Azure PROJECT

Sector

AzureProject MEMBRANE Finite element model validation

Project topics

Analytical test

Comparison of membrane analysis results with a commercial FEM/FEA tools.

Results

The results obtained from AzureProject and midasNFX are very close:

<0.2% differences on maximum displacement

From 0.4% to 0.9% the maximum difference on the maximum von Mises stress

Reference:

Malpede, S., D'Angeli, F., Bouzaid, R. (2013), Advanced structural analysis method for aeroelastic simulations of sails, Proceedings of the Third International Conference on Innovation in High Performance Sailing Yachts, Lorient.

Baraldi, A., Malpede, S.(2008), A fully integrated method for optimising fiber-membrane sails, Proceedings of the 3rd High Performance Yacht Design Conference, Auckland.

midasNFX www.midasnfx.com

INTRODUCTION

AzureProject is a user-friendly software application for the design and analysis of sails. The analytical modules include the fluid-dynamic, structural and fluid-structural interaction methods to calculate the sailing loads in user-defined sailing and trimming conditions and the corresponding flying sail-shape. All methods have been developed in house by the SMAR Azure team and are integral part of the software packages AzureProject and SA Evolution.

This document illustrates some of the validation tests carried out on the membrane finite element model developed to model the sail structural behaviour.

THE MEMBRANE ELEMENT

The structural analysis consists of computing the deformation and stress distribution of the sails by using a nonlinear finite element method where geometric nonlinearities are taken into account for, keeping material properties linear. The approach is well suited for the problem involved where large displacements are encountered and the material is expected to work within the linear region of the stress-strain function; no yielding is modelled. Since a nonlinear problem is solved, Raphson's method is used to find the deformed equilibrium state.

- **SAIL MEMBRANE MODELLING**

When the ratio between the thickness and the other dimensions of a structural shell is very low, the flexural stiffness contribution to the system equilibrium can be neglected; this is verified in the case of a yacht sail, therefore a simple membrane model fits the purpose. The consequence of this is that the structure possesses no out of plane stiffness and small imperfections lead to local instabilities that can be observed in the form of wrinkles in regions of compressive stress. The SMAR Azure method also includes the correction for wrinkles. Full details are provided in the papers under References.

- **VALIDATION TEST DESCRIPTION**

A simple flat square membrane has been created in AzureProject. The same model has been created as similar as possible in midasNFX. The flat square membrane has been analysed applying the same uniform pressure. Displacement and stress patterns and maximum values have been collected and presented on a list of results and images for comparison.

MODEL DESCRIPTION

- **Flat quadrangular membrane**

The edge of the flat square membrane is 1m long, divided in 11 segments for the triangular mesh, which is unstructured. Structural grid is very similar between AzureProject and midasNFX, although not exactly the same.

AzureProject mesh is more regular and symmetric while midasNFX mesh appears to have slightly more elements. Those small differences should not cause relevant differences on the results. Both solvers adopt nonlinear geometry through load steps. The material of the flat square membrane is nylon, with the same properties on both finite element models:

- Tensile modulus = 4 GPa
- Poisson ratio = 0.4
- thickness = 0.1 mm

- **Load and boundary conditions**

A uniform pressure of 21.507 Pa has been applied on the square flat membrane on both solvers on every load case. Different combinations of the constraints at the edges and at the corners produced different load cases as described:

Load Case 1. 3 edges fixed, only 1 edge free.

Load Case 2. 2 opposite edges fixed (remaining 2 edges free).

Load Case 3. 1 edge and the opposite 2 corners fixed (3 edges free except on the corners).

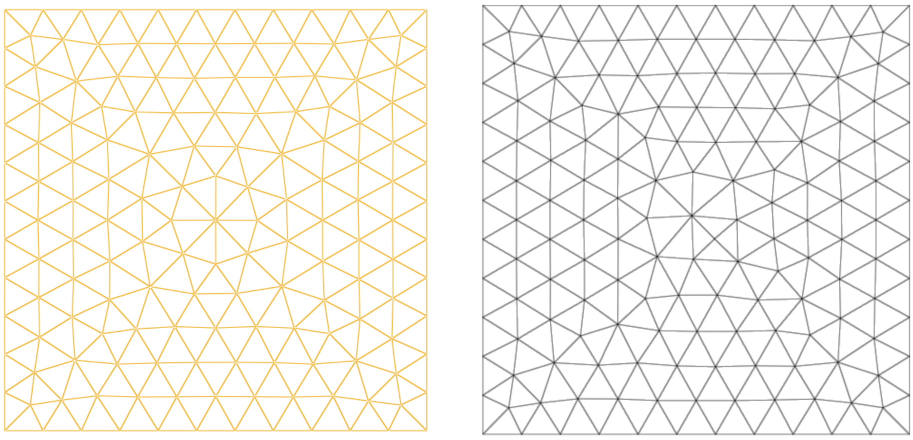


Figure 1 *Structural grid comparison: AzureProject on the left and Midas NFX on the right.*

