Transient analysis of air pressure loaded lightweight fabric and beam structures

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Abstract: SinusPro GmbH is tasked to help ensure the safety of removable lightweight structures which support banner advertisements and wind reduction sails at large sport events. The lightweight structures consist of fabrics, ropes and masts and are built on-sight within a few days. They have to withstand wind forces higher than the event-terminating wind speed (18 m/s) and have to be "unloadable" under full wind load within minutes.

SinusPro uses Abaqus/CAE for model setup and postprocessing, and Abaqus/Explicit as solver. To the customer, the rope and mast cross sectional forces were of special interest to provide for proper anchoring and a comfortable safety margin against breaking of a rope.

Keywords: Buckling, CFD Coupling, Collapse, Connectors, Dynamics, Fabrics, Mechanisms

1. Introduction

Large sport events nowadays generate huge revenues, so the probability of an event-terminating mishap must be reduced. Such mishaps can be loose banner advertisements or strong winds at some locations and can become potentially life threatening for the athletes.

Alpina Sicherheitssysteme GmbH is provider for mobile banner advertisements and wind reduction sails for large winter sport events, and has tasked SinusPro GmbH with analysis of their structures to ensure enough safety margin on the one hand and keep the structures from becoming too heavy on the other hand.

2. Banner advertisement analysis

The first object to be analyzed is the finish line gate banner of the Kitzbühel ski downhill event 2012.

As can be seen in figure 1, the structure consist of two masts, each held by four struts which are anchored to the snow. The two masts are connected by the main cable, so the masts are able to stand without the banner attached to the structure.

The banner is held by one runner every 0.5 m which are hooked to the main cable.

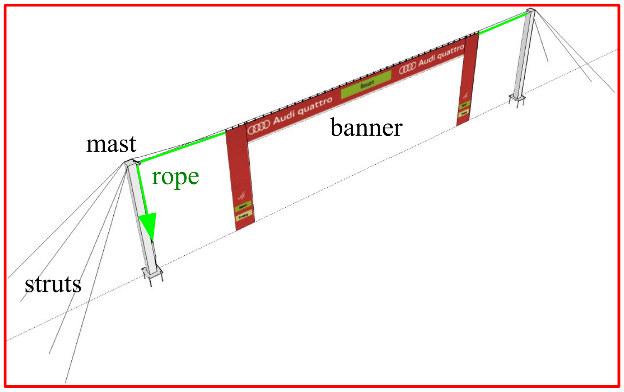

Figure 1: Kitzbühel 2012 ski downhill event

Ropes attached to the upper corners of the banner provide the force to keep the banner horizontally stretched.

2.1. Abaqus model setup

The banner is modelled using membrane elements, struts and the end of ropes are modelled with truss elements. The masts consist of beam elements and the ropes are modelled with slip-ring connector elements (figure 2).

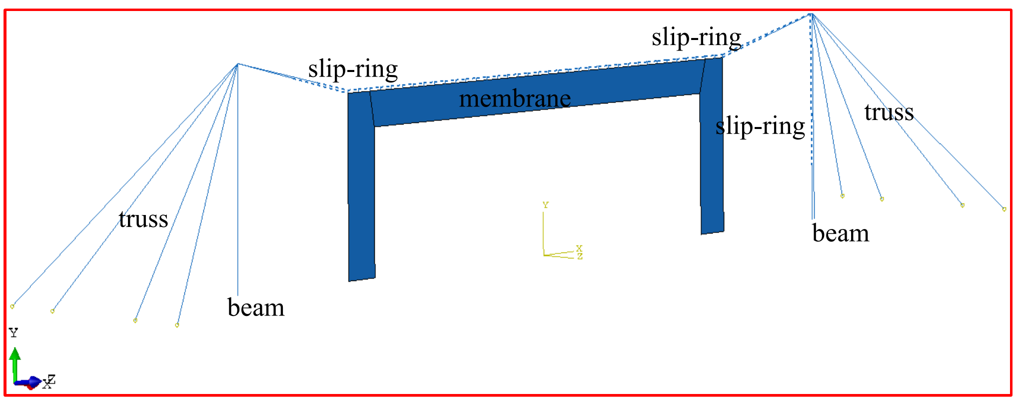

Figure 2: Banner model overview

The analysis is carried out using Abaqus/Explicit in two steps:

