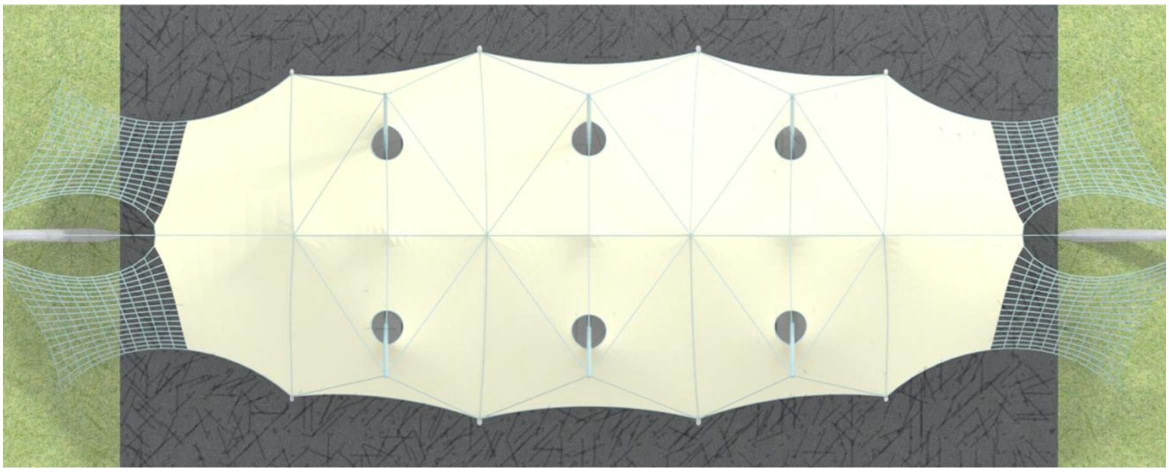
MM03 Membrane Programs

Materials/Form Finding

Structural calculation Wind & Snow

Patterning



Contents

1. INTRODUCTION

1.1 Description of MM03-Membrane Programs task

The MM03 task is to:

- Make a preliminary design (materials and technology to use)
- Perform a Form finding analysis and feasibility
- Make a Membrane structural calculation (Snow and Wind load)
- Analyze patterning

All these tasks have to be performed in according to what has been done in the MM01 – Architecture Module.

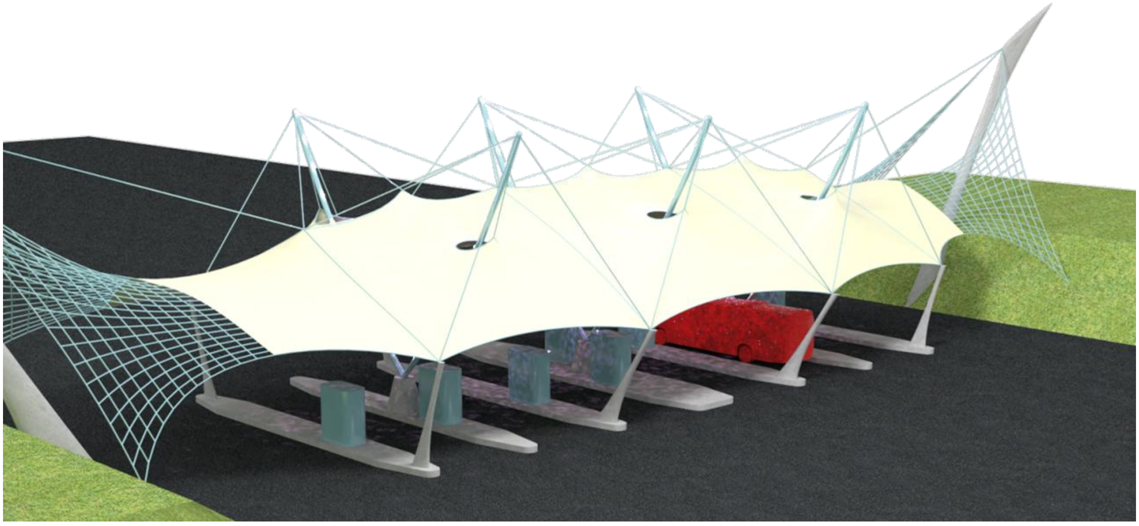
1.2 Description of MM01 – Architectural Module design

The goal of MM01 is to design a cover for a Toll Booth plaza on a highway in a rural environment. It is on a level terrain and it has to cover at least 4 incoming lanes and 4 outgoing lanes.

The proposal must fulfill the technical conditions respecting the dimensions necessary for the toll booth to function properly. This means the appropriate width and height has to be respected to be able to let trucks and buses to pass.

Designs limit conditions:

- min. clear height is 5.40m
- protections against rain at 45 degree



The basic idea was that of designing a toll booth with 3 different architectural level each with a well-defined function. In this design it is possible to find:

- In the upper level, which is the hanging level, we have 3 V-Shaped steel masts and 2 big concrete antennas.
- In the middle level we have membrane structure, the covering element.
- In the lower level we have all the anchoring point, 8 concrete columns and 4 pile or massive anchoring foundations.

With this design we didn't want to have any sort of structure to support the membrane from below.

This proposal is supposed to be set up in the southern part of Italy on the Salerno Reggio Calabria Highway.

2.1.1 Upper level – The hanging level

For the hanging level I decided to use:

- 2 big concrete antennas to withstand the bending moment due to the possible high tension in the hanging cable. In order to do this, the idea is also to have the cable net to give some of post tensioning to the concrete antennas and to deviate downward the hanging cable tension from its direction.
- The steel masts will be used as a supporting structure in case of snow load, they will be anchored to the concrete columns. In first instance I'm planning to use 3 V-Shaped curved masts just as an architectural choice, but in case of high bending moment and/or buckling problem is it possible to change the configuration to 6 separate straight steel masts stabilized with some cables for preventing buckling.

2.1.2 Middle level – The membrane structure (The leaf)

The membrane structure is set up to resemble a leaf trapped inside a spider web. The middle level is composed by:

- The Fabric structure.
- The cable net connecting the membrane to the hanging antennas.
- The edge cables

2.1.3 Lower level – The anchoring layer

For the anchoring level I decided to use:

- 8 concrete columns to resist bending moment and to have high mass in case of car accidents.
- 4 ground anchors.
- Down cables to help the membrane structure to withstand wind suction. During the final stage of the design, in case of high traction forces in the concrete columns, it is possible to increase concrete section for lowering the stresses or to use a slight amount of post-tensioning

For further information please refer to Appendix A – Architectural Module Presentation

2. CALCULUS BASES

2.2 Code selection

During the design will be used the Italian Code:

- Norme tecniche per le costruzioni – DM 14 gennaio 2008

2.3 Materials

The following materials will be used:

- Reinforced Concrete
- Construction Steel
- PVC coated polyester fibers membrane

2.3.1 Reinforced concrete

According to the UNI 11104:2004 and UNI 206-1:2006 we define the exposure classes for the structure. In particular we are going to use:

- XC4 class for the corrosion due to carbonation
- XD3 class for the corrosion due to the Cl^- apart from that of sea water
- XS1 class for the corrosion due to the Cl^- of sea water

We will not take in account any chemical attack and “Freeze and Thaw” problem.

