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DEVELOPMENT OF AIR-INFLATED LIFTING EQUIPMENT

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Summary. The research aimed to develop air-inflated equipment for lifting catamaran components during construction. The main structural parts of a newly developed catamaran are two hulls and three closed boxes. The three boxes connect the hulls and hold the deck. Different construction procedures were analysed to connect the main structural parts. One possibility is to float the hulls and the three boxes one by one on the water, lift the boxes to the required position with inflated tubes or pillows and connect the parts. Air-inflated tubes with various geometry and internal pressure have been analysed with the help of the Dynamic Relaxation Method. The deformed shape of the floating tubes, the membrane stresses, and the lifting forces were determined.

1 INTRODUCTION

During the planning of a new catamaran, the possibility arose that the main elements would not be assembled in the shipyard but on the water. The main structural elements of the catamaran are the two hulls and the composite boxes connecting them. The research dealt with the possibility of lifting the boxes to the desired height on the water using inflated tubes. The advantage of this procedure is that the transport from the shipyard to the port is significantly easier, and the launch into the water can also be completed with simpler tools. Figure 1 shows the bottom of the prototype catamaran during construction.

The numerical analysis of the inflated tubes is based on the Dynamic Relaxation Method[1,2] (DRM). DRM is a step-by-step method especially suitable for the nonlinear analysis of tensile structures. The applied procedure and numerical model were previously validated with experiments during the 4-point bending test of an inflated tube[3], and their effectiveness was proven during the examination of additional pneumatic structures[4,5].

The aim of the presented numerical tests was to determine whether it is possible to achieve the desired lifting force with air-pressured tubes under the given geometrical boundary conditions. After a simplified two-dimensional calculation, the results of the three-dimensional analysis, the membrane forces occurring in the inflated tubes of different sizes and the lifting forces for different lifting heights as a function of internal pressure is presented in detail.

Figure 1: The bottom of the catamaran during construction

The distance between the two hulls is 3.0 m, and the longitudinal dimension of the largest box is 2.3 m (Figure 2). The required lifting force per box was 6.1 kN (which corresponds to the self-weight of the box + the approximate weight of two people working in the box during assembly). Since a box would be lifted by two inflated tubes parallel to the hulls, the lifting force to be achieved per tube is at least 3.05 kN. The planned height of the bottom plane of the boxes above the waterline is a maximum of 0.6 m, which gives the required lifting height.

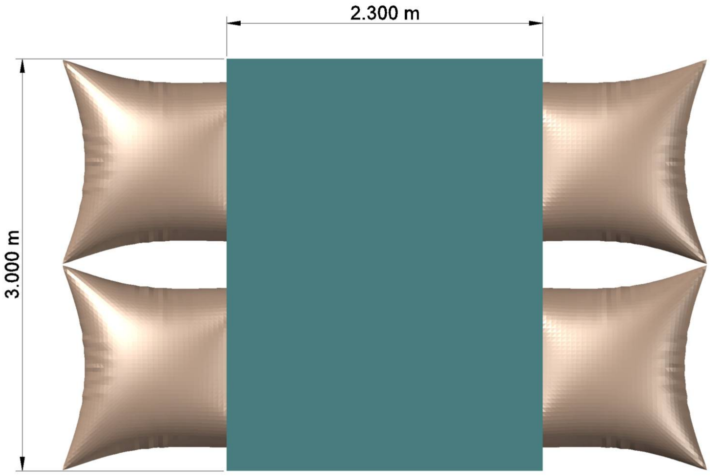

Figure 2: Top view of the largest composite box with two inflated tubes

2 PRELIMINARY TWO-DIMENSIONAL CALCULATIONS

Before the detailed spatial investigation, a two-dimensional DRM analysis aimed to decide whether there was a realistic chance of achieving the required lifting force with the size limitations of the tubes.

In the first step, the two-dimensional model of an inflated tube was analysed with horizontal support at the bottom. The model represented a one-meter-long segment of the inflated tube. The stress-free perimeter of the tube was 3 m. The curved cross-section of the tube was approximated with 100 straight two-node cable elements. A normal stiffness of *EA*=400 kN was taken into account for the cable elements (corresponding to the normal stiffness of a one-meter-wide PVC-coated polyester material). Figure 3 shows the shape of the inflated tube and the lifting force acting on the box, according to *p*=3.5 kN/m internal pressure and various lifting heights.