- Application of gravity
- Additional wind load

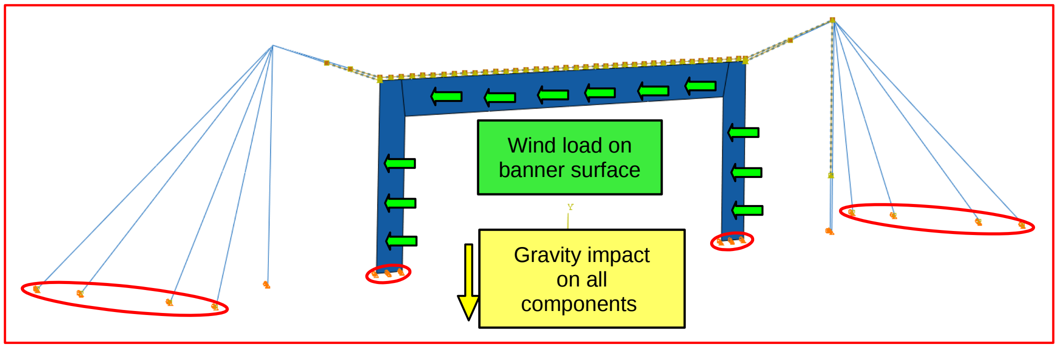

Figure 3: Loads and boundary conditions

Damping is provided by spring/dashpot elements acting between many of the strut nodes and a point far away from the model.

The anchor nodes, the mast ends and the lower rim of the banner are constrained in the 3 translational degrees of freedom.

2.2. Description of connector elements of type "slip-ring"

Slip-ring elements are special elements which are able to simulate ropes sliding through runners, without actually having to move one of the nodes of the slip ring element. This is possible because the slip-ring connector element has an additional degree of freedom, number 10. This DOF 10 is called "material flow" and can be imagined as production of "thread" like a spider can do.

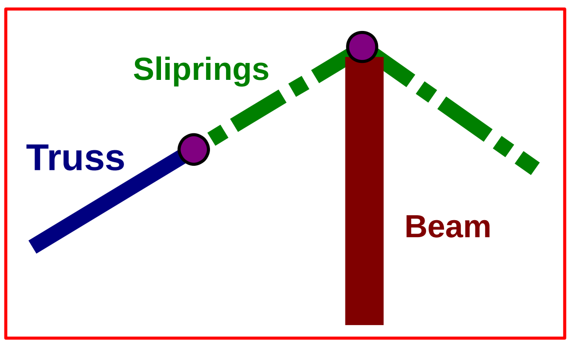

Figure 4: Slip-Ring connector element

At nodes which have one slip-ring connector element attached, the "spider" "produces" so much thread, that no force is acting on the "spider". If the DOF 10 is constrained at such a node, no thread is produced, and the node acts like the end of a rope – it has to follow the the rope's movement, unless it is constrained itself in some other manner.

At nodes which have two slip-ring connector elements attached, the "spider" will "eat" thread at one of the elements, and will "produce" the same amount of thread on the other element. Again, if DOF 10 is constrained at this node, no "eating" or "producing" of thread will occur, and the node has to move with the rope.

