

FUNDAMENTAL DESIGN PRINCIPLES FOR TENSILE MEMBRANE STRUCTURES A CALL FOR STRUCTURAL AWARENESS IN ARCHITECTURAL PRACTICE

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ECCOMAS THEMATIC CONFERENCE



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IACM SPECIAL INTEREST CONFERENCE

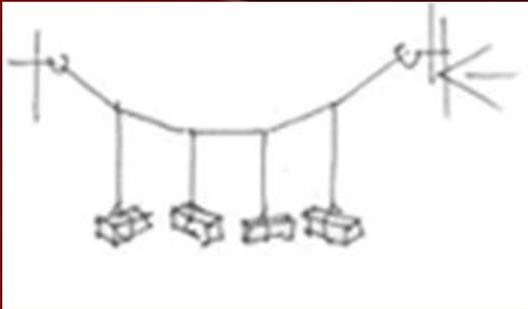
INTRODUCTION

- ❑ Company established in 2011
- ❑ Working on the company since end of 2016
- ❑ First contact with tensile structures: IMS Bauhaus Tensile Intense September 2018
- ❑ Business model largely based on public work bids

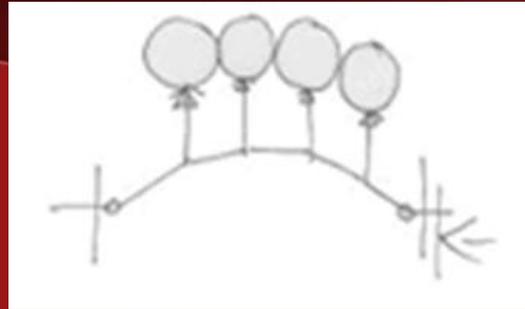


WHY THIS PRESENTATION

- ✓ Lack of awareness in Spain
- ✓ Problems in the field: flat shapes, rigid edges, and absence of ponding analysis.
- ✓ Consequences: leaks, overstresses, collapses, costly corrections.



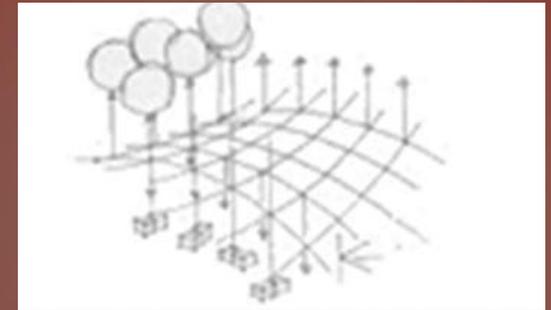
Hanging loads on a cable will give such a shape. The cable will pull on the anchoring hooks.



Upwards pulling forces will create the same shape in the opposite direction.



The result shows that to be able to fix a point three-dimensionally, we need 4 opposite anchoring directions.

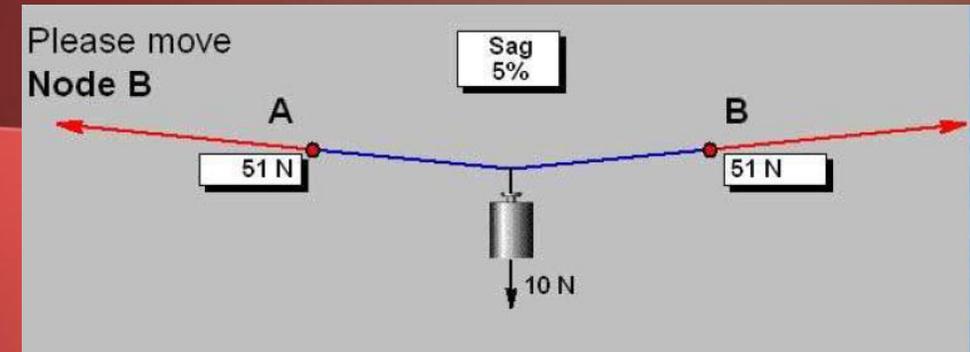
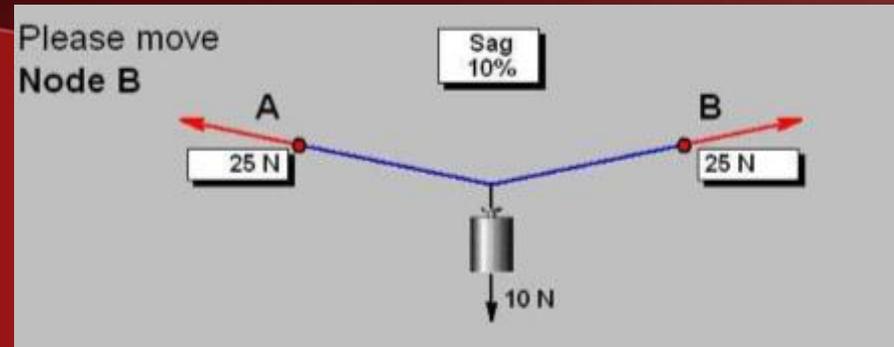
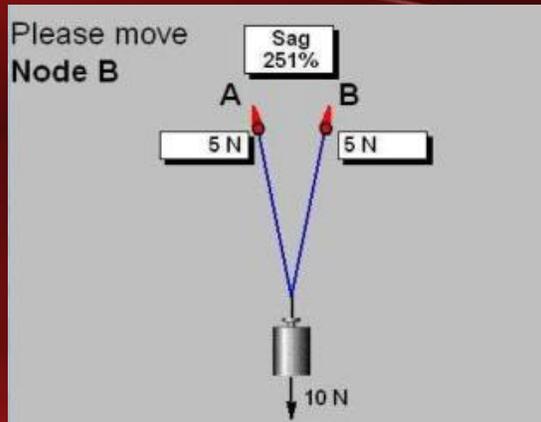


To stabilize an entire surface we have to apply this principle on every point of the surface. Now the three-dimensional counter curved surface is created. In scientific terms it is called "Anticlastic Shape".