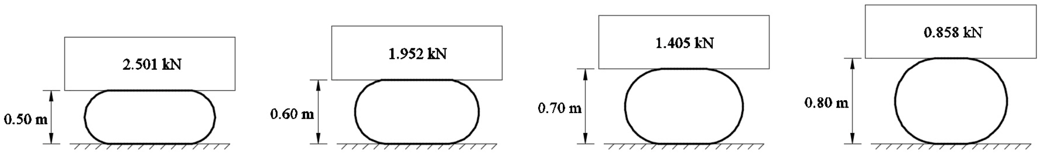

Figure 3: Lifting forces acting on the box for different lifting heights, horizontal support, *p*=3.5 kN/m internal pressure

In the second step, the two-dimensional model of an inflated tube floating on the water was analysed. In the case of elements below the water level, the water pressure was considered as an external distributed load proportional to the depth. Compared to the first case (fixed horizontal support), the lifting force of the floating tube was significantly lower (Figure 4). The maximum tension in the tube was 1.54 kN (corresponding to 1.54 kN/m membrane force), and it was detected in the case of 0.8 m lifting height.

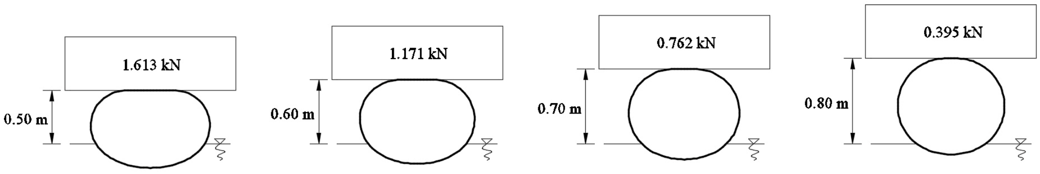

Figure 4: Lifting forces acting on the box for different lifting heights, floating tube, p=3.5 kN/m internal pressure

Figure 5 shows the lifting forces as a function of the lifting height for the two different boundary conditions. These results of the two-dimensional approximate calculation proved that achieving the desired lifting forces can be a realistic goal.

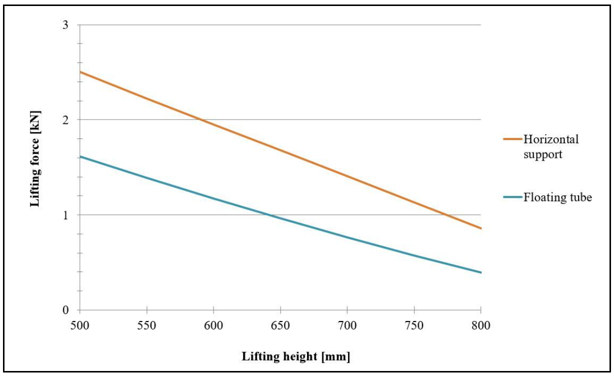

Figure 5: Lifting forces acting on the box as a function of lifting height

3 THREE-DIMENSIONAL ANALYSIS

In the next step of the investigation, the pneumatic tubes were approximated with a mesh consisting of flat triangular membrane elements. The following material properties were considered during the numerical analysis: $EA_{\text{warp}}=EA_{\text{fill}}=400$ kN/m, $G=10$ kN/m, $\nu_{\text{wf}}=\nu_{\text{fw}}=0.3$, $m=0.8$ kg/m^2. A rectangular cutting pattern that corresponds to the cheapest and fastest manufacturing (thanks to the simple, straight weldings) was applied. The warp fibre direction in the membrane material was parallel with the longer side of the cutting pattern.

3.1 Mesh and initial shape

The initial geometry corresponds to the flat, rectangular shape of the uninflated tube or pillow. Figure 6 shows the applied triangle mesh. The upper and lower layers of the mesh are connected at the four edges of the flat pillow. Pillows with various widths and lengths have been analysed; Figure 6 shows one example of the applied sizes.

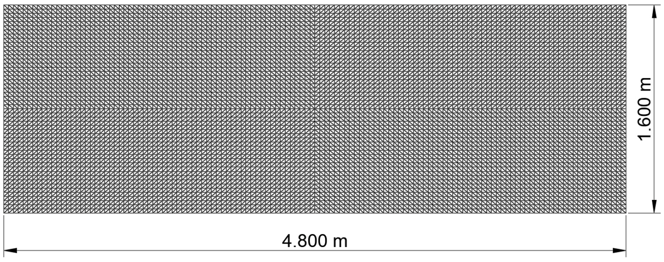

Figure 6: The initial, flat shape and the triangle mesh

3.2 Inflated shape

Figure 7 shows the shape and sizes of the inflated tube (corresponding to the example introduced above).