2.3. Deformed structure

The run of the simulation shows a deformation as can be seen in figure 5

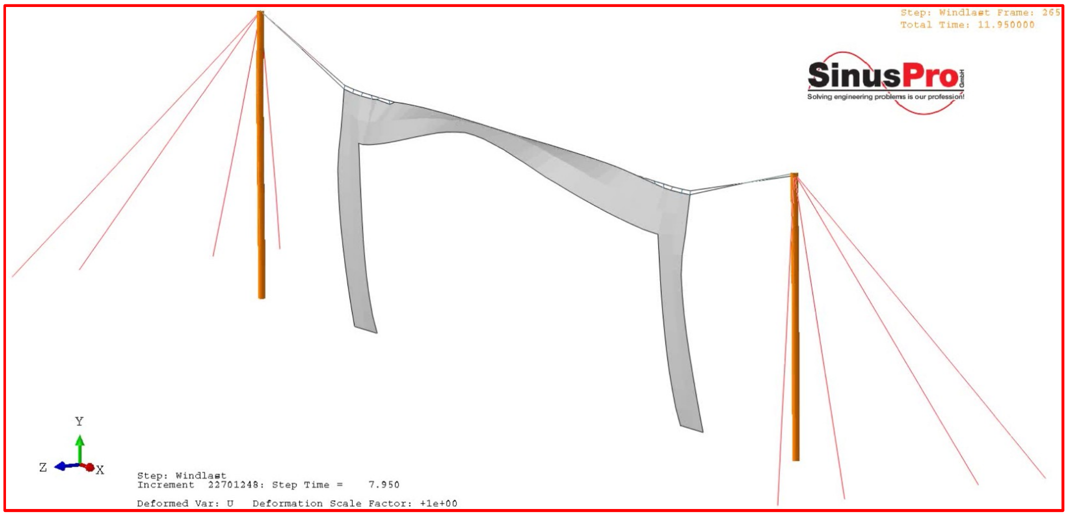

Figure 5: Calculated deformation under gravity and wind loading

3. Wind reduction sail analysis

For ski-jump events, winds of even moderate speed can lead to termination of the event, as they put the athletes to considerable amount of risk. Additionaly, the wind provides unfair advantages or disadvantages to some athletes.

Figure 6: Wind reduction sail

Therefore, Alpina Sicherheitssysteme GmbH erects a removable leightweight structure (figure 6) which has to be capable of supporting a wind reduction sail in winds up to 18 m/s. SinusPro GmbH is tasked to simulate the behavior of the structure at these high wind speeds, and also to provide information about the size of the wind reduced zone behind the wind reduction sail.

3.1. Abaqus model setup

To get a principal understanding of the mechanics of the structure, a reduced complexity model has been set up (figure 7).

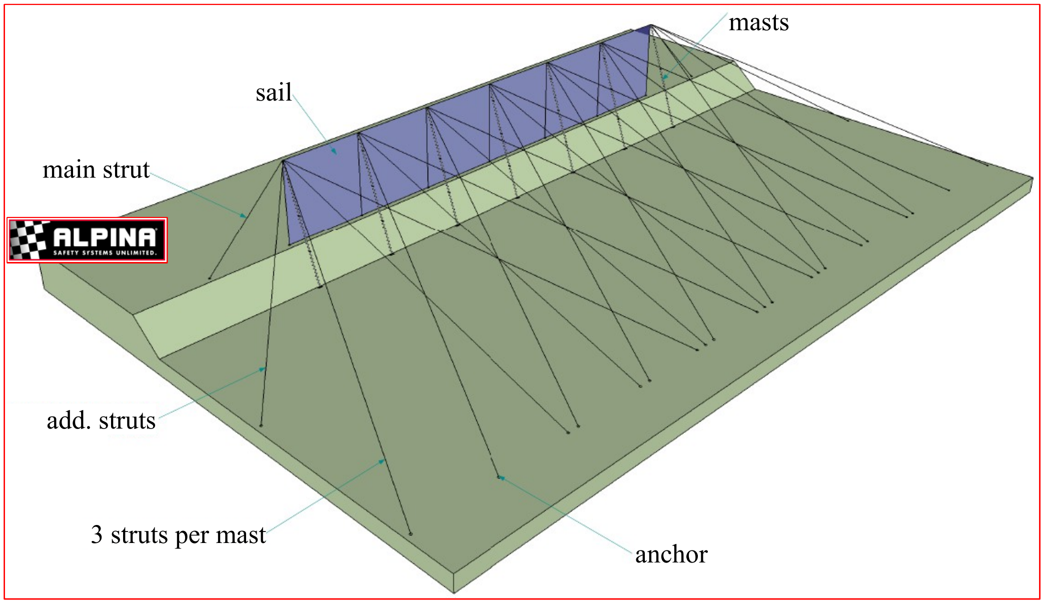

Figure 7: Reduced complexity model

Like for the finish line banner, extensive use of beam, truss, membrane and slip-ring connector elements are made. As the sail itself consists of perforated material, anisotropic material behavior has to be taken into account.

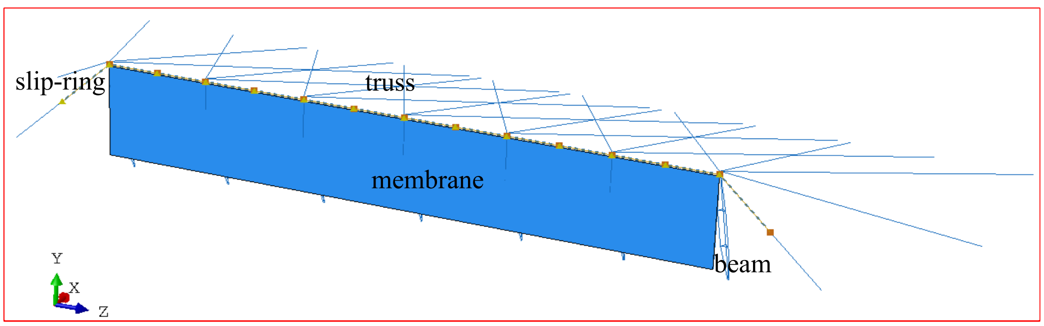

Figure 8: Abaqus model

The analysis is also carried out in two steps in this case, application of gravity and pre-tension in first step and additional wind load in second step

3.2. Deformed structure

To find the best setup, two different approaches are made: For the first analysis run the sail is pre-tensioned, for the second analysis run the sail is loosened by lifting the lower rim by 1 m at zero wind speed.

