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Structural Analysis of Tensile Structure Roof with and without Cable.

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ABSTRACT

This technical research paper presents a comprehensive analysis of two distinct tensile structures: Model 01, featuring a cable support system, and Model 02, a conical structure without cables. The study focuses on gaining valuable insights into the structural behavior of these models. Examination of the tension generated by the membrane reveals minimal differences between the models, underscoring the efficiency of the membrane in uniformly distributing tension. Notably, Model 01, utilizing a cable support method, exhibits the largest displacement, while Model 02, based on a support structure primarily consisting of pipes, and significantly reduces displacements. This disparity emphasizes the substantial impact of structural components on overall deformation behavior. The utilization of RFEM for analysis, coupled with adherence to EURO standards for steel and tensile structure design, ensures a robust and reliable evaluation of structural response. The findings highlight the pivotal role of the structural system's composition in determining deformation properties, as Model 01's cable retention system increases flexibility and displacement, while the cable-less tapered shape of Model 02 reduces displacement. Beyond the specific models analyzed, these insights contribute to a broader understanding of the design and optimization of tensile structures.

Introduction

The initial step involves creating accurate 3D models of the tensile roof structures using RFEM. The conventional tensile roof, characterized by its simplistic membrane geometry, is modelled to represent a common application of tensile structures. Additionally, the conical tensile roof, introducing innovative design elements, is meticulously designed in the software to reflect its unique architectural characteristics.

Material properties, including tensile strength and elasticity, are incorporated into the models based on literature review findings and industry standards. The membrane is defined with appropriate thickness, and supports are established to replicate real-world conditions. The modelling phase ensures that the virtual representation closely mirrors the physical reality of tensile roof structures.

Application of Static and Dynamic Loads

The analysis phase involves subjecting the models to a range of static and dynamic loads. Uniform distributed loads (UDL) and point loads simulate common static loading conditions, while dynamic loads such as wind and snow loads are applied to assess the structures' responses under varying environmental conditions. RFEM's dynamic analysis capabilities are leveraged to simulate real-world scenarios.

Modelling

Table 1 Models

Model	Particular
Model 01	Tensile roof with cable
Model 02	Tensile roof without cable, conical.

Code used –

EN 10210-2: 2006 is a European Standard that specifies technical delivery conditions for hot-finished hollow sections of circular, square, rectangular, and elliptical forms for structural purposes.

This standard is part of the EN 10210 series, which covers technical delivery conditions for hot-finished hollow sections of non-alloy and fine grain structural steels.

The overview of EN 10210-2: 2006:

Title: Hot finished structural hollow sections of non-alloy and fine grain steels - Part 2: Tolerances, dimensions, and sectional properties

Scope: EN 10210-2 specifies technical delivery conditions for hot-finished hollow sections of circular, square, rectangular, and elliptical forms for structural purposes. The hollow sections are made from non-alloy and fine grain structural steels as specified in Part 1 of the standard.

Key Aspects:

1.Tolerances: The standard provides tolerances on dimensions and shape for hot-finished hollow sections.

2.Dimensions and sectional properties: It includes details on dimensions and sectional properties of the hot-finished hollow sections.

Application:

EN 10210-2 is used for structural hollow sections in applications like building construction, bridge construction, lattice towers, etc.It ensures that the delivered hollow sections meet specified requirements for dimensions, tolerances, and other technical properties.

Steps involved in modelling and analysis –

Modeling and analysis of tensile structures in RFEM requires several steps.

Here is a general overview of the process:

1.Define the geometry: - Start by defining the overall geometry of the tensile structure.This includes the shape and dimensions of the membrane and supporting elements.

2.Material Properties: – Specify the material properties (tensile strength, elasticity, etc.) of the tensile membrane. Also define the material properties of all load-bearing elements.

3. Constraints: - Specify appropriate constraints for the model. Tensile structures are often supported at the ends or at specific locations. Install fixtures or supports as needed.