THREE NON-NEGOTIABLE REQUIREMENTS

In order to find a shape, we have to introduce the principle of **Prestress**;
with this approach we can find a **shape**

Form finding → process is unique for membrane structures



- ✓ Double curvature (non-zero Gaussian curvature).
- ✓ Adequate biaxial prestressing (warp / weft).
- ✓ Compatible edge/support stiffness (to achieve and maintain prestressing)

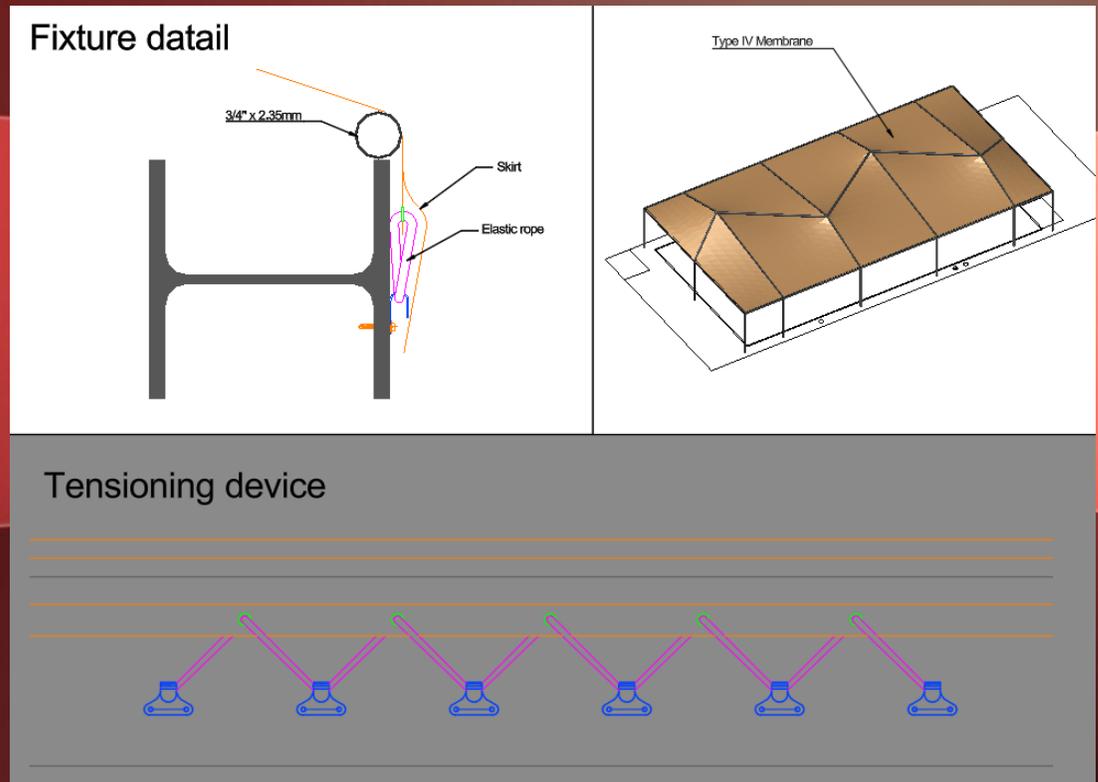
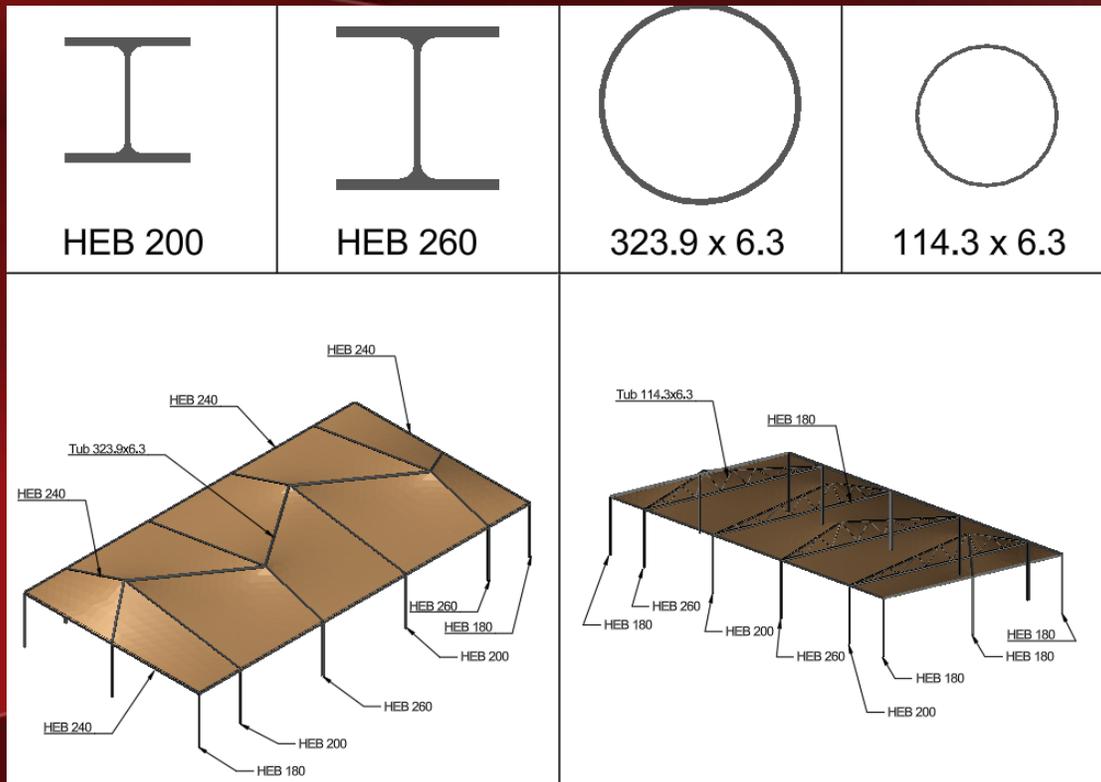
CONTRIBUTING FACTORS TO FAILURE