This comparison shows how a pre-tensioned structure would react to additional wind loading, and how some slack in the initial setup helps reduce the load on the structure. This behavior correlates very well with the experience of Alpina Sicherheitssysteme GmbH.

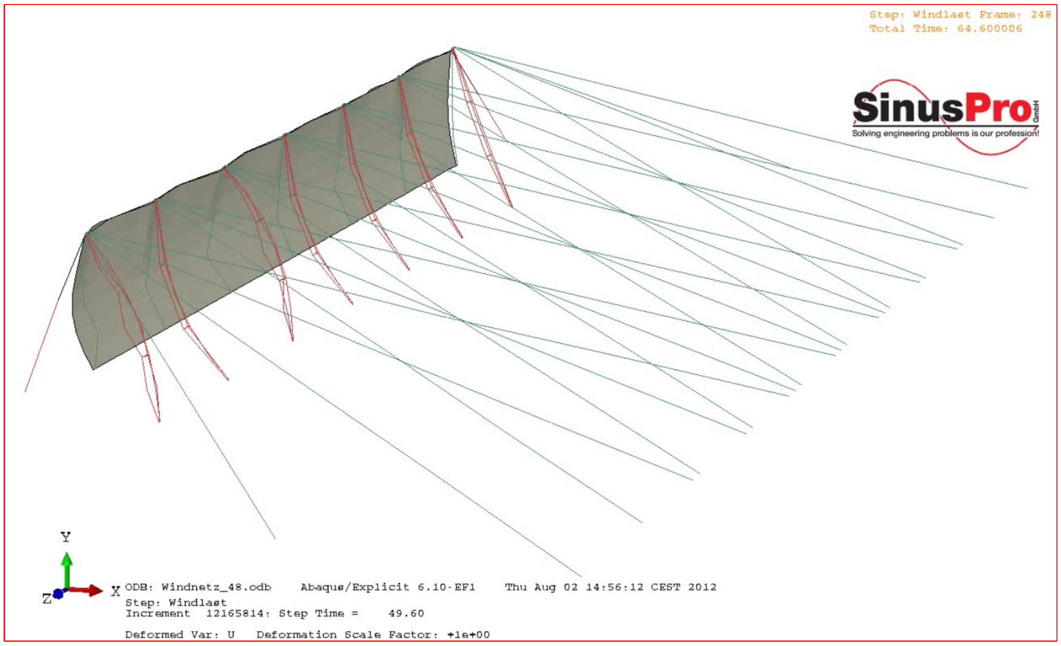

Figure 9: Deformed wind reduction sail with pre-tension

As can be seen in figure 9, the pre-tensioning of such a sail results in very high anchor and mast forces. The masts buckle extensively and would have bent and broken in reality.

3.3. CFD analysis of the wind reduction sail

Alpina Sicherheitssysteme GmbH also wanted to know how much influence the sail has on the wind itself, especially the size and shape of the wind reduced zone is of importance. For this purpose a reduced complexity landscape model with the deformed sail modelled as porosity is set up and analyzed using Fluent (figure 10).