4.Load Applications: - Apply loads to simulate real-world conditions. This includes dead loads (self-weight), live loads (wind, snow), and other relevant loads.

Consider both static and dynamic loads.

5. Meshing: - Divide the membrane into elements through meshing.

RFEM utilizes finite element analysis, and an adequate mesh is crucial for accurate results. Adjust mesh parameters to achieve the desired level of detail.

6. Modelling Columns and Connections: - Model additional supports or connections such as: An anchor point or connection to a supporting structure. Ensure that your model accurately represents the physical reality of tensile structures. In this thesis model used are taken reference from RFEM website.

7. Define load combinations: - Define load combinations based on the applicable design code or standard. Consider different load cases to simulate different scenarios such as maximum load conditions.

8.Analysis Settings: - Configure the following analysis settings in RFEM: Type of analysis (linear, nonlinear) considering the behavior of tensile membranes under varying loads.

9. Run Analysis:- Run analysis in RFEM.This step involves solving a mathematical model to determine the response of the tensile structure to applied loads.

10.Extract Results:- Extract and evaluate the results produced by the analysis.Evaluate structure behavior by checking membrane stresses, deformations, and other relevant results.

11.Validation: - Validate results against theoretical expectations or empirical data.Ensure that the model's response aligns with anticipated behavior.

12. Optimization: - If necessary, iterate and optimize the model based on the initial results. This may involve adjusting parameters, refining the mesh, or modifying support conditions.

13.Documentation: - Document the modeling and analysis process, including assumptions, input parameters, and key results. This document is essential for design review and future reference.

14. Design Code Compliance: - Compare results to relevant design codes or standards to ensure tensile structures meet safety and performance standards .

15. Post-Processing: - Utilize post-processing tools in RFEM to visualize and interpret the results effectively.

Generate reports or graphical representations for clear communication of findings.

