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ON THE CALCULATION OF TEXTILE HALLS

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1 INTRODUCTION

The calculation of textile membranes should never be carried out independently of the primary construction, because the separation of the calculation into membrane calculation on the one hand and the calculation of the primary structure on the other hand, in which the reaction forces of the retained membrane are applied as external loads, results in quite considerable differences, which actually always lead to a significantly higher steel consumption and are therefore uneconomical. The idea that the savings from the hybrid calculation (i.e. the calculation of the membrane and the primary construction) are only given for double-curved membrane surfaces is to be refuted in this paper. Even with straight membrane surfaces, as they are usually present in textile halls in general, we obtain smaller cross-sections for the primary construction through the coupled or hybrid calculation. Nevertheless, to date these more accurate models are little used in practice, because their generation is time-consuming and not all requirements can be represented in usual software packages. In particular, membrane fields that are not firmly attached to the steel or aluminum elements, but rather membrane surfaces that slide over them, are a problem. In the article it is shown that a fast modelling under consideration of sliding conditions yields results that are below the usual deformations and metal quantities.

2 FAST GENERATION OF HYBRID STRUCTURES

Textile halls are currently still calculated in a simplified way. The load-bearing effect of the prestressed membrane is often not taken into account. This is also due to the complexity of the three-dimensional model. Therefore, it is very important to generate the models quickly and reliably. How this is done will now be shown [7].

It is assumed that the bending stiff elements of the primary structure are available. We - as a software producer - also offer programs for the fast generation of the lattice structure with input values as lengths, widths, inclination, number of frames, etc. Here we assume the presence of a lattice model.

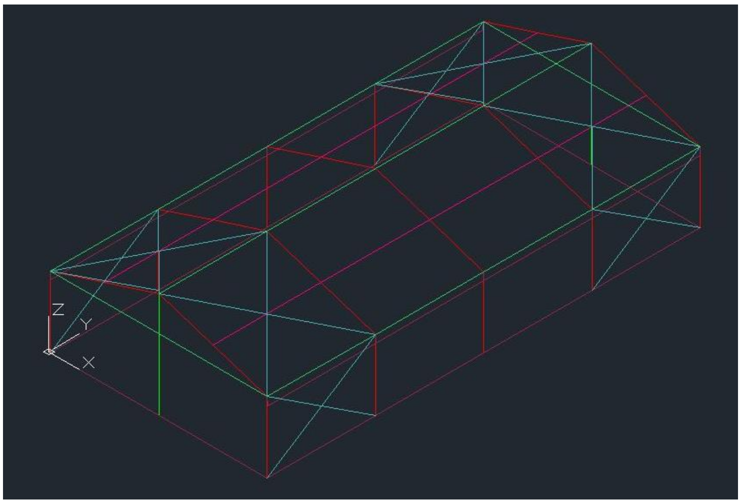

Figure 1: Frame and Diagonal Cables of the Hall (DXF/DWG)

When importing it into our software, the different cross-sections are included up to the static calculation. In our example, many membrane surfaces are to be generated. If these surfaces are already available as polygons from the DXF/DWG files, a quick generation is possible. On the other hand, we can also use a mesh generator to automatically generate the meshes of the polygons from the lattice model. Fig. 3 shows already the 40 polygons needed to automatically generate the membrane surfaces. Fig. 2 shows a membrane surface made in one piece that goes over 6 membrane fields. This membrane surface is only attached to the tensioning beams and to the frames on the left and right in a keder profile. It only rests on the yellow purlins and can slide over them. The red area shows a membrane surface made in one piece, which consists of 6 partial surfaces, and which is not fixed to the ridge and the purlins, but only rests on them. After erection, the membrane surfaces are brought to the target prestress with the tensioning beams (blue element); in particular the purlins are deformed during the prestress procedure.

We have defined the geometry and the membrane surfaces and can now quickly make further specifications in a graphic editor and generate the hybrid model. In detail, these are: mesh sizes of the membrane, orientation, pretension and stiffnesses of the warp and weft threads, crimp and shear stiffness of the membrane, etc.. Also important in this context is the way the membrane is fixed, e.g. sliding on the purlins and possible lifting possibly in case of wind suction.

