VI International Conference on Textile Composites and Inflatable Structures
STRUCTURAL MEMBRANES 2013
K.-U.Bletzinger, B. Kröplin and E. Oñate (Eds)

THEORY AND EXPERIMENT RESEARCH ON THE STATIC CAPABILITY AND DYNAMIC PROPERTY OF INFLATABLE BEAMS

STRUCTURAL MEMBRANES 2013

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Key words: Inflatable Beam, Load Bearing Capacity, Dynamic Property, Experiment.

Summary. The paper analysis static load bearing capacity and dynamic properties of two examples of inflatable beams, the membrane material selected for the first example is the ETFE coated fabric, and the membrane material of the second example is airship envelop fabric, Uretek3216L. The load-displacement curve of inflated beam in bending is obtained and compared with the experimental data. The deflections calculated of ETFE inflatable beams show coincidence with measured curves, but the deflection calculated of airship envelop inflatable beam has deviations between calculated and experimental results. The dynamic properties of ETFE inflatable beams showed good coincidence with experimental results, but the first frequency of airship envelop inflatable beam have difference with experimental results.

1 INTRODUCTION

The paper analysis static capability and dynamic property of two examples of inflatable beams, the membrane material selected for the first example is the ETFE coated fabric, and the membrane material of the second example is airship envelop fabric, Uretek3216L. The wrinkles are easy to be formed when a tip load is applied on the inflated beams, the implicit scheme can lead to severe instabilities due to the lack of stiffness in the fabric, explicit time schemes overcome this difficulty, but they need a huge number of time steps to obtain a realistic stable final shape. The simulation of inflated beams by the FEM adopting these two methods.

2 TECHNIQUE FOR INFLATABLE BEAMS

2.1 Inflating simulation

In this work the influence of the pressure and volume coupling on structure behaviour is studied, a technique with a layer fluid element connecting all nodes of the membrane is implemented into a finite element model to take into account the influence of gas volume variation, with corresponding change in pressure for enclosed gas on the stiffness of inflatable membrane structures[1].

2.2 Imperfection planting

Initial imperfection planting in inflated beam can make the bending analysis more smooth, the top 10 order bulk modes were selected to form the imperfection of inflated beam, the imperfection of the inflated beam is selected as 20% of the thickness of fabric.

2.3 Contact simulation

The membrane body will mutually contact when the inflated beam was bended to a certain extent, in addition, the end part of beam will contact with the fixed support component. The aim of simulating contact is to confirm the contact area and to calculate the contact pressure. Coulomb friction was used to describe the friction model between contact surfaces in both implicit scheme and explicit method, the friction coefficient is set as zero.

3 ETFE INFLATABLE BEAM

The dimensions of the ETFE inflatable beam are shown in Figure 1(unit is mm), the thickness of ETFE coated fabric is 250µm. The ETFE coated fabric is isotropic material, the elastic modulus of ETFE is selected as $E_{Warp} = E_{Weft} = 0.68kN/mm^2$, and the Poisson's ratio is selected as 0.38. The nonlinear load bearing capacity of inflated beam was analyzed when a homogeneous load was applied on loading belt, three points are selected to record load-displacement curves of them, positions of three points are also shown in Fig.1.

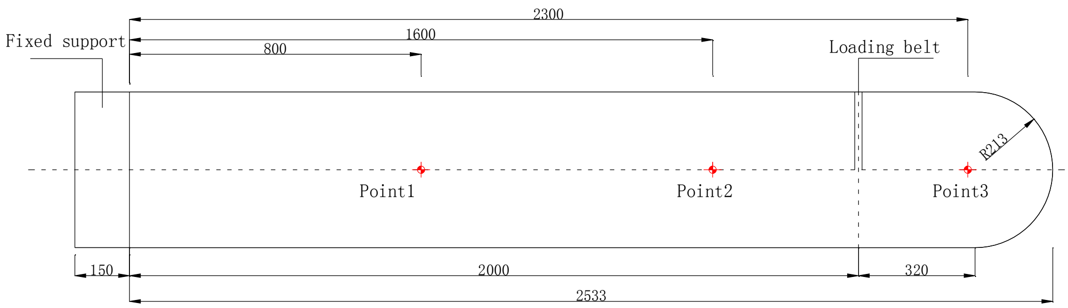
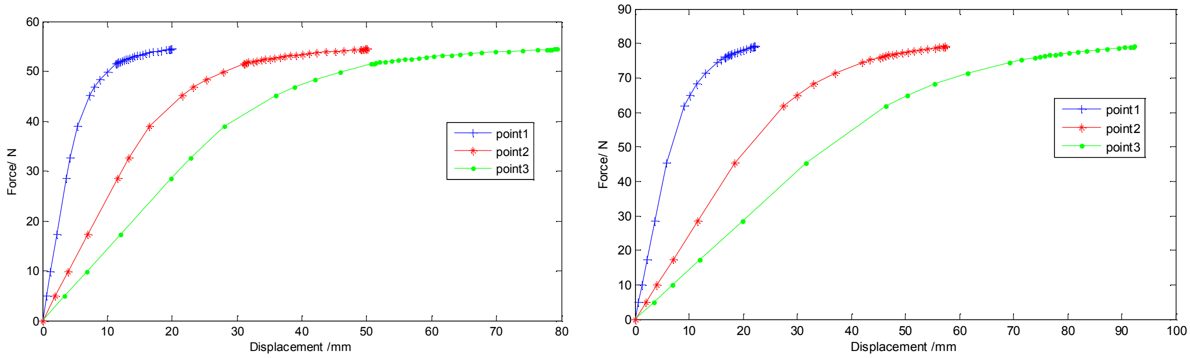