Model 01

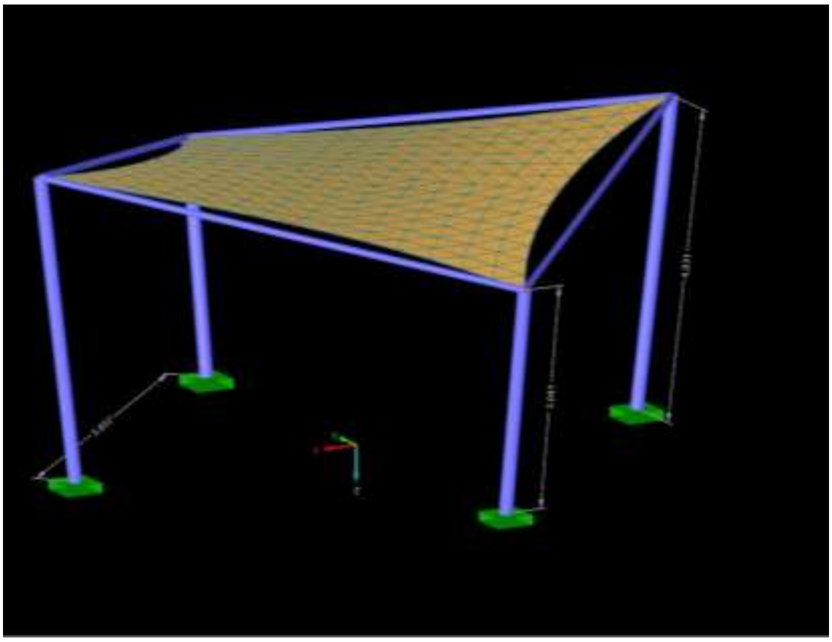


Figure 1 Model 01

Model 02

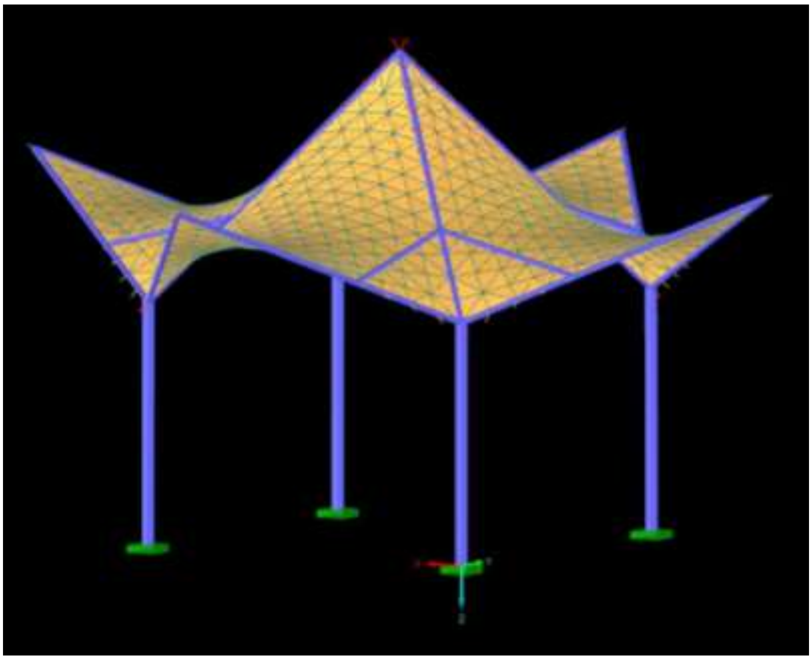


Figure 2 Model 02

Member Details –

The following table describes the assigned member details.

Member No.	Member Type	Material	Cross-Section	Length L [m]	Axial Force N [kN]	Member Coefficients [-] $\square_y$	$\square_z$
1	Beam	1 - Steel S 235	1 - RO 182x5.0	4.031	0.66	-	-
2	Beam	1 - Steel S 235	1 - RO 182x5.0	4.031	0.66	-	-
3	Beam	1 - Steel S 235	1 - RO 182x5.0	3.041	-0.66	0.054	0.054

4	Beam	1 - Steel S 235	1 - RO 182x5.0	3.041	-0.66	0.054	0.054
5	Beam	1 - Steel S 235	2 - RO 85x5	6.442	-13.47	1.515	1.515
6	Beam	1 - Steel S 235	2 - RO 85x5	6.442	-13.47	1.515	1.515
7	Beam	1 - Steel S 235	2 - RO 85x5	6.442	-13.47	1.515	1.515
8	Beam	1 - Steel S 235	2 - RO 85x5	6.442	-13.47	1.515	1.515
9	Cable	1 - Steel S 235	3 - Cable PE 20	6.477	10.78	-	-
10	Cable	1 - Steel S 235	3 - Cable PE 20	6.477	10.78	-	-
11	Cable	1 - Steel S 235	3 - Cable PE 20	6.477	10.78	-	-
12	Cable	1 - Steel S 235	3 - Cable PE 20	6.477	10.78	-	-

Load –

For this thesis loads has been generated using, auto load generate option for member. Also the following load has been considered for the analysis.

Deal Load –

(1) Self-Weight with factor 01.

(2) 2 KN/m UDL on horizontal member.

Live Load –

(1) 1 KN/m UDL on horizontal member.

Fabric Details –

Defining specific values for tensile fabric properties in RFEM will depend on the material specifications provided by the fabric manufacturer or from testing. Below are example values for some properties; however, please note that these are illustrative and may not be representative of any specific fabric. Actual values should be obtained from fabric testing or manufacturer specifications:

1. Material Type: - Tensile Fabric

2. Elasticity:

- Modulus of Elasticity in Warp Direction: 2,000 MPa
- Modulus of Elasticity in Weft Direction: 1,500 MPa

3. Poisson's Ratio:

-Poisson's Ratio: 0.2

4. Thickness:

- Fabric Thickness: 0.2 mm

5. Yield Strength:

- Yield Strength: 150 MPa

6. Ultimate Strength:

- Ultimate Tensile Strength: 300 MPa

7. Tensile Testing Data:

- Stress-Strain Curve (example values):
  - At 10% Strain: 30 MPa
  - At 20% Strain: 60 MPa
  - At 30% Strain: 90 MPa

8. Creep and Relaxation:

- Creep and relaxation properties may need to be obtained from long-term testing of the specific fabric.