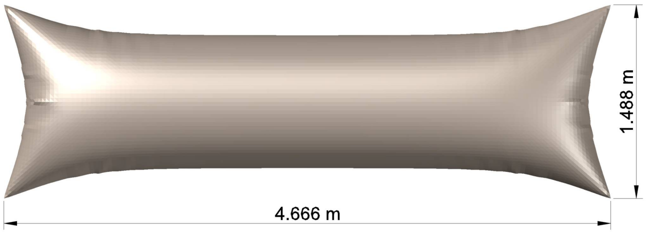

Figure 7: The inflated tube, $p=35$ mbar

Figures 8 and 9 show the membrane forces in warp and fill directions. The black areas mean the lack of tension in the membrane. The lack of tension results in wrinkles, which are also visible on the surface of the mockup presented in Section 5.

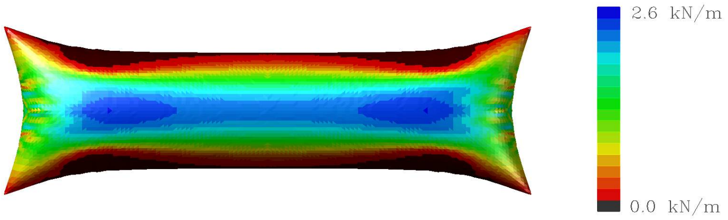

Figure 8: Membrane forces in warp direction in the inflated tube, *p*=35 mbar

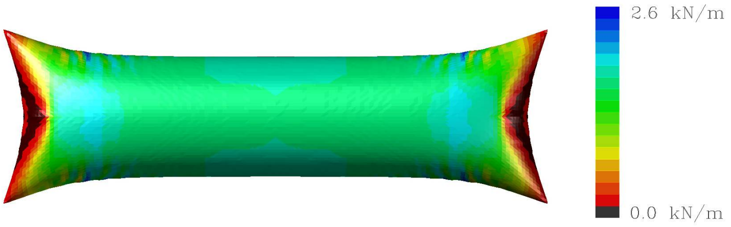

Figure 9: Membrane forces in fill direction in the inflated tube, *p*=35 mbar

3.3 Floating and loaded tube

The final step of the analysis was the determination of the deformed shape of the loaded, floating tube (Figure 10). Figures 11 and 12 show the membrane forces in warp and fill directions. Based on the results of several analysed cases, it can be stated that in the applied pressure range (20 - 50 mbar), the membrane stresses are significantly lower than the tensile strength of technical PVC-coated polyester textiles intended for structural purposes.

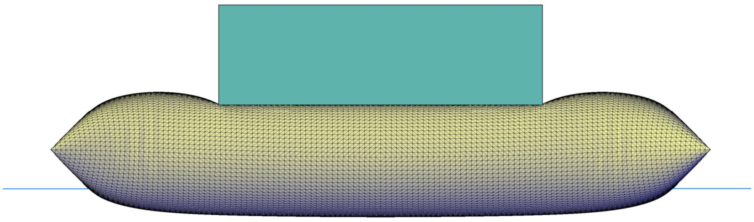

Figure 10: The loaded, floating tube, *p*=35 mbar, the working height is 0.6 m

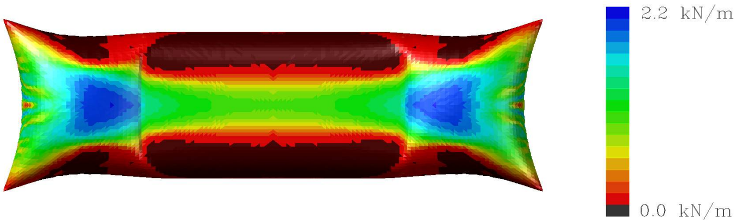

Figure 11: Membrane forces in warp direction in the loaded, floating tube, *p*=35 mbar

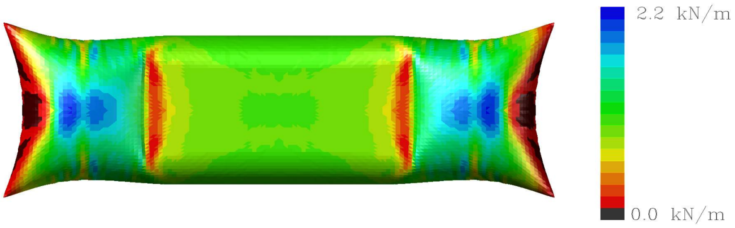

Figure 12: Membrane forces in fill direction in the loaded, floating tube, *p*=35 mbar