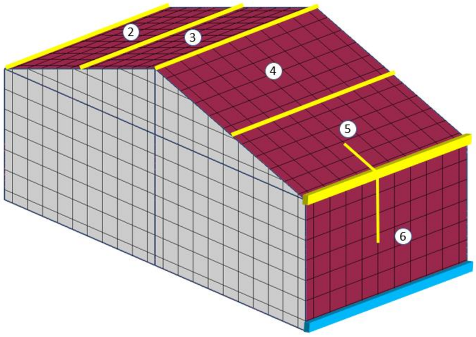

Figure 2: One piece of the red membrane covers 6 membrane fields

The hybrid model can now be created, modified and calculated. Fig. 3 shows the graphical editor and Fig. 4 shows the final hybrid model with the membrane surface. In Fig. 5 we see the final model with all its definitions concerning the fixities of all points, sliding conditions and the beam-elements with its joints. The example is 20 m long, 10 m wide and 4.88m at the ridge.

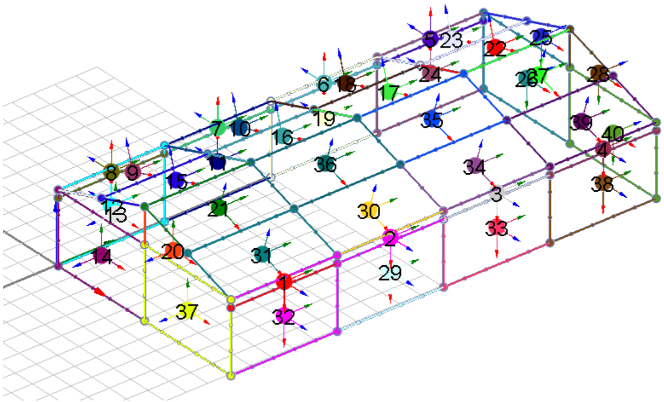

Figure 3: Graphical Editor for the fast model generation

The blue tensioning beam from Fig. 2 is here only 35 cm below the eave purlin, so the membrane field 6 is only 35 cm long. The complete wall behind is another membrane field (see Fig. 3 e.g. field 32 or in Fig. 4 field 2) Field 1 and field 3 in Fig. 4 are made from one piece and at the end of field 3 we have the tensioning beam (field 3 is inclined to clarify the situation).

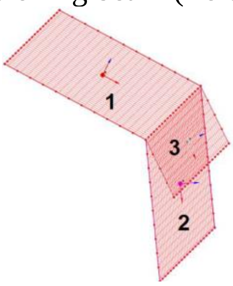

Figure 4: Graphical Editor for the fast model generation

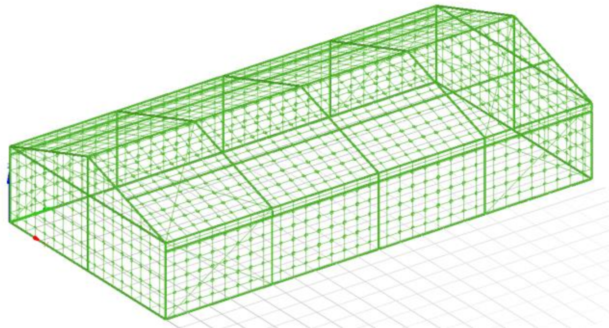

Figure 5: Hybrid model with primary structure and prestressed membrane

3 FORMFINDING TAKING INTO ACCOUNT THE FLEXIBILITY OF THE PRIMARY STRUCTURE

In the following, I would like to address an important point in the calculation of prestressed halls. The manufacturers of the halls want to optimize the cross-sections of the aluminum or steel elements in a cost-efficient way. This means that the elements already deform so much under the pretension of the membrane that these deformations have an influence on the cutting patterns of the membrane. For this reason, form-finding must be carried out with the real cross-sections of the bending beams. Formfinding here means that the membrane pulls with a constant pretension, independent of its deformation and without consideration of the material laws. [1], [2], [3]. In formfinding calculation, we define stress-fields and so we achieve a constant stress-level in the membrane. The result of this formfinding is a balanced structure under prestress. Now the cutting patterns of the membrane can be developed from this deflected geometry and static calculation can be performed. With the cutting patterns we mean the unstressed element geometry. The static calculation of the load case 'prestress' is now identical to the formfinding result. The pre-stresses are (more or less) constant and correspond to the originally desired stress-fields. Without this formfinding step the membrane stresses would be very small as the deformation of the primary structure was not considered.