- ✓ Pay attention to the **form** from the **initial design**
- ✓ Lack of knowledge and stubbornness
- ✓ Tight budgets
- ✓ **Not all forms are possible:** Low curvature → structural inefficiency, risk of non-linear phenomena (snap-through) and ponding.
- ✓ **“More tension” doesn't fix** the geometry when the **supports are flexible.**
- ✓ Monitor the water drainage paths.

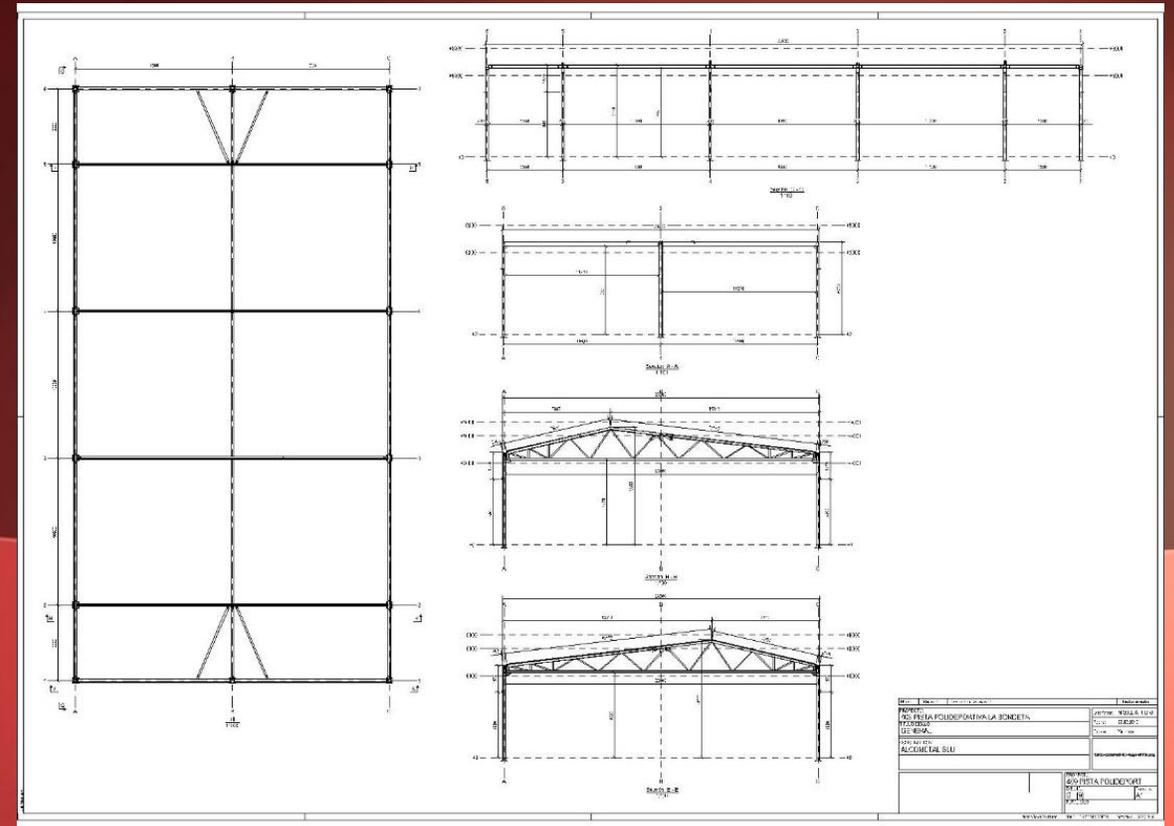
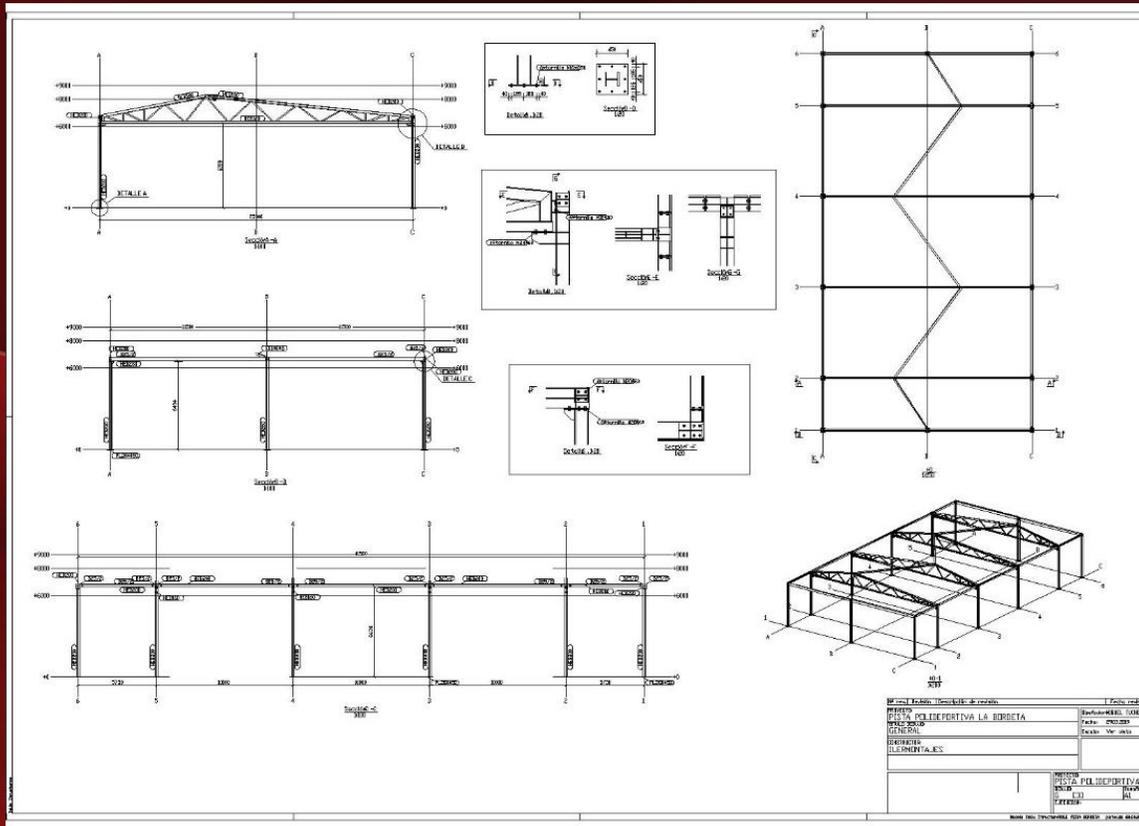
CASE A — ORIGINAL CONCEPT