9. Temperature Dependency:

- Thermal expansion coefficient: 0.0005 per °C

10. Friction and Slip:

- Coefficient of Friction: 0.2

- Coefficient of Slip: 0.1

11. Anisotropic Behavior:

- Anisotropic behavior factors: 0.8 (Warp) and 0.6 (Weft)

Load Combination as per Euro Code-

EN 10210-2:2006 is a European Standard that specifies technical delivery conditions for hot-finished hollow sections of non-alloy and fine grain structural steels. Load combinations for steel structures design in Europe are typically defined by Eurocode 0 (EN 1990) and Eurocode 1 (EN 1991). Here's a general guideline on load combinations according to Eurocode:

Load Combinations (Eurocode 0 and Eurocode 1):

Ultimate Limit State (ULS) Load Combinations (EN 1990:2002, Annex A):

1. Permanent Actions (G): 1.35 * G

2. Variable Actions (Q): 1.5 * Q

3. Wind Load (W): 1.5 * W

4. Snow Load (S): 1.5 * S

5. Imposed Load (I): 1.5 * I

6. Special Actions (E.g., Seismic) (A): 1.5 * A

Serviceability Limit State (SLS) Load Combinations (EN 1990:2002, Annex B):

1. Permanent Actions (G): G

2. Variable Actions (Q): 1.0 * Q

3. Wind Load (W): 1.0 * W

4. Snow Load (S): 1.0 * S

5. Imposed Load (I): 1.0 * I

6. Special Actions (E.g., Seismic) (A): 1.0 * A

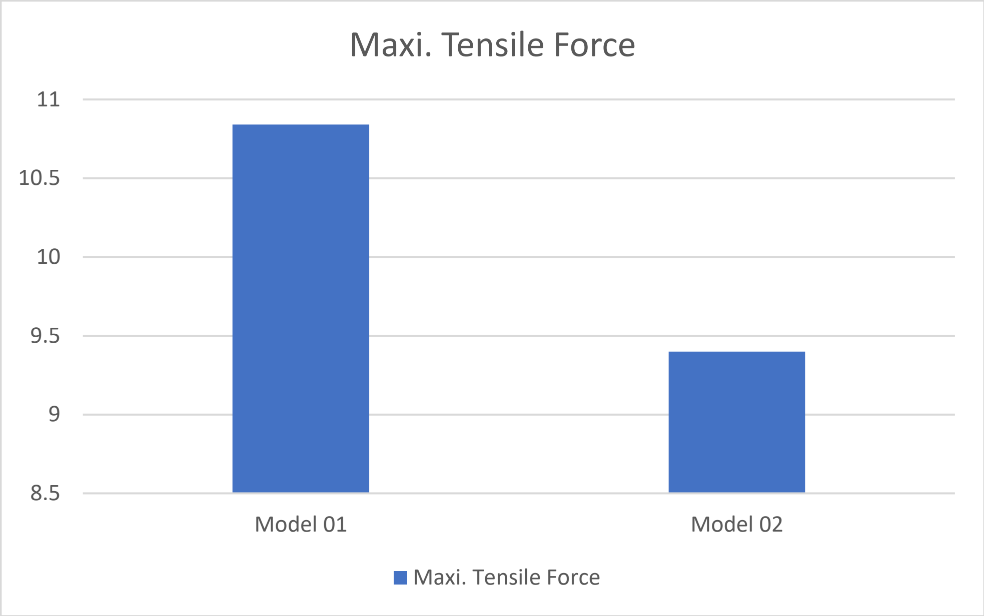
As the objective of this thesis is to explore the different type of tensile structure, this will only focus form-finding and structural stability under general loading condition. Lateral forces can be considered in future explorations.