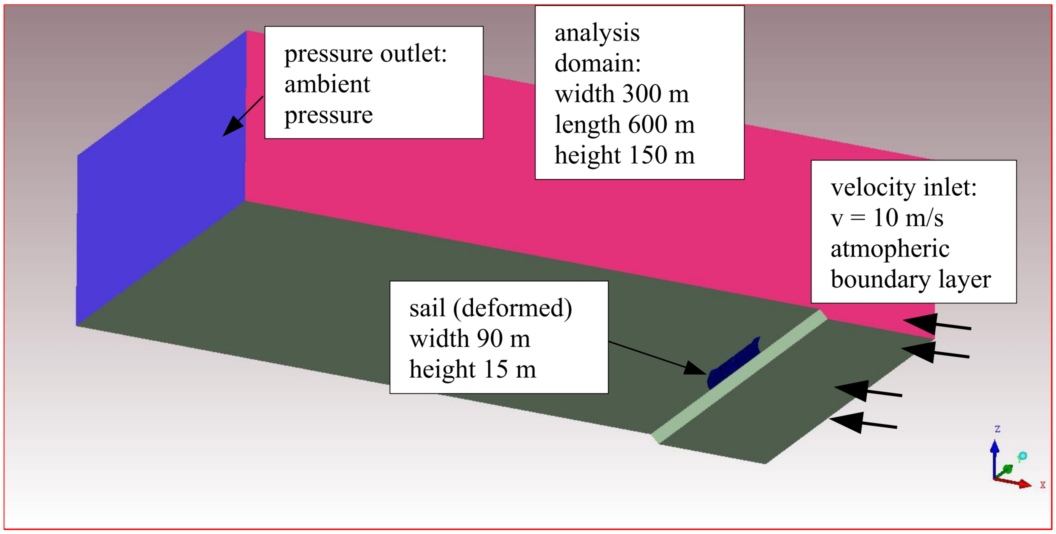

Figure 10: CFD model setup in Fluent

The pressure difference between upwind and downwind side shows only small differences from the assumed pressure distribution used in the structural model, so no mapping and recalculating of the sail's deformed shape is done.

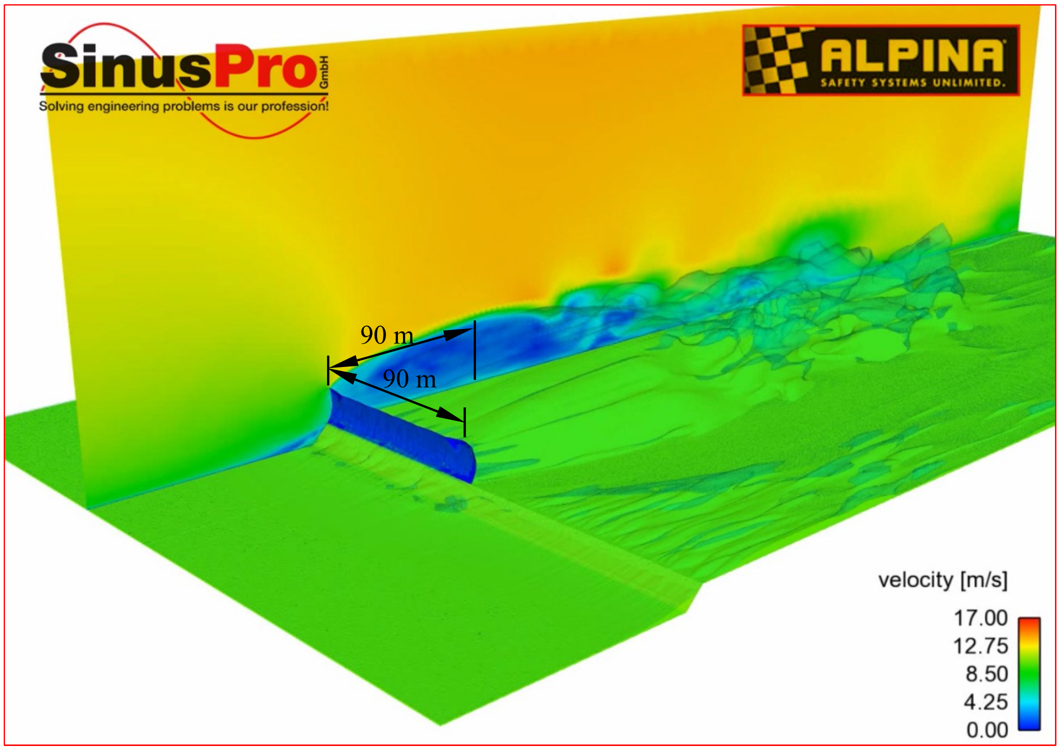

Figure 11: Velocity distribution behind the sail

As can be seen in figure 11, the volume of reduced wind speed extends approximately 90 m downwind from the sail. This means lower risk for the athletes while at the same time reducing the likelyhood of event termination.

4. Conclusion

The simulation of removable lightweight structures under wind load shows that pre-tension of the banner or sail can lead to dangerously high forces on the masts and struts. To avoid such a loading scenario, a certain amount of slack has to be defined. Additional CFD analysis can provide insights into the turbulences caused by this structure.

Outdoor sport events have a lower environmental footprint if lightweight structures are used. The designers of the structures now have the possibility to simulate the behavior already before a critical wind load occurs and can define a wind speed limit with more confidence.