The Concrete used for the columns and the antennas will be C35/45.

For the reinforcing will be used a B450C steel

G = 25 kN/m^3

2.3.2 Construction Steel

For the construction steel will be used a S355H and circular hollow profiles.

G = 78 kN/m^3

2.3.3 Membrane structure

For the membrane structures will be used:

- FERRARI Precontraint with PVDF on the back side for a better resistance to pollution
- Strand cables

2.4 Actions and load combinations

According to the Italian Code we are going to consider the following limit states:

- Ultimate Limite States
- Seviceability Limite States

A nominal lifespan of 50 years will be considered for the structure

In this phase no extraordinary and seismic actions will be considered.

Load Combinations

The design of the toll booth will be done according to the following combination:

- Fundamental combination, generally used for ULS

$$\gamma_{G1} \cdot G_1 + \gamma_{G2} \cdot G_2 + \gamma_P \cdot P + \gamma_{Q1} \cdot Q_{k1} + \gamma_{Q2} \cdot \psi_{02} \cdot Q_{k2} + \gamma_{Q3} \cdot \psi_{03} \cdot Q_{k3} + \ldots$$

- Rare combination

$$G_1 + G_2 + P + Q_{k1} + \psi_{02} \cdot Q_{k2} + \psi_{03} \cdot Q_{k3} + \ldots$$

- Frequent combination

$$G_1 + G_2 + P + \psi_{11} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \psi_{23} \cdot Q_{k3} + \ldots$$

- Permanent combination, used for long term effect.

$$G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \psi_{23} \cdot Q_{k3} + \ldots$$

Where:

G are the dead loads / super imposed dead loads

P are the post/pre tension loads

Q are the live loads such as wind and snow loads

2.4.1 Wind loads

Wind Pressure

According to the Italian Code, the wind pressure can be considered as a static load. In particular the wind pressure is defined by the following equation:

$$p = q_b \, c_e \, c_p \, c_d$$

where:

- q_b is the reference kinetic wind pressure
- c_e is the exposure factor
- c_p is the form factor
- c_d is the dynamic factor, set equal to 1

reference kinetic wind pressure

the reference kinetic wind pressure q_b in kN/m^2 is:

$$q_b = \frac{1}{2} \rho v_b^2$$

where:

- v_b is the wind velocity in m/s
- ρ is the air density assumed equal to 1.25 kg/m^3.

Exposure factor

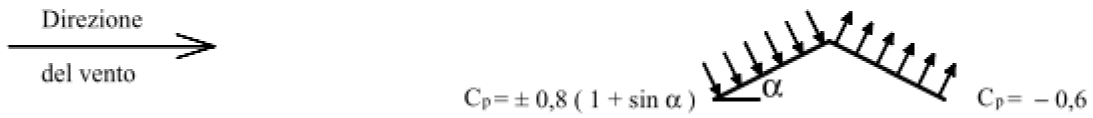
$$c_e(z) = k_r^2 \, c_t \ln(z/z_0) \, [7 + c_t \ln(z/z_0)] \qquad \text{per } z \geq z_{min}$$
$$c_e(z) = c_e(z_{min}) \qquad \text{per } z < z_{min}$$

where:

- k_r, z_0 and z_{min} are defined in the following table
- c_t is the topography factor, usually set equal to 1

Exposure category	k_r	z_0 [m]	z_{min} [m]
I	0.17	0.01	2
II	0.19	0.05	4
III	0.20	0.10	5
IV	0.22	0.30	8
V	0.23	0.70	12

Form factor



The plus or minus sign has to be used according to the most unfavorable condition.

As a preliminary design value, considering an overall value of the inclination of the membrane structure of 30 degrees, we will use:

- 2.00 kN/m^2 in pression
- 1.00 kN/m^2 in suction

Tengential Wind Action

No tangential wind action will be considered in this preliminary design.

2.4.2 Snow loads

According to the Italian Code, the snow load is defined by the following equation:

$$q_s = \mu_i \cdot q_{sk} \cdot C_E \cdot C_t$$

where:

- q_{sk} is the characteristic snow load at ground – set equal to 0.60 kN/m^2
- C_e is the exposure factor – set equal to 0.90 since the High wind effect we have on this kind of structure
- C_t is the termal factor – set equal to 1.0
- μ_i is the form factor – set equal to 0.80

As a preliminary design value, considering an overall value of the inclination of the membrane structure of 30 degrees, we will use 0.48 kN/m^2.

3. MATERIALS AND FORM FINDING

3.1 Concrete structures

During the form finding process all the concrete structures are considered as fixed point. In the following stages they will be considered as simple cantilever beams and will be calculated in order to have small displacement and to withstand the internal forces.

3.2 Steel structures

During the form finding process the masts are considered as fixed point. In the following stages they will be considered in the FEM model in ixForten to analyze the structural behavior of these elements. Cable elements are considered in the Form Finding procedure.

3.3 Membrane structures

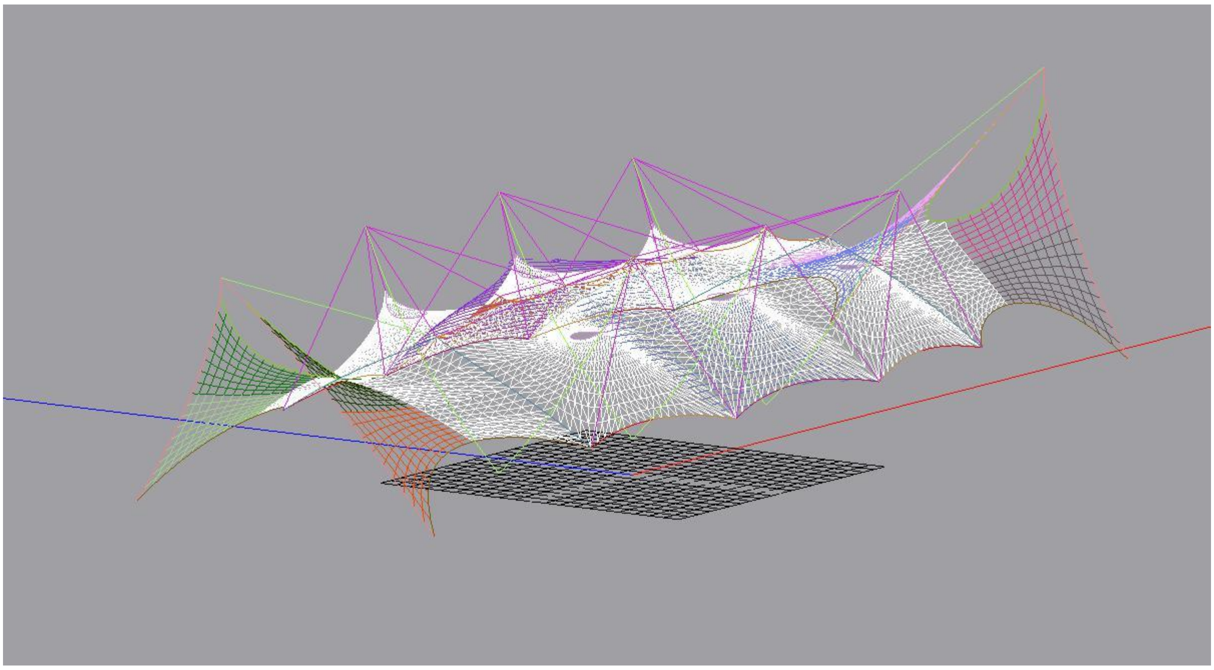
The cover of Toll Booth is made of membrane and boundary cables connected to the supporting structure. Boundary cables are used to get desired shape at the membrane edges.
In first instance I have chosen PVC coating polyester fibers fabric, like FERRARI Precontraint 1500.