Context notes:

- ❑ Spans ~10 m with almost flat panels (no curvature).
- ❑ Rigid lower edge receiving the membrane.
- ❑ Rigid membrane; no explicit drainage strategy.



CASE A — WHAT WENT WRONG



- ✓ A uniform prestress was not achieved (structure too flexible for the membrane)
- ✓ Ponding formed on the rigid lower edge → progressive deflections
- ✓ Edge detail working in bending → stress concentrations → collapse.

CASE A — LESSONS LEARNED

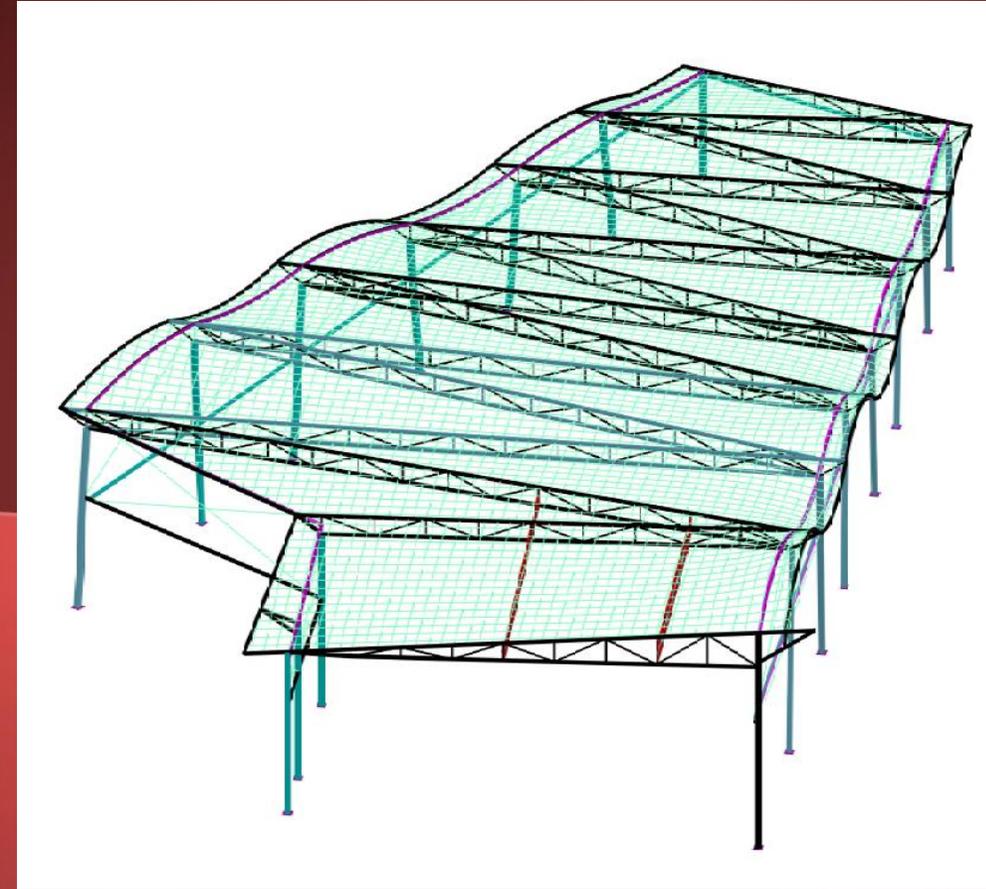
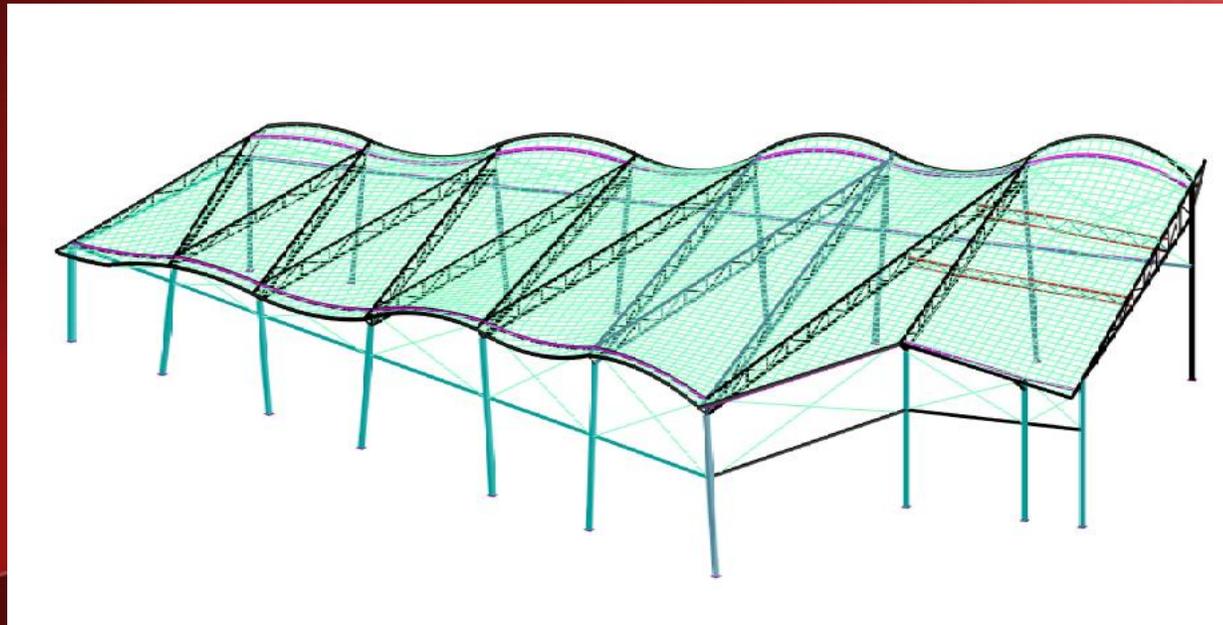


- Flat panels = tensostructure
- Low rigid edge + zero curvature = water trap
- **Mandatory: form-finding, ponding verification, and positive drainage.**