4 SPECIAL FEATURES OF THE STATIC CALCULATION

After these preparations, the static calculations can be carried out. The pre-stress of the membrane, which is pulled over the frame grid, stiffens the primary structure. This stiffening leads to smaller deformations of the bending elements and thus has potential savings. [4],[5]. In order for the static calculation to be carried out realistically, the membrane fields must be able to move over the purlins; lifting under e.g. wind suction and pushing the beams under snow load is also necessary. How this is realized is shown in Fig. 6. A vector is defined for each cable that rests on the beam, which decides whether the cable presses on the beam or lifts off. Moving the cable over the beam is possible because there is only one piece of cable CDE. So not as usual 2 pieces of cable, CD and DE with 2 unstressed lengths and with a point D fixed on the beam, but only one piece of cable CDE with one unstretched length and one free point D. If the reaction force in D points into the half-space of the vector, the point lifts off, if the reaction force is against the half-space, it loads the beam with its reaction force in D.

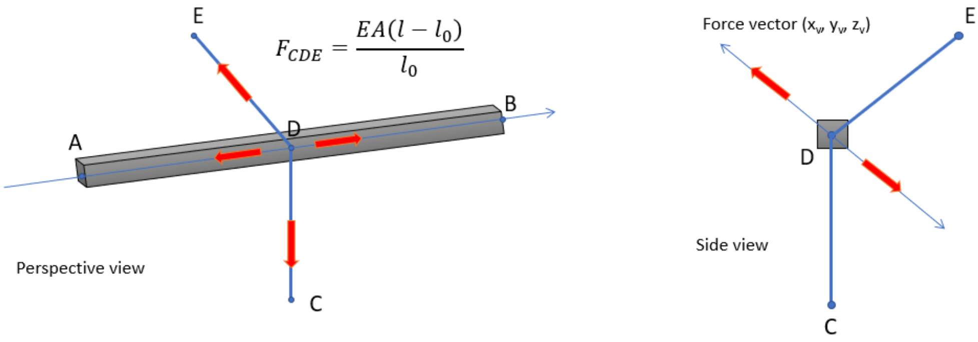

Figure 6: Sliding of a cable over a beam-element

Now static calculation can be performed; in our example with 3 simple load cases. (Wind in y-direction, Wind in x-direction and Snow on the roof surface).

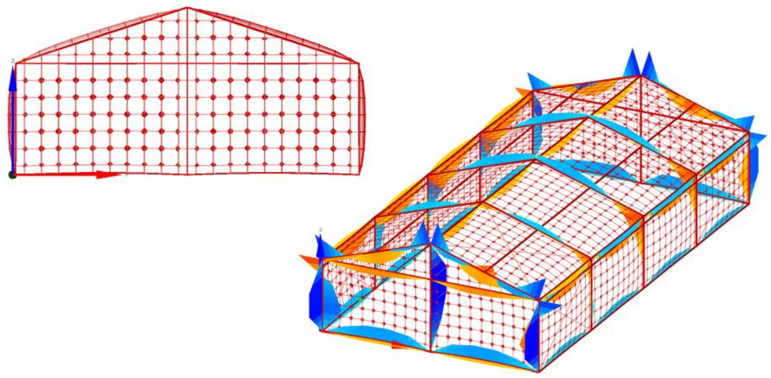

Figure 7: Deflections and bending moments (wind in y-direction)

You can see how the roof surface lifts above the central purlins, leeward the central support does not bend because the membrane surface is there as well uplifted.

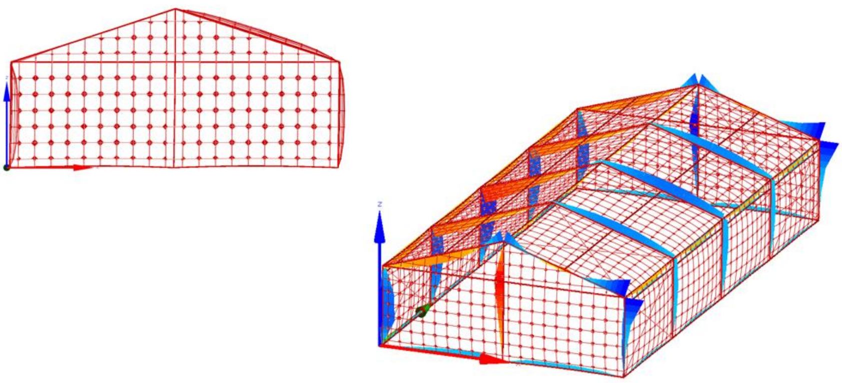

Figure 8: Deflections and bending moments (wind in x-direction)

Note the two long wall surfaces. Pressure on the frame on the left and lift-off on the right side.