Fig.1: The etfe inflated beam and point layout

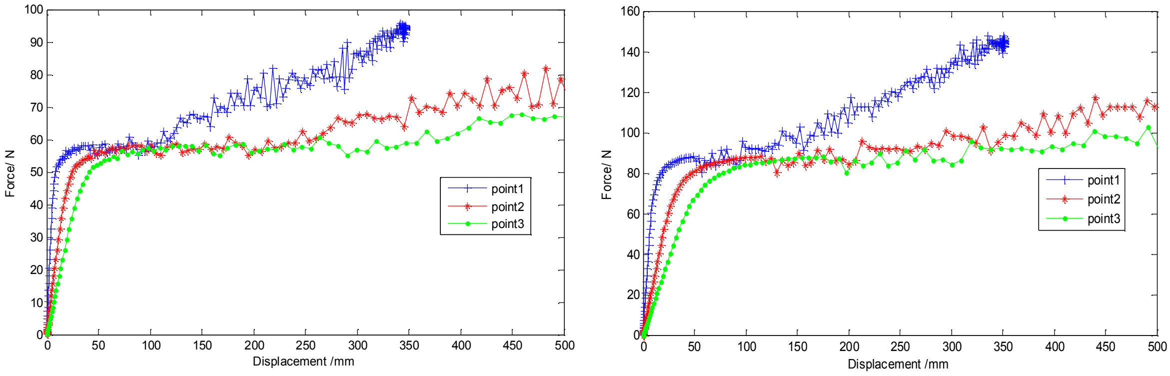
3.1 Static load bearing capacity analysis

The wrinkles are easy to emerge when bending load is applied on the inflated beams, the implicit scheme can lead to severe instabilities due to the lack of stiffness in the fabric, explicit time schemes overcome this difficulty, but they need a huge number of time steps to obtain a realistic stable final shape, the simulation by the FEM of inflated beams adopting these two methods. FEM calculations were conducted at air pressures values of 3000 and 5000pa, the load-displacement behavior of ETFE inflated beam adopting implicit scheme is shown in Fig.2, and the load-displacement behavior of the ETFE inflated beam adopting explicit scheme is shown in Fig.3.



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa

Fig.2: Analytical load-displacement behavior of the ETFE inflated beam adopting implicit scheme



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa

Fig.3: Analytical load-displacement behavior of the ETFE inflated beam adopting explicit scheme

Seen form Fig.2 and Fig.3, the calculation is not convergent when the ETFE inflated beam was bended at certain degree adopting implicit schemes, but the calculation can continue to destination when adopting an explicit scheme. The load-displacement behavior before the beam is unstable using an explicit scheme show a correspondence with that using an implicit scheme.