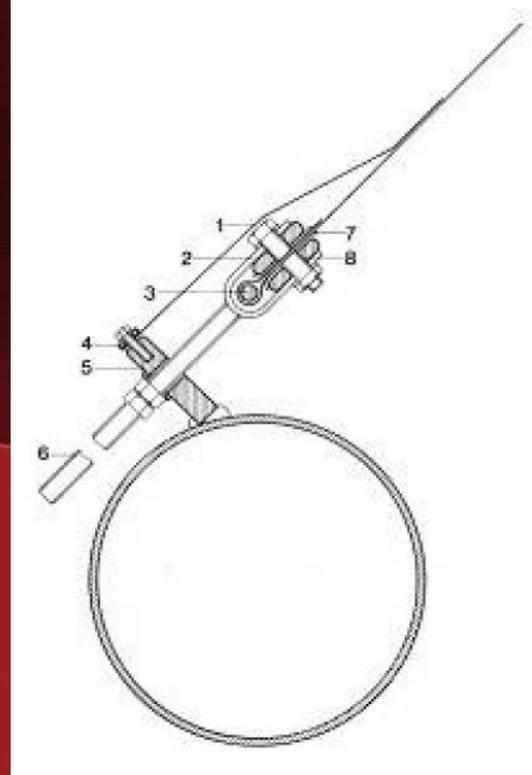
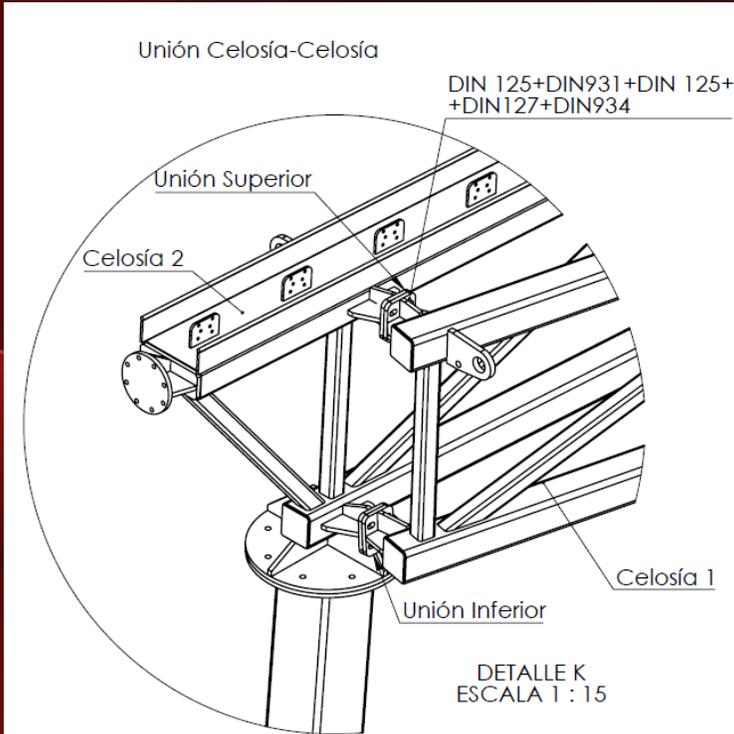
CASE B — CONSTRAINTS AND RISKS

Context notes

- ❑ Spans up to 30 m with very low curvature
- ❑ Fixed geometry initially flexible supports
- ❑ Risks: insufficient prestressing and ponding



CASE B — INTERVENTION



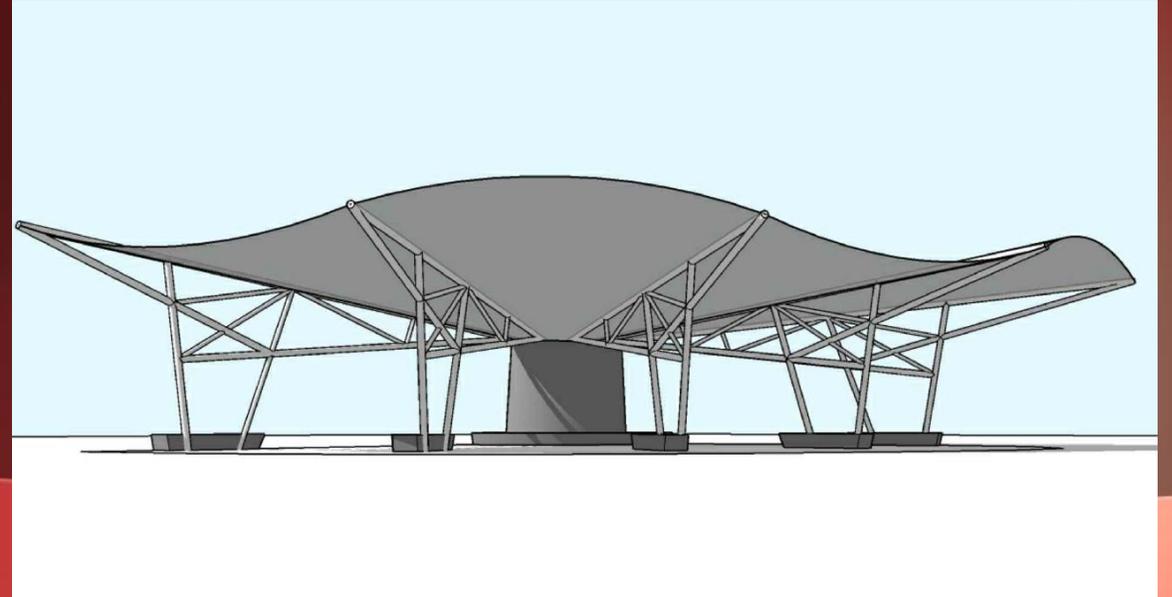