Now it follows the comparison with a conventional calculation. I have also taken a 3D model and applied the surface loads to the membrane as adequate line loads to the elements.

COMPARISON WITH CONVENTIONAL CALCULATION

We will now compare the hall with a prestressed membrane with the conventional calculation (line loads on the 3D model). The comparison will show 2 points.

1. The hall stiffened by a membrane has smaller deformations.
2. The hall stiffened by a membrane has a smaller metal quantity.

Ad 1.) With 'error ellipsoids', the flexibility of the nodes can be shown very clearly [6]. I would like to explain it more detailed: the deflections of a point are on the surface of the flexibility ellipsoid when a unit load is rotating around the point.
We use it to show the differences.

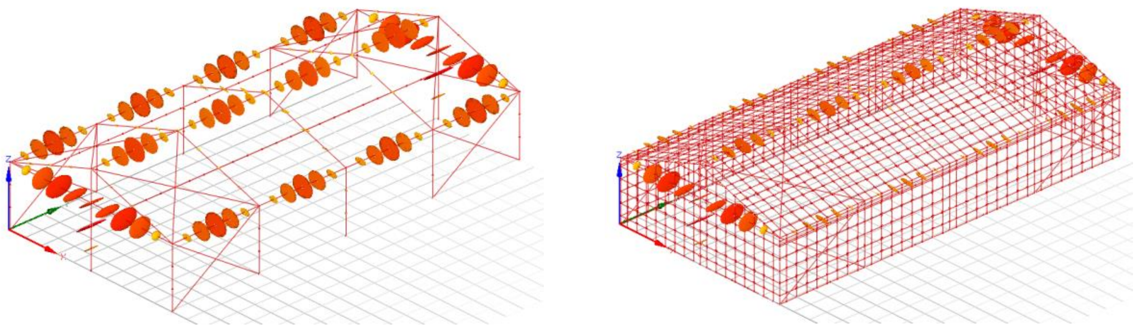

Figure 9: Conventional and hybrid model

In Fig. 9 we can see that the flexibilities of the ridge and eave purlins are far bigger in the conventional calculation without considering the membrane. We see: the membrane stiffens the steel-structure.

Ad 2.) Now we check the material consumption. The greatest differences between the two systems are in the 5 frames and the 3 purlins at the eaves and ridge.

In the calculation without the membrane, the purlins are subjected to insignificantly less stress, but the frames are subjected to much more. The left picture of Fig. 10 shows the 5 frames and the purlins. On the middle picture we see the frames. The cross-section of these frames are far smaller in the hybrid model. The cross-section of the left picture (Fig. 10) are a little bit smaller in the conventional calculation (as they are not loaded by prestress).

Overall, this leads to a reduction in the amount of metal by 20% for the specified cross-sections. In relation to the total amount of metal, we obtain approx. 15% as all other beam-elements are more or less in the same range. Fig. 10 shows the purlins and the frame-elements which are compared.

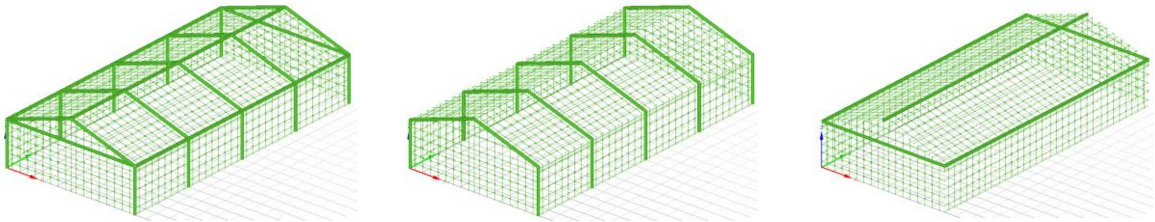

Figure 10: The green beam-elements are used for the comparison

5 Summary

Even with flat membrane surfaces, the static consideration of the prestressed membrane is highly recommended, because the deformations are smaller and so are the cross-sections. The simple and fast modelling, the formfinding of the membrane considering the primary steel-structure with its real cross-sections and the subsequent static calculation can be performed rapidly by the usage of approbriate software.

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