using a series of straight-line segments (a piecewise model).

Defines the precise geometry based on initial CAD plans.

This "straight segment" method allows for detailed analysis, as STAAD.Pro's native "curved beam" element has limitations.

Material properties (e.g., concrete, steel) are assigned.

Strength Requirements: The analysis results are used to inform the final design. Members are sized to meet strength requirements based on the calculated internal forces (moments, shear).

Serviceability: The structure is checked to ensure it meets serviceability requirements, such as limits on deflection, to ensure user comfort and structural integrity.

Code Compliance: The final design is verified against relevant building codes and standards (e.g., IS 456) to ensure safety and compliance**.**

Key Aspects of Curved Structures: -

Aesthetic & Structural Efficiency

Curved forms are not just for aesthetics; they can be highly efficient in distributing loads, especially for large-span projects

Modeling & Load Complexity

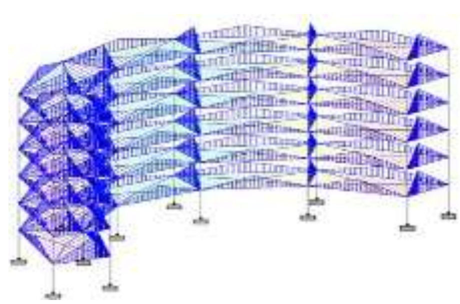
Accurately modeling the curved elements and considering the unique, often asymmetrical, impact of wind loads are the primary challenges.

The Role of STAAD.Pro

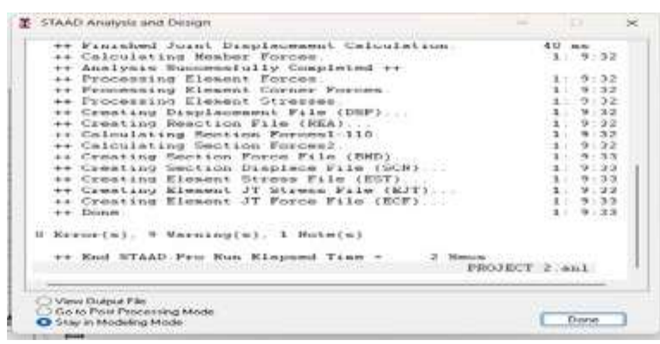
"STAAD.Pro shows high efficiency for complex geometries and large-span projects"

V. CURVED STRUCTURES

1. Click on STAAD.Pro icon → Select New Project → Select Space → Select File Name → Select Location → Select Unit → Click on Next → Click on Finish.
2. User interface opens with grid system → Keep it in Front View → Go to Edit option in Grid → Change the length and breadth to 5m → Click on OK
3. Click on Snap/Grid option → Select node 0 to 30 m in Y direction → Select node 5 to 10 m in X direction → Join the nodes in X direction up to 0 to 30 m in Y direction → The shape becomes Rectangle.
4. Click on Snap/Grid option → Select a node 0 to 30 m in Y direction → Remove the default grid setting.
5. Click on Circular Repeat → Select axis of rotation (Y-direction) → Enter Total Angle (e.g., 160°) → Enter Number of Steps (e.g., 5) → Select node to point the centre of structure → Click on Link Steps → OK.
6. Click on whole structure → Place in the Isometric View → Delete / Remove the centre beam.
7. Keep the structure in front view → Delete / Remove the bottom beam of structure.
8. Select the second beam from the bottom → Click on Cut Section → Click on Select to View → Click on OK → Select the second beam from the bottom.
9. Keep it in Isometric view → Select 4 noded plates → Select the nodes of 5 steps → Click on Whole Structure → Select the plate cursor → Select whole structure.
10. Click on Translational Repeat → Select Y direction → Select No. of steps → Set the spacing → Click on Link Steps → Click on OK.
11. Click on General → Select Support → Keep the structure in front view → Click on Create → Select Fixed Support → Click on Add.
12. Select the support → Click on Assign → Use cursor to assign → Click on Assign.
13. Click on Material → Select Concrete → Click on Create → Select title as Concrete in display bar → Edit title as M20 → Change the density as 25 → Click on Add → Close.
14. Now add M20 grade by selecting Assign to View → OK.
15. Go to Property → Select Define → Select Circular → Circle dimensions 600 mm in Y- direction → Select material as M20 → Click Add.
16. Select Rectangle dimensions 600 mm in Y-direction and 400 mm in Z-direction → Select material as M20 → Click on Add → Click on Close.
17. Select Thickness → Click on Plate Element Thickness → Select value as 0.15 m → Click on Add → Click on Close.
18. Go to Select → Click Beams Parallel to X → Select Control button and select beams parallel to Z-direction → Now click Assign to Selected Beams → Click on Assign → OK.
19. Similarly assign to columns by selecting beams parallel to Y-direction.
20. Assign plate thickness by clicking Assign to View.
21. Go to Load & Definition → Select Load Case Details → Click on Add → Select loading type as Dead → Type title as DL → Click on Add → Select loading type as Live → Type LL → Click on Add.
22. Select Dead Load → Click on Add → Select Self Weight → Click on Add → Close → Now assign by selecting Assign to View → Assign → OK.
23. Select Live Load → Click on Add → Select Floor Load → Add Pressure [-5] → Min 5 m to Max 30 m.
24. Repeat for Floor Load → Add Pressure [-1.5] → Min 5 m to Max 30 m.
25. Assign them to the structure.