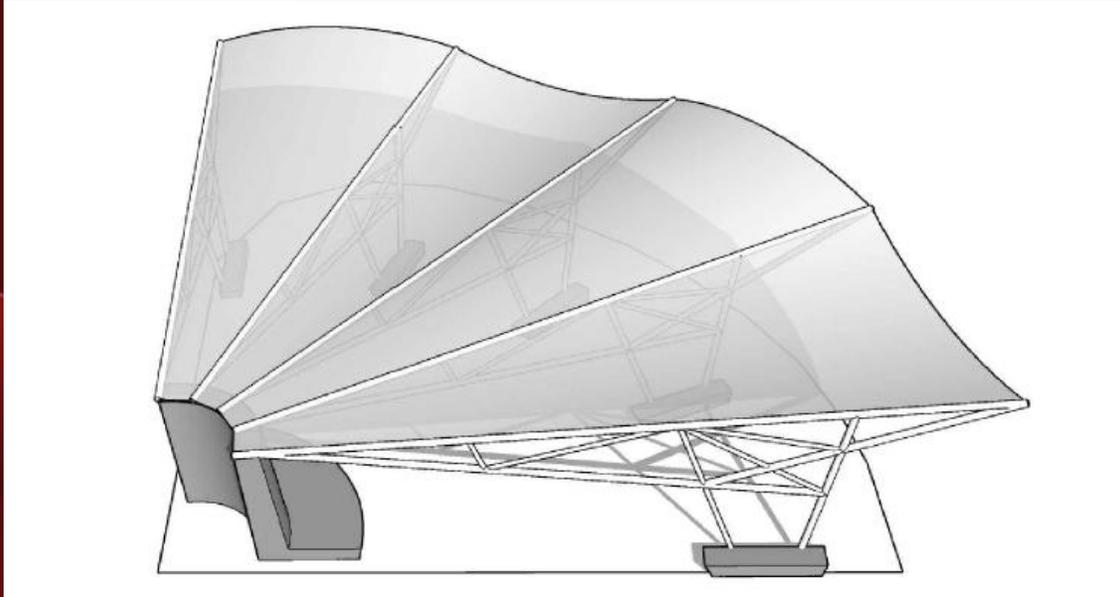
- ✓ Increase in transverse stiffness to support greater prestressing.
- ✓ Design of tensioning devices (travel/stroke, lever, locking).
- ✓ Selection of compensations according to the material and assembly sequence.
- ✓ Ponding analysis → 3 risk zones → notches / drains (or scuppers / drainage).