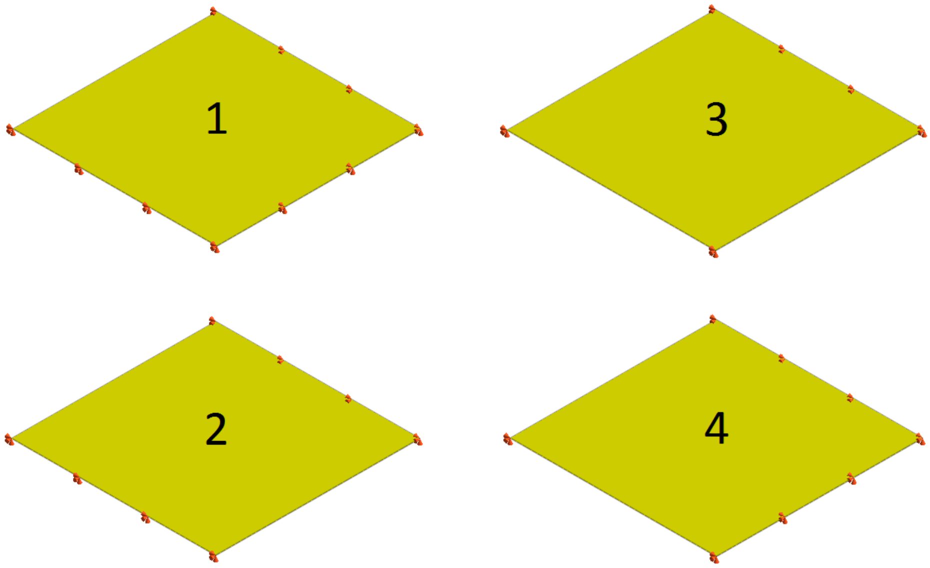


Figure 2 *Load cases: constraints*

Load Case 4. 2 adjacent edges and the opposite corner fixed (2 adjacent edges free except on the corner).

RESULTS COMPARISON

The numerical comparison is focused on the maximum displacement and on the maximum equivalent stress (computed with Von Mises formula). Results and comparison are shown in the table below.

The largest difference on the maximum displacement is less than 0.2% for all load cases (in absolute value); whilst the difference on the maximum stress is less than 1% on all load cases.

CONCLUSIONS

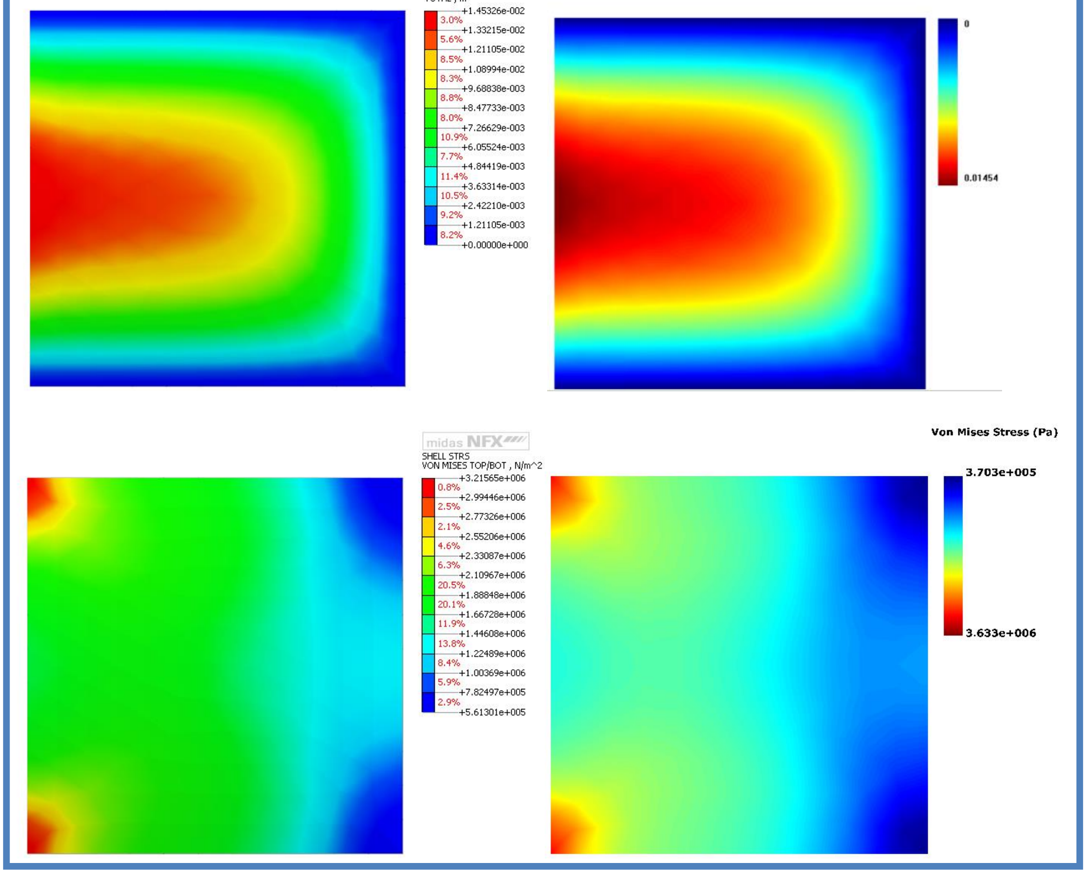
SMAR Azure team considers the results satisfactory as a general validation of the AzureProject finite element method for the membrane elements, which is in very good agreement with midasNFX.