4 RESULTS OF THE PARAMETRIC ANALYSIS

A parametric study has been performed to get a more general picture of the available lifting force. The effect of the pillows' length, width, and internal pressure was analysed. The results are presented in Figures 13-15. The presented diagrams are suitable for the determination of the sizes of the applied inflated tubes and the internal pressure for the required lifting height and force. (The dimensions of the lifted box were not varied.)

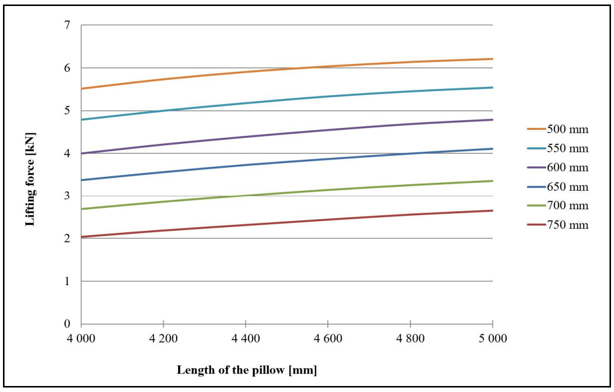

Figure 13: The lifting force for different lifting heights between 500-750 mm as a function of the cushion length (width of the flat pillow is 1600 mm, *p*=35 mbar)

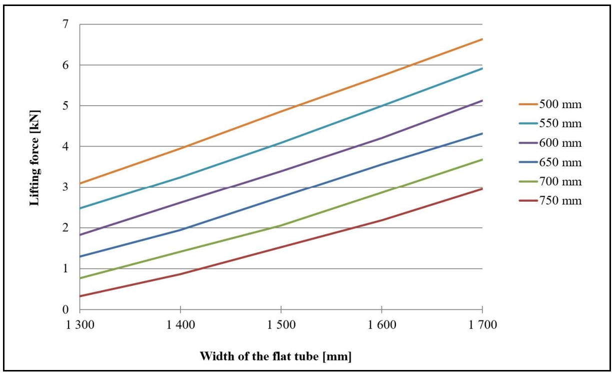

Figure 14: The lifting force for different lifting heights between 500-750 mm as a function of the cushion width (length of the tube is 4200 mm, *p*=35 mbar)

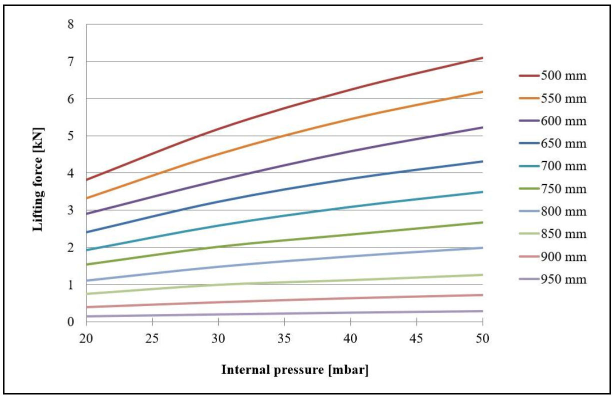

Figure 15: The lifting force for different lifting heights between 500-950 mm as a function of the internal pressure (the width of the flat pillow is 1600 mm, and its length is 4200 mm)

5 MOCKUP

A 5-meter-long mockup has been prepared to check the welded connections and the shape of the inflated pillow in the case of a rectangular cutting pattern. The internal pressure was increased to 75 mbar. Figure 16 shows the inflated mockup. The wrinkles along the short and the long side of the pillow show the lack of tension in fill and warp directions, respectively (see Figures 8 and 9).

Figure 16: Inflated mockup

6 CONCLUSIONS

The presented research determined the lifting force that can be achieved with the help of air-inflated cushions floating on water. The presented results are suitable for selecting the required pillow dimensions depending on the internal pressure. A 5-meter-long mockup proved that the simplest rectangular cutting pattern could provide the right solution with its simple welding. There was a good agreement in the location and direction of the wrinkles on the inflated surface in the case of the numerical solution and the mockup.

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