CASE B — OUTCOME



- Target prestress achieved; deformations controlled.
- No episodes of standing water after commissioning.
- Mitigation hierarchy: stiffen → tensioning system → compensation → drainage

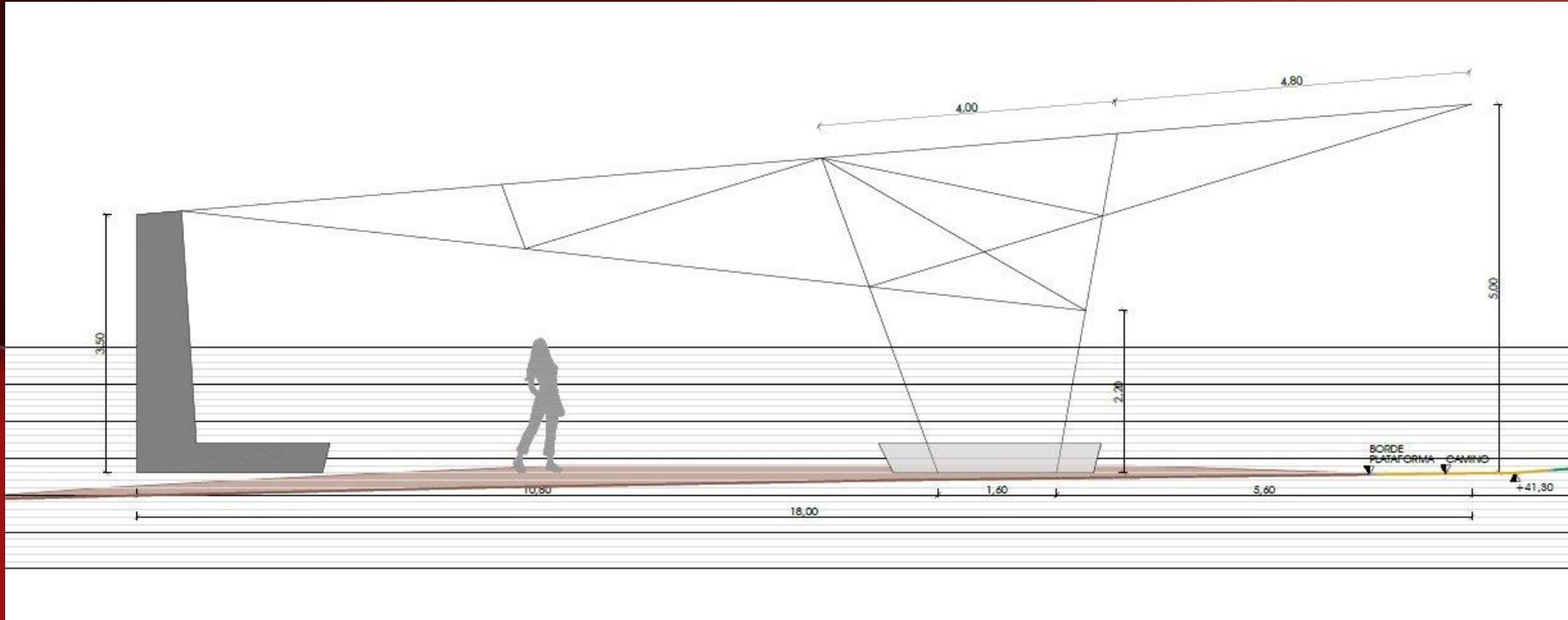
CASE C — STARTING DESIGN



Context notes:

- ❑ Asymmetric canopy with very low-curvature sectors; Type III membrane.
- ❑ No clear prestressing instruction: $3.0 \rightarrow 1.3$ kN/m.
- ❑ Slender frames with long spans and shallow deflections between posts..