Table 1: *Maximum displacement and maximum stress from midasNFX and AzureProject*

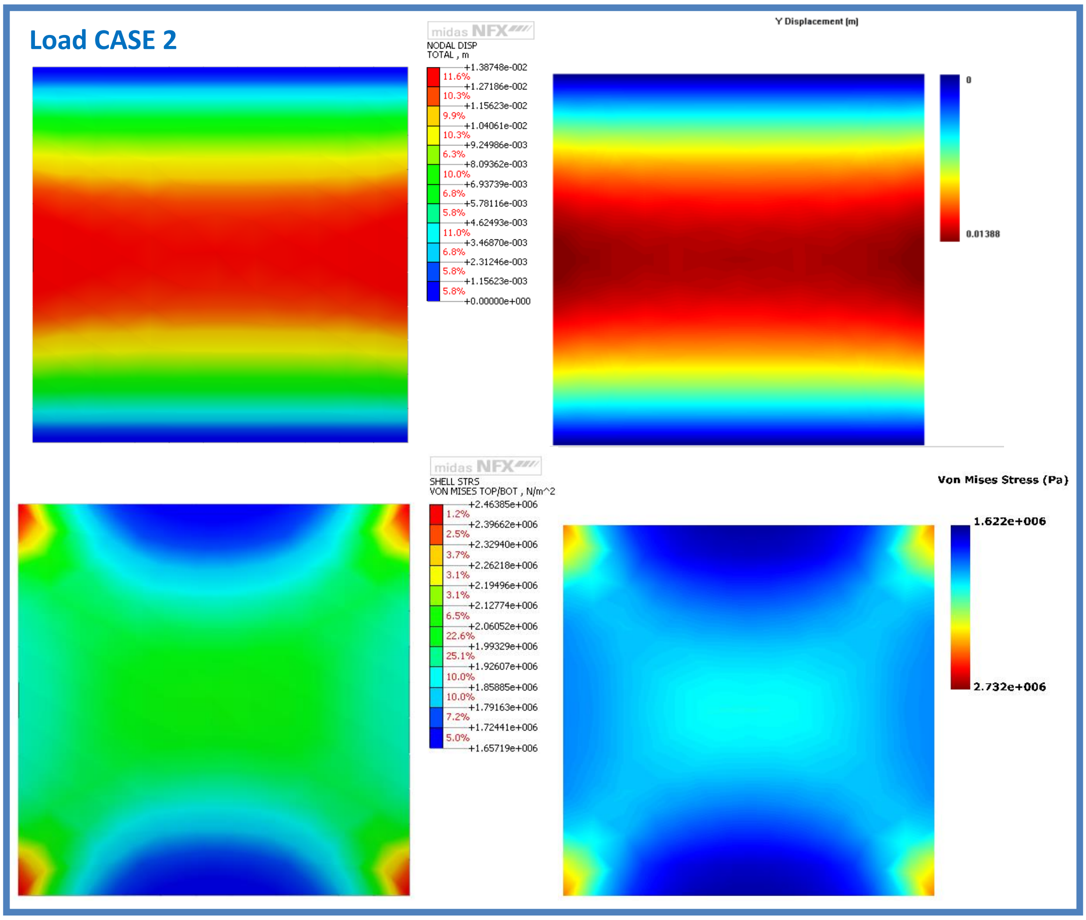
	midasNFX		**AzureProject**		***Difference (%)***	
Load case	**Max displ [mm]**	**Max stress [MPa]**	**Max displ [mm]**	**Max stress [MPa]**	***Max displ***	***Max stress***
1	14.53	3.654	14.54	3.633	*0.1%*	*-0.6%*
2	13.87	2.756	13.88	2.732	*0.1%*	*-0.9%*
3	20.94	14.53	20.92	14.47	*-0.1%*	*-0.4%*
4	18.23	14.11	18.19	14.04	*-0.2%*	*-0.5%*