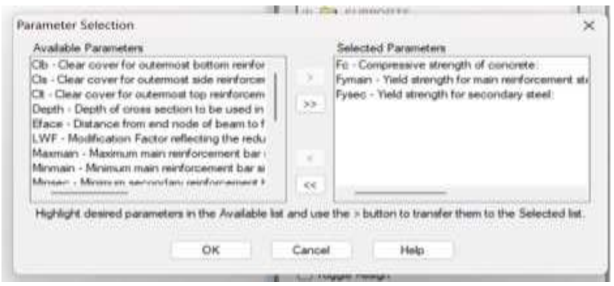
26. Go to Analyze & Print → Click on All → Save.
27. Go to Analyze → Run Analysis → Check Errors.



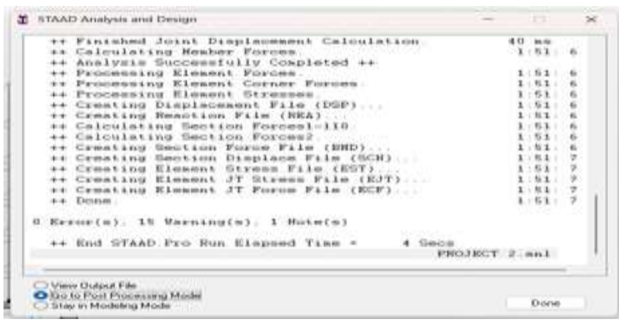
✓ *DESIGN PART*

- Click on deign → select concrete on left side → select IS 456 on right side
- Go design parameters → click on left side arrow mark → select Fc –compressive strength of concrete, fymain and Fysec and select right arrow → click on ok.

- Go to design parameters → click on Fc main and select grade of concrete (20 N/mm^2)
- → select Fymain and select grade of steel (415 N/mm^2) → select Fysec and select grade of steel (415 N/mm^2) → click on OK → click on close
- Go to design parameters → select design beam → select deign column→ click on ok.



- → close
- Now assign all by selecting assign to view
- Go to analysis and print → analyze →run analysis



VI. LIMITATIONS AND FUTURE SCOPE

✓ *Limitations of curved structure*

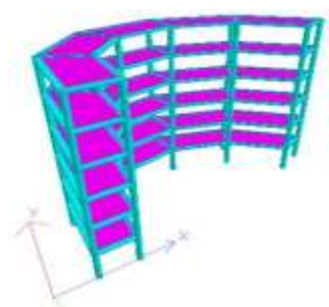
- *Linear Static Analysis*: The current project likely focuses on linear static analysis. In reality, curved structures (especially large-span ones) may exhibit non-linear behaviour under heavy loads or extreme weather, which was not accounted for.
- *Idealized Support Conditions*: The supports are likely modelled as perfectly "Fixed" or "Pinned." In actual field conditions, soil-structure interaction and the flexibility of the foundation can significantly alter the stress distribution.
- *Environmental Factors:* The study primarily focuses on Gravity (Dead/Live) loads. It may not have deeply integrated complex Dynamic Loads such as fluctuating wind gusts (vortex shedding) or site-specific seismic time-history analysis.
- *Material Assumptions:* The analysis assumes concrete and steel are perfectly homogeneous and isotropic. It does not account for long-term effects like creep, shrinkage, or thermal expansion which are critical for curved concrete geometries.

✓ *Future Scope*

- *P-Delta Analysis:* Future studies could perform P-Delta analysis to account for secondary moments caused by the displacement of the curved members under high axial loads.
- *Dynamic and Seismic Evaluation:* The project could be expanded to include Response Spectrum Analysis or Time History Analysis to observe how the curved structure behaves during an earthquake.
- *Optimization of Curvature:* A parametric study could be done to find the "Optimum Radius" of curvature that provides the highest strength-to-weight ratio, potentially saving more material.
- *Implementation of BIM:* Integrating the STAAD.Pro model with BIM (Building Information Modelling) software like Revit could help in detailed 3D reinforcement detailing and 4D construction scheduling.
- *Wind Tunnel Testing:* For very large curved roofs (like stadiums), physical scale-model testing in a wind tunnel or Computational Fluid Dynamics (CFD) analysis could be used to validate the STAAD.Pro wind load results.

VII. RESULTS

- 3D rendering view of the structure.



VIII. CONCLUSION

Curved roof trusses are highly efficient in distributing loads evenly, reducing stress concentrations compared to flat or pitched roofs, making them ideal for large-span structures like stadiums and airports. STAAD.Pro simplifies the design and analysis process by accurately simulating complex load combinations and providing detailed insights into stress, deflection, and stability. Curved roofs demonstrate superior performance under wind and dynamic loads due to their aerodynamic shape, making them suitable for regions prone to high winds or seismic activity.

The geometry of curved trusses allows for significant material savings, reducing project costs without compromising structural integrity, especially when advanced materials are used. Beyond structural benefits, curved roofs offer aesthetic appeal and sustainability advantages, such as improved natural lighting, ventilation, and energy efficiency, aligning with modern architectural and environmental goals.

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