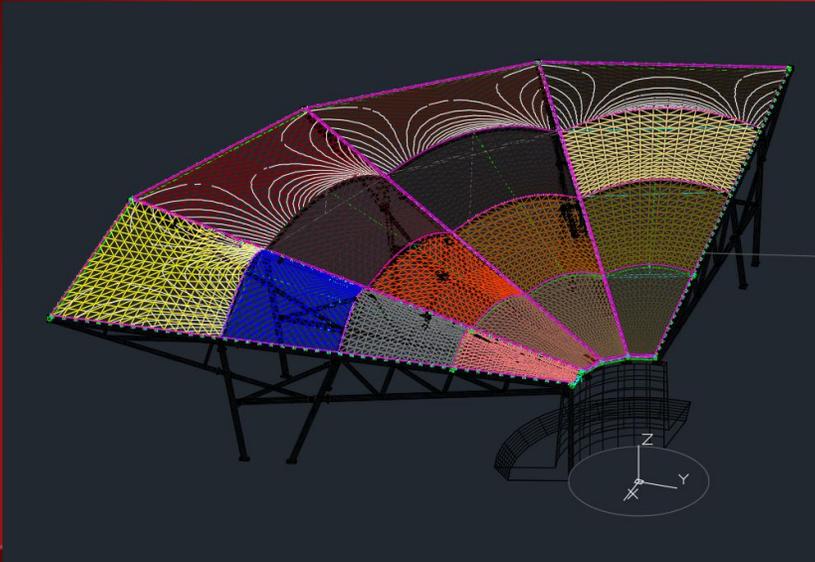
CASE C — RED FLAGS



- ✓ Insufficient curvature in various fields → prone to ponding.
- ✓ Probably inadequate edge stiffness for 3.0 kN/m.
- ✓ Inconsistent prestressing specification → unclear design basis/compensations.
- ✓ Edge details sensitive to flexure.

CASE C — PLAN OF ACTION

- Update shape to increase curvature (crests/valleys or cable edges).
- Establish definitive biaxial prestress + tolerances + compensations (Type II).
- Global stiffness check (under prestress, wind, snow).
- Hydrostatic ponding analysis; if the geometry is fixed, add local notches/drains (or scuppers).
- Detail access and stroke/travel for retensioning.

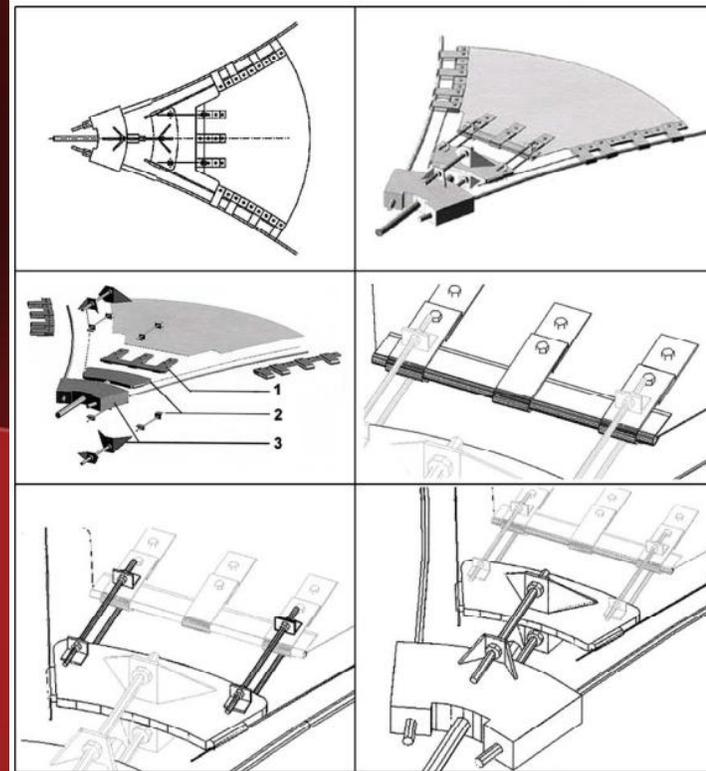


MEMBRANE MATERIAL: A PERFORMANCE DECISION



- ✓ Align with local use, climate, and maintenance.
- ✓ PTFE/glass → maximum durability/high cost
- ✓ PVC-PES Type II/III/IV → cost-performance balance (thermal sensitivity/creep)
- ✓ HDPE meshes → shade only (not waterproof/watertight).
- ✓ Practical criteria: service life, thermal range, wind/rain/ice, reflectance/thermal gain, local availability.

DETAILING & CONSTRUCTABILITY: SITE COMPATIBLE DESIGN PROCESS



Details compatible with workshop and field tolerances.

Accessibility to tensioners and defined tensioning sequence.

Fewer incidents, shorter deadlines, and profitable bottom line.

CONCLUSIONS

- ❑ **Enroll or seek advice from a tensile structure specialist from early phases.**
- ❑ **Make prestressing and ponding mitigation non-negotiable requirements in specifications.**
- ❑ **Respect the trio: Curvature – Prestress – Stiffness.**
- ❑ **Architecture-engineering integration = safety, performance, and profitability.**





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Thank you – Questions session

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