The following pictures show the displacements and stress distribution as calculated by midasNFX (on the left) and AzureProject for each load case.

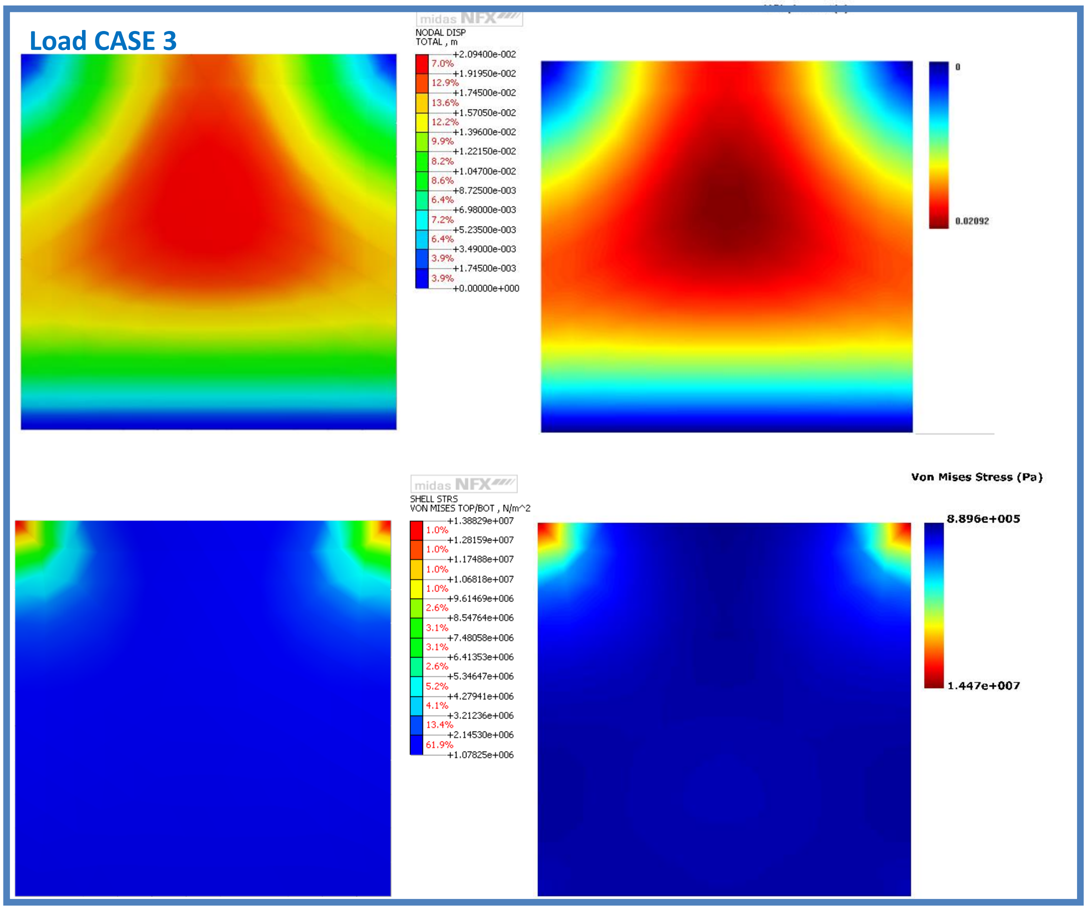
Load CASE 1



Load CASE 2



Load CASE 3



Load CASE 4