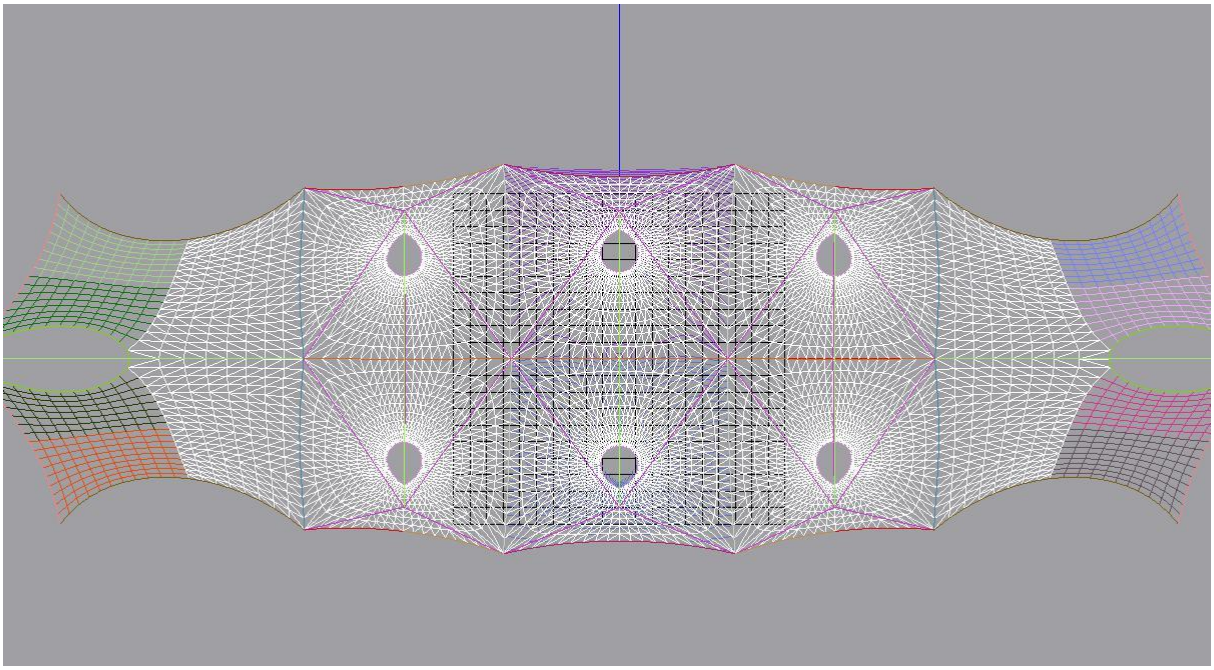
3.4 Form finding

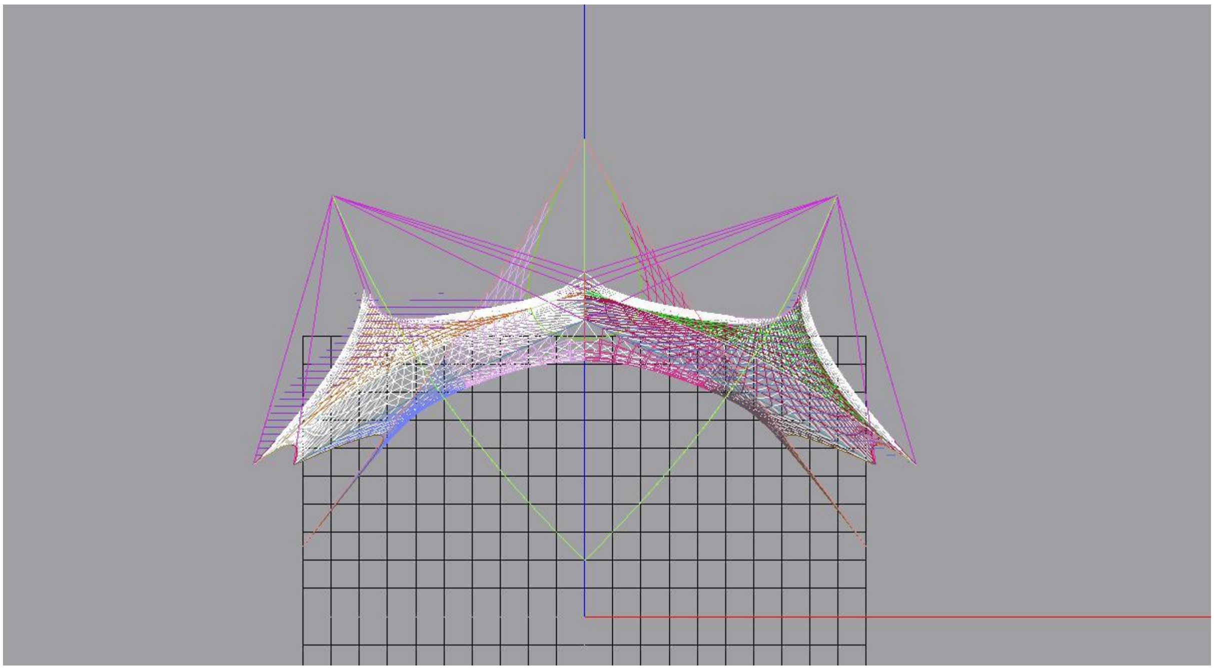
Assigned C value for membrane is:

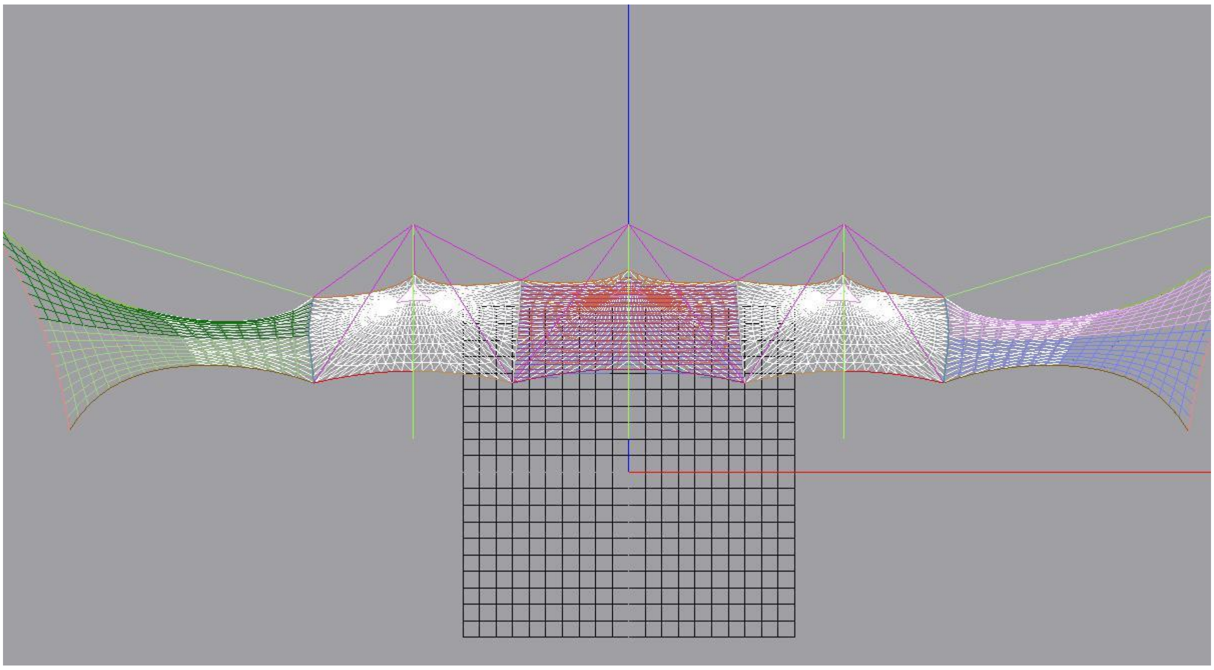
- 3 for the 6 cones in the circular direction
- 1 for the 6 cones for the bottom-up direction
- 3 for the external areas in the vertical direction
- 1 for the external area in the horizontal direction

All the cables are adjusted to get the final desired shape.