Results

The results derived from the intricate analysis of the tensile structure using the powerful RFEM software. The findings discussed herein unravel the structural nuances, behavioral patterns, and performance characteristics of the tensile membrane under various loading scenarios.

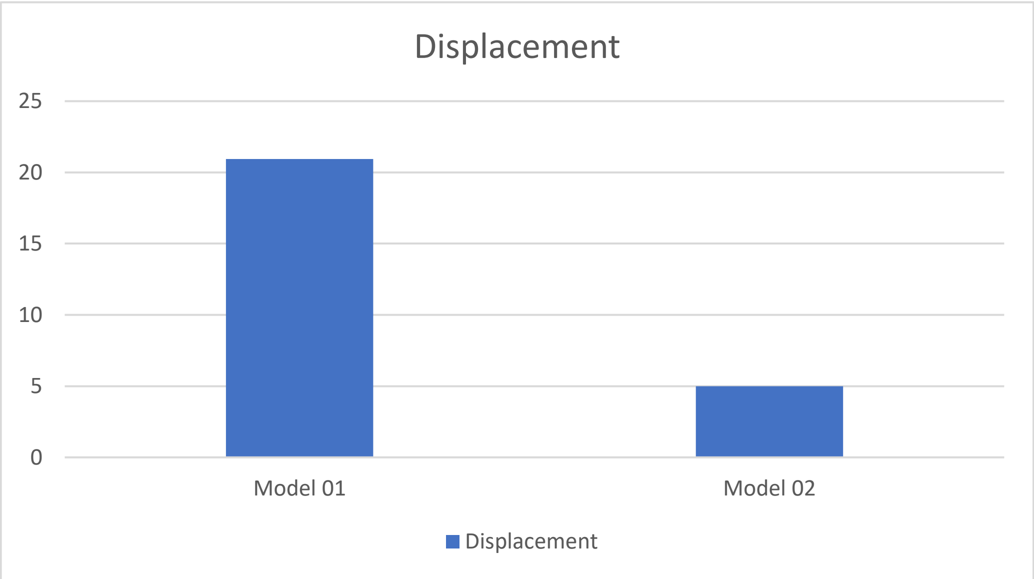
Maximum Tensile Force in structure

Model 01	10.84 KN
Model 02	9.4 KN



Maximum Displacement in structure

Model 01	20.94 mm
Model 02	5 mm



Comment

As evident from the provided table and graph, the tensile forces generated by the membrane exhibit minimal variation across the models. However, a significant distinction emerges in terms of displacement between Model 01 and Model 02. Model 01, characterized by a cable support system, experiences maximum displacement. In contrast, Model 02, with a supporting structure predominantly composed of pipes rather than cables, demonstrates considerably reduced displacement. This discrepancy underscores the influence of structural components on the overall deformation behavior, emphasizing the pivotal role of the support system composition in determining the structural response.

Conclusion –

In summary, the comprehensive analysis of tensile structures, especially model 01 with cable support system and conical model 02 without cables, provides valuable insights into the structural behavior. Examination of the tension generated by the membrane revealed minimal differences between the models, indicating the efficiency of the membrane in uniformly distributing tension. There was a noticeable difference in displacement, with Model 01, which adopted the cable support method, having the largest displacement. In contrast, Model 02 was based on a support structure consisting primarily of pipes rather than cables, which significantly reduced displacements.

This observation highlights the significant influence of structural components on the overall deformation behavior. The use of RFEM for analysis, combined with compliance with EURO standards for the design of steel and tensile structures, ensured a robust and reliable evaluation of the structural response. This result highlights the central role of the composition of the structural system in determining the deformation properties of tensile structures. Model 01's cable retention system increased flexibility and increased displacement, while cable-less Model 02's tapered shape reduced displacement. These findings not only contribute to the understanding of the specific model analyzed, but also provide broader implications for the design and optimization of tensile structures.

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