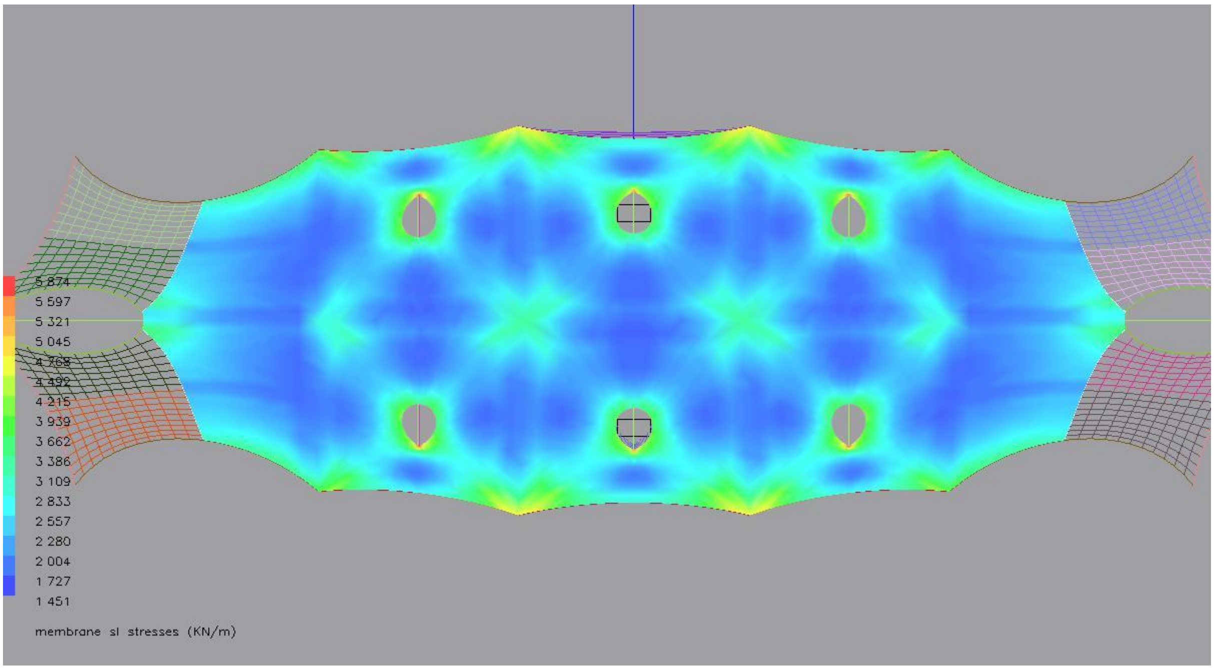




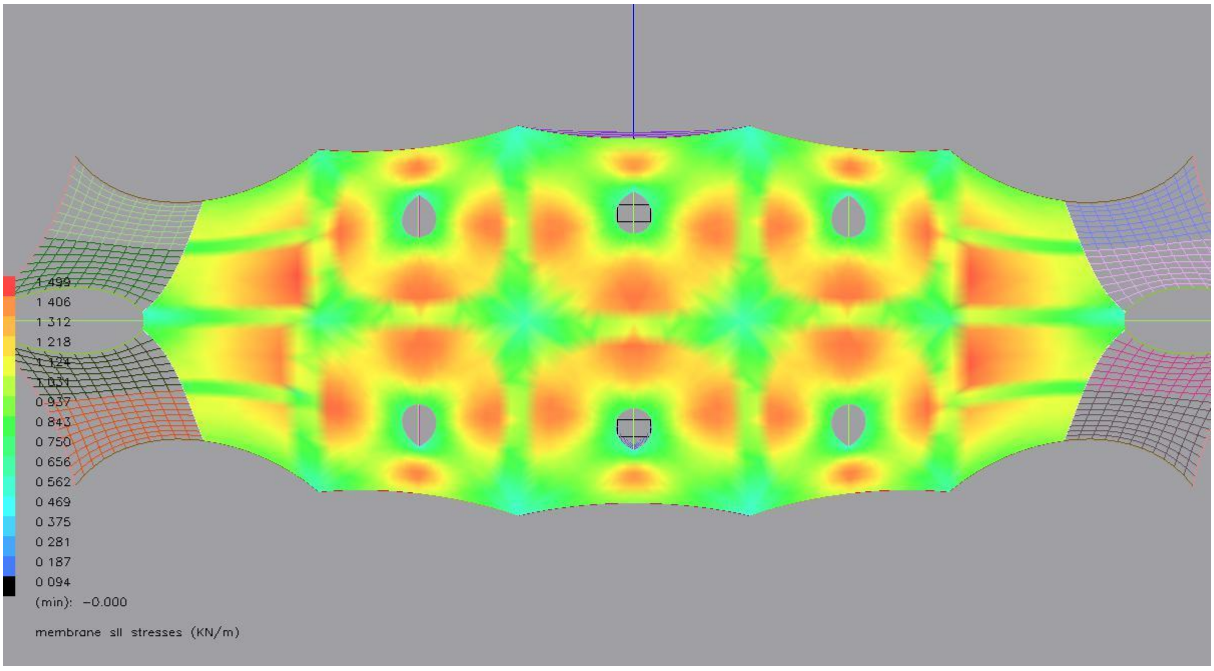




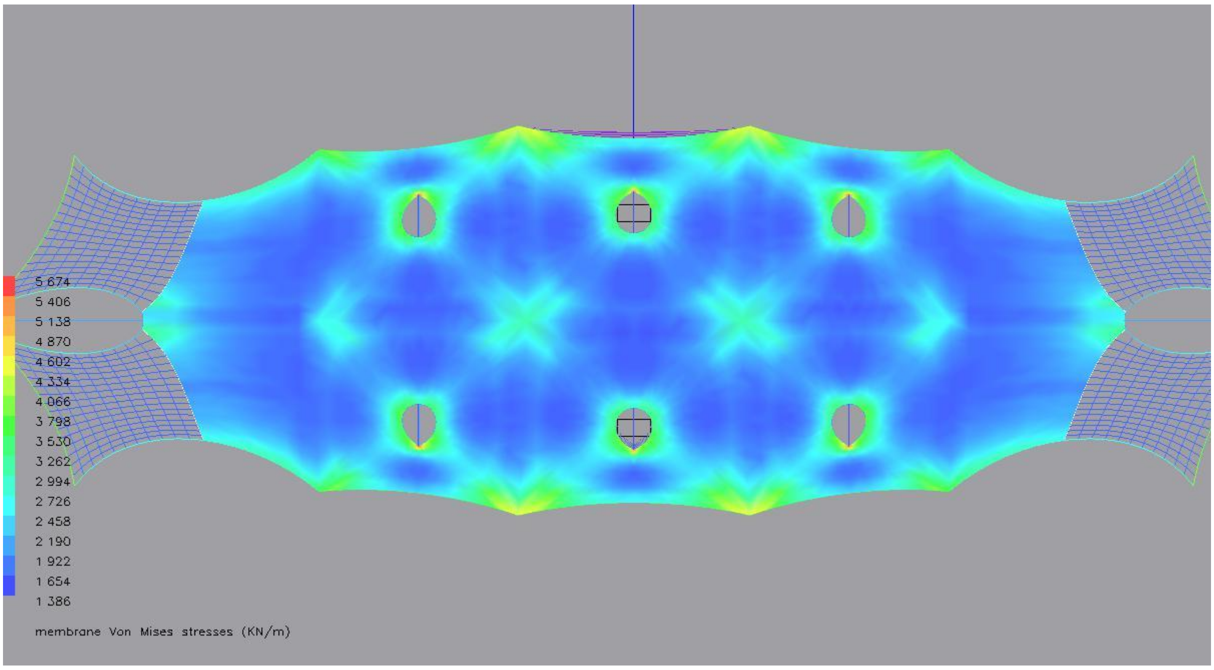
Stresses for pretension(FF – S1):



Stresses for pretension(FF – S2):



Stresses for pretension(FF – Von Mises):



3.5 Feasibility

The Toll Booth cover is designed to protect Booths from rain, snow and sun. For what regard snow and wind, we will not have ponding water in any of the design combination.

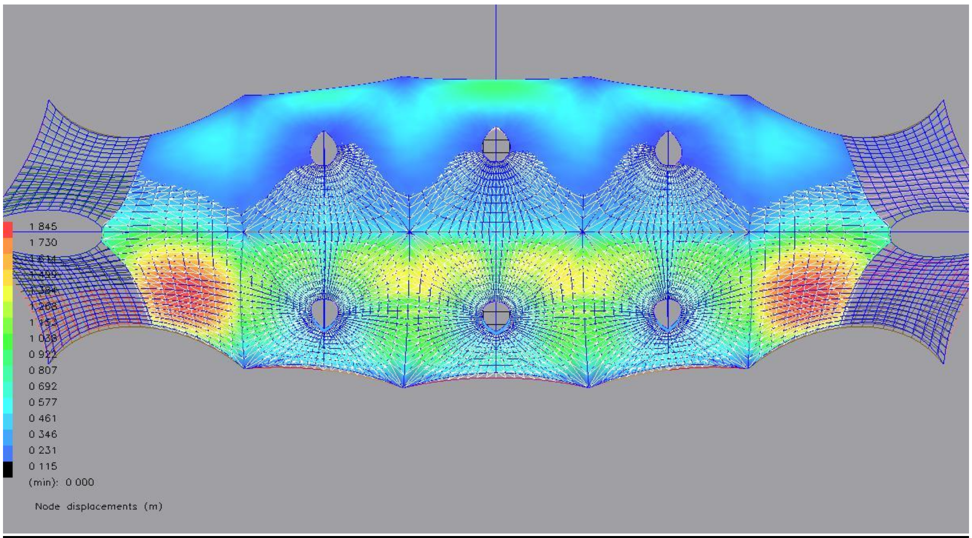
High local stresses will be considered in successive stages by eventually using a double layer membrane to get a reasonable allowable stress.

4. STRUCTURAL CALCULATIONS

4.1 Results

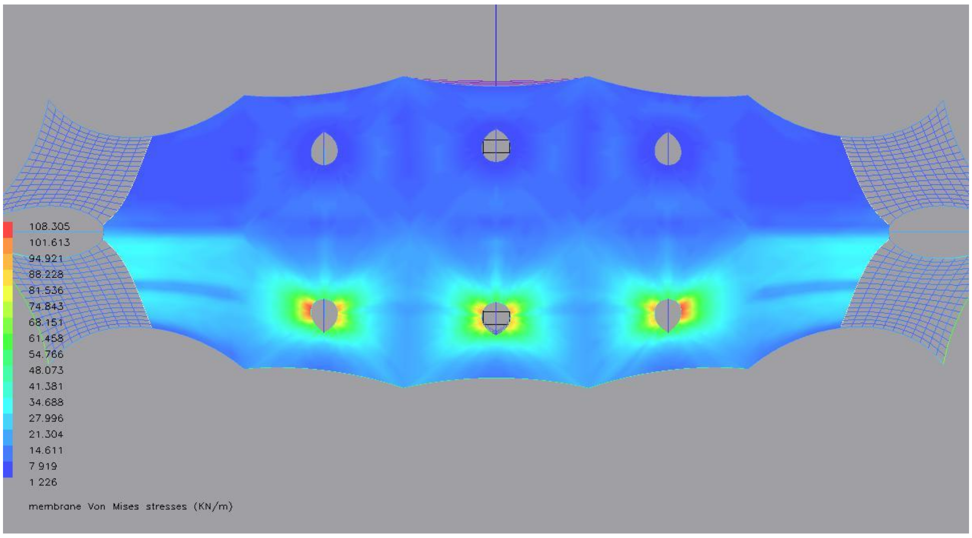
ULTIMATE LIMITE STATE 1:

- Self weight 1.35
- Snow load 1.50
- Wind load 1.50*0.6 = 0.9



Max displacement 1.845 m

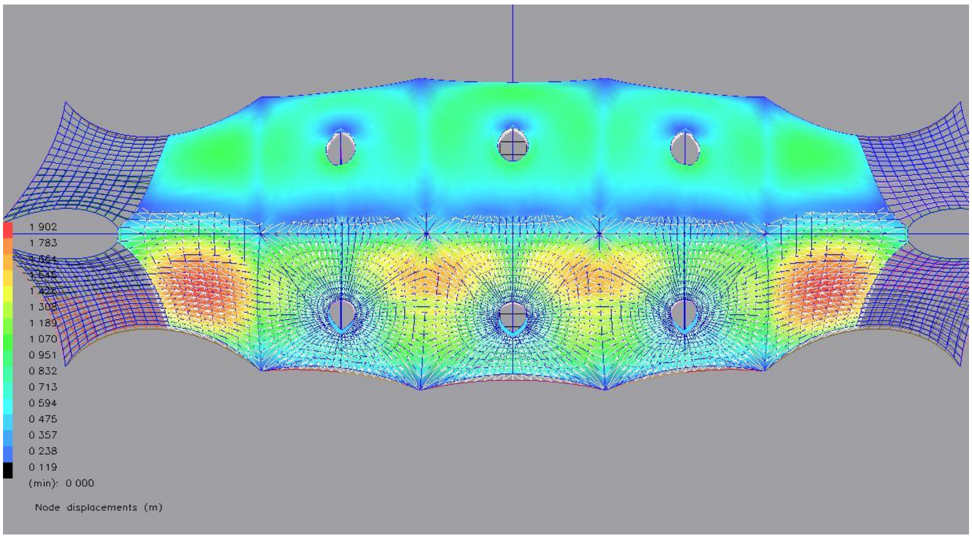
No ponding water



Von Mises stresses 108 kN/m

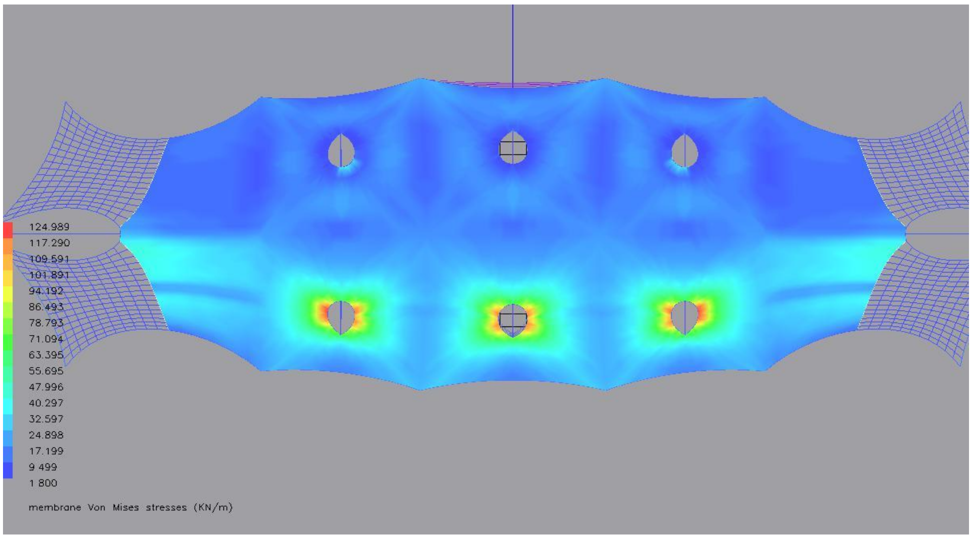
ULTIMATE LIMITE STATE 2:

- Self weight 1.35
- Snow load 1.50*0.5 = 0.75
- Wind load 1.50



Max displacement 1.902 m

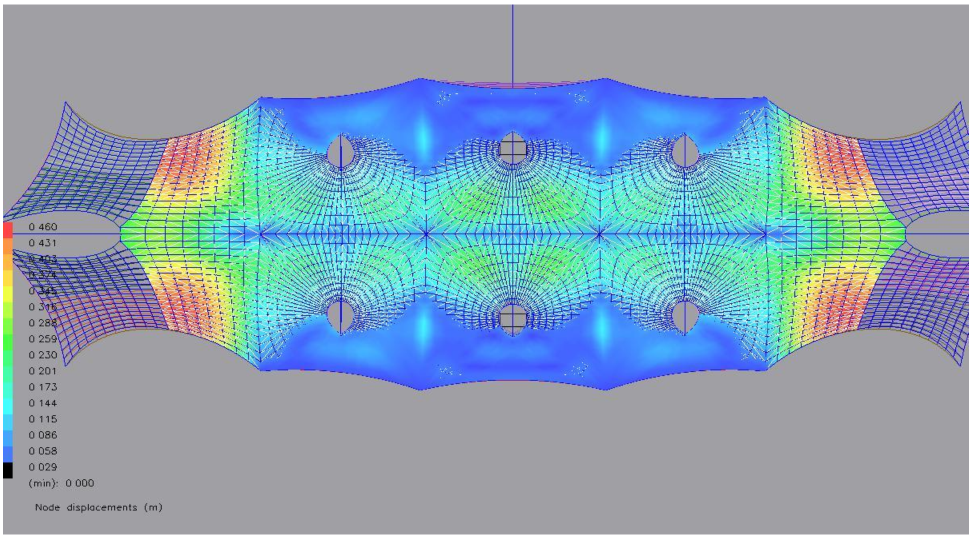
No ponding water



Von Mises stresses 108 kN/m

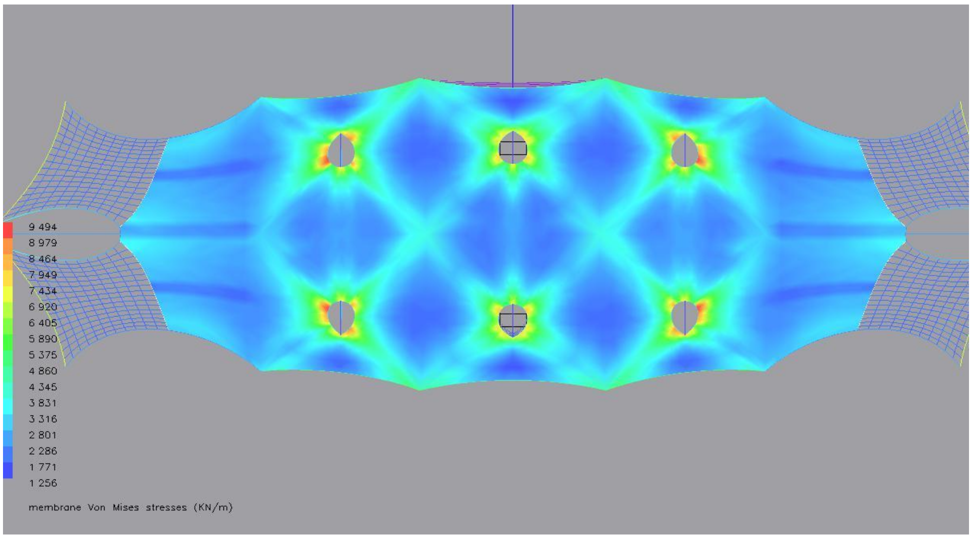
SERVICEABILITY LIMIT STATE 1 – Frequent combination:

- Self weight 1.0
- Snow load 0.2
- Wind load 0.0



Max displacement 0.480 m

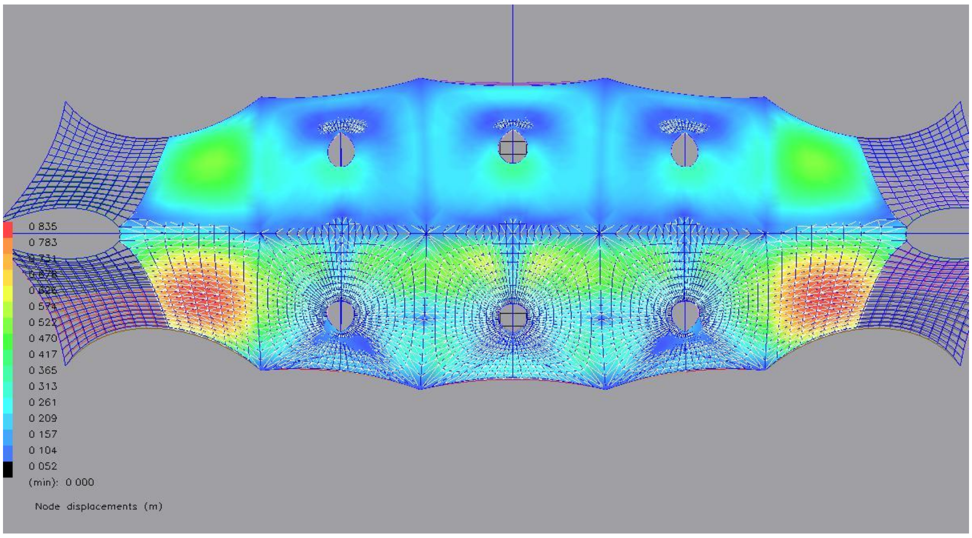
No water ponding



Von Mises stresses 9.49 kN/m

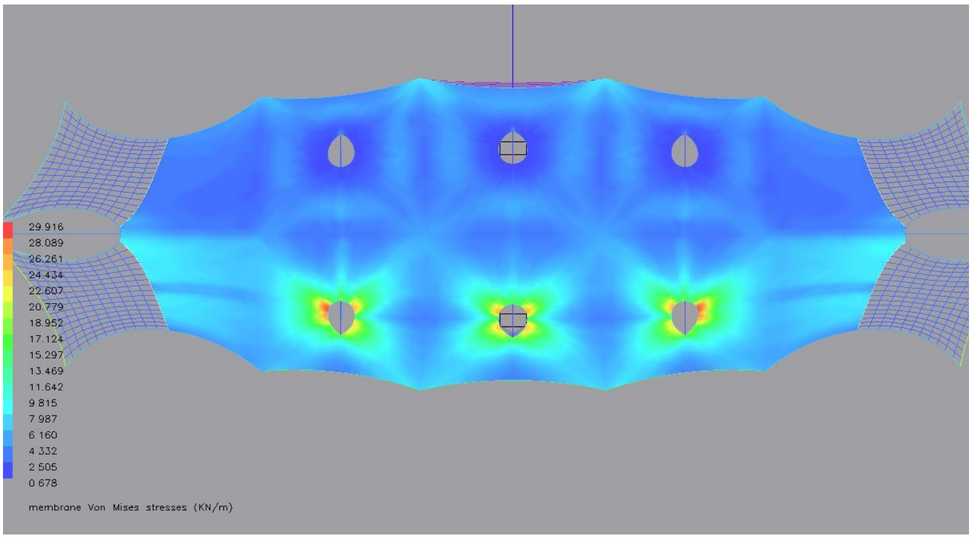
SERVICEABILITY LIMIT STATE 2 – Frequent combination:

- Self weight 1.0
- Snow load 0.0
- Wind load 0.2



Max displacement 0.835 m

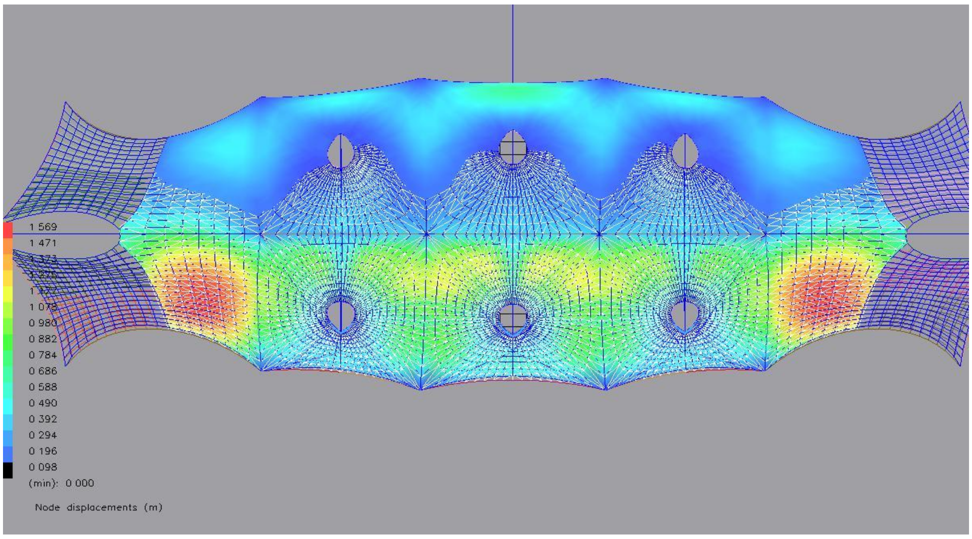
No water ponding



Von Mises stresses 94.72 kN/m

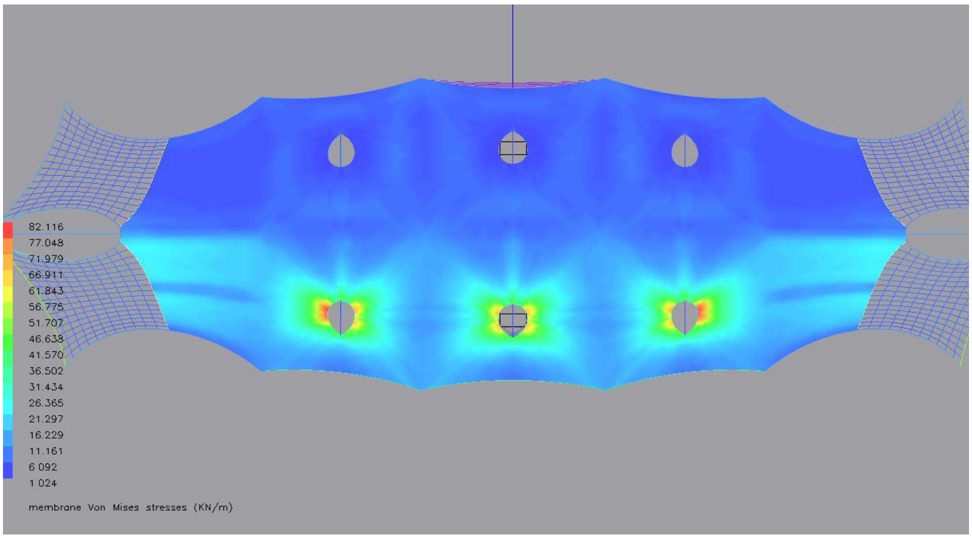
SERVICEABILITY LIMIT STATE 3 – Rare combination:

- Self weight 1.0
- Snow load 1.0
- Wind load 0.6



Max displacement 1.569 m

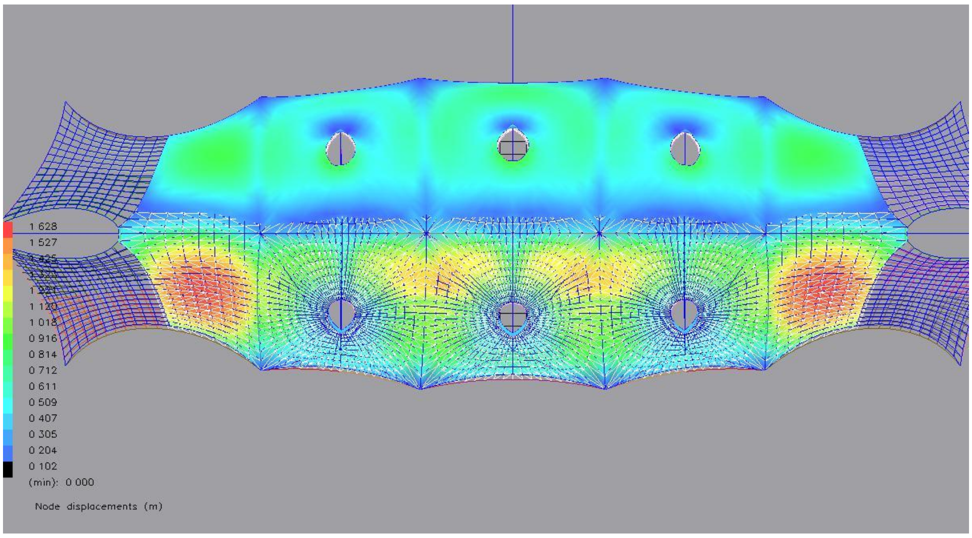
No water ponding



Von Mises stresses 82.12 kN/m

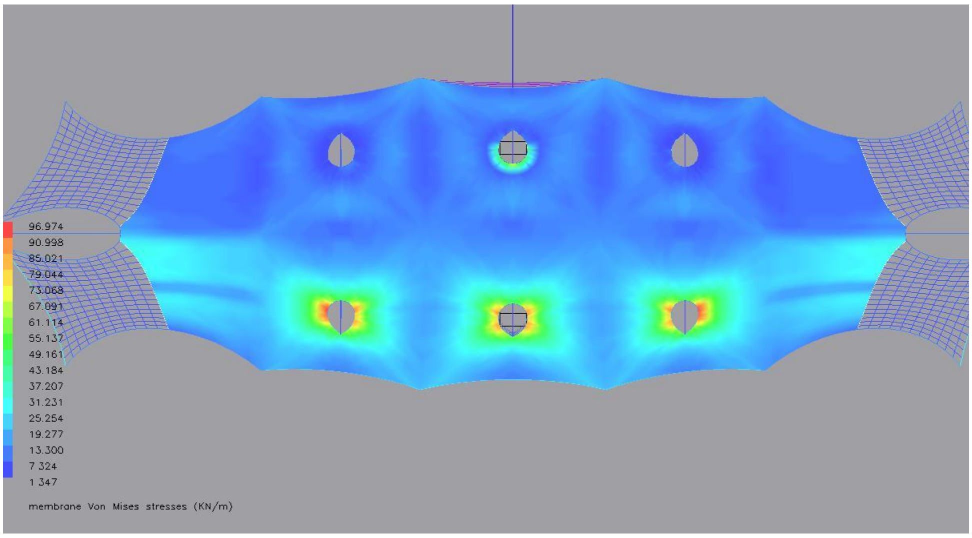
SERVICEABILITY LIMIT STATE 4 – Rare combination:

- Self weight 1.0
- Snow load 0.5
- Wind load 1.0



Max displacement 1.628 m

No water ponding

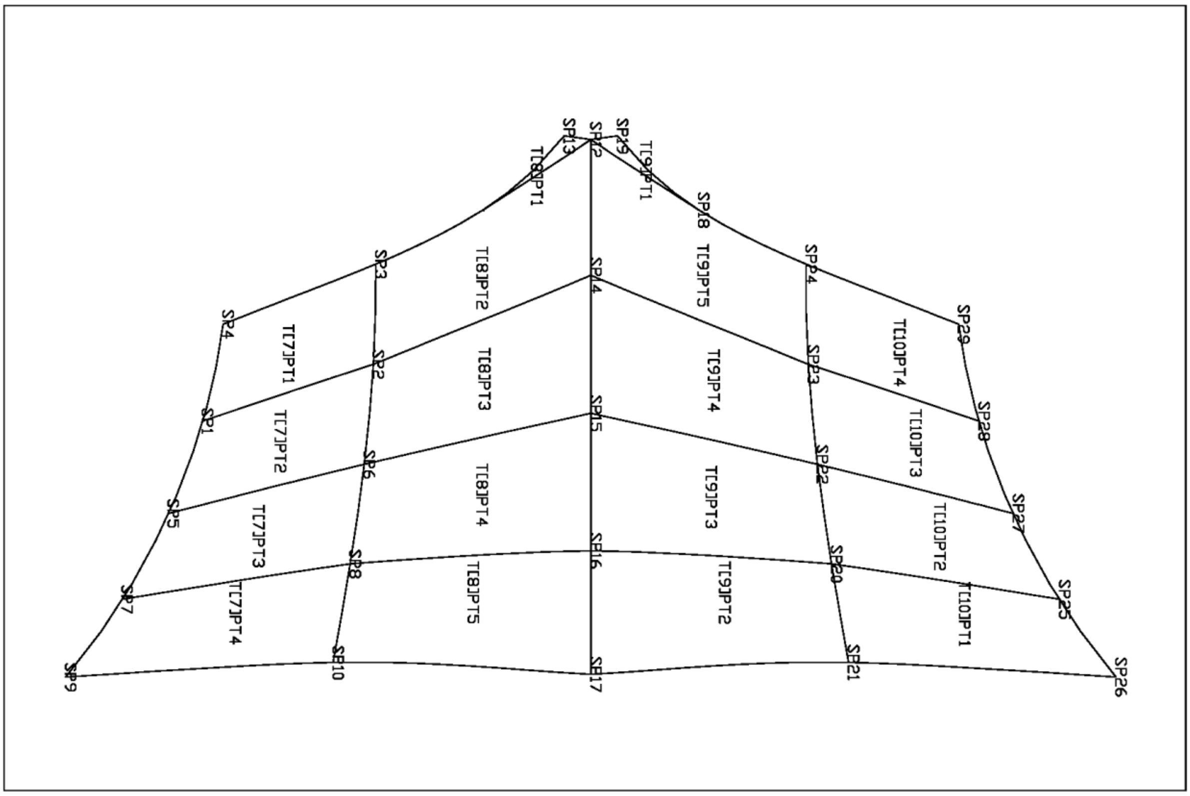


Von Mises stresses 96.97 kN/m

5. PATTERNING

For patterning we used the optimization option of Ix-Forten to search for geodesic cutting lines.

The layout of patterning was chosen in order to have seam lines parallel to the higher pretension stresses.



Pattern layout of the left wing

In the Appendix B there is the patterning of the left wing as an overview of the patterning phase.