3.2 Experiment of static load bearing capacity

The full-scale ETFE inflated beam was fabricated and the deflections of three points under bending are measured. An experiment of ETFE inflated beam under bending is shown in Fig.4. The experimental displacement-force curves of three points for air pressure of 3 and 5kPa are shown in Fig.4

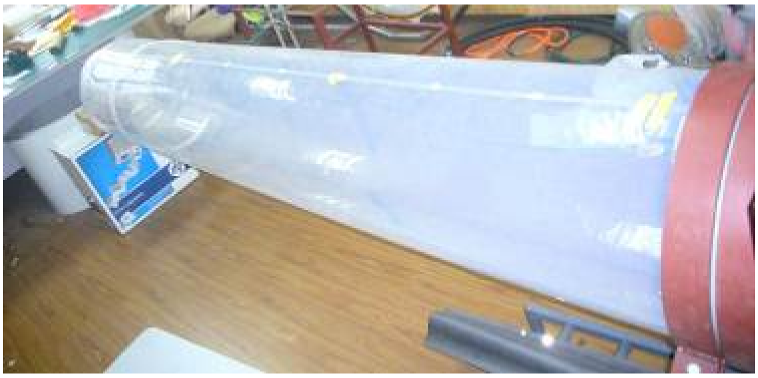
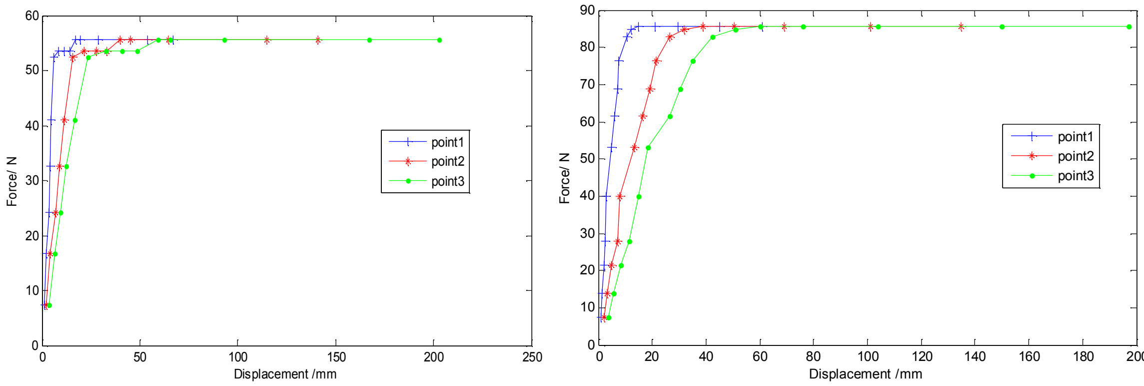


Fig.4: Experiment of ETFE inflated beam under bending



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa

Fig.5: Experimental load-displacement behavior of the ETFE inflated beam

The deflection calculated of ETFE inflatable beams show excellent coincidence with measured curves comparing Fig.2, Fig.3 and Fig.5.

3.3 FEM results of dynamic properties

The frequencies and modes of beams are conducted by FEM for two cases, viscosity acting force of outer air is not considered for one case, while viscosity acting force of outer air is considered for another case. The frequencies of ETFE inflated beams were calculated using added air mass when considering viscosity of outer air, added mass of outer air is calculated through equation (1), which is proposed by Yu through test of cylinder structure[2].

$$m_a = 1.9\rho\pi D^2 L/4 \tag{1}$$

where, D is diameter of the cylinder, L is length of the cylinder, ρ is density of outer fluid.

The FEM results of first order frequency for two cases at pressure values of 3, 4 and 5kPa are shown in Table 1, there are about 30% differences between values in two cases. The first order mode of the ETFE inflated beam is shown in Fig.6.

Table 1:FEM results of the 1^{st} order frequency

Inner Pressure Value (Pa)	The 1^{st} order frequency (Hz)	
	Not considering added air mass	Considering added air mass
3000	8.91	7.10
4000	8.93	7.15
5000	8.97	7.18

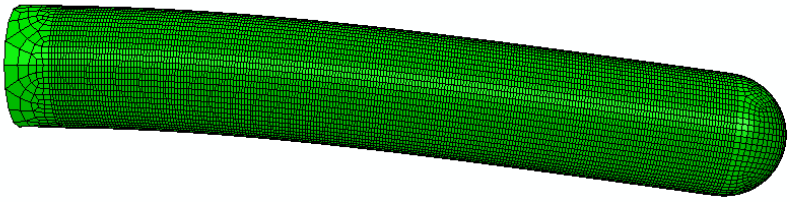


Fig.6: FEM result of the first order mode of the ETFE inflated beam

3.4 Test of dynamic properties

The frequencies and modes of beams are tested using laser vibraometer, the test results of first order frequency value at pressure values of 3, 4 and 5kPa are shown in Table 2, and the tested first order mode is shown in Fig.7.

Table 2: Test results of the 1^{st} order frequency

Inner Pressure Value (Pa)	The 1^{st} order frequency (Hz)
3000	7.38
4000	7.50
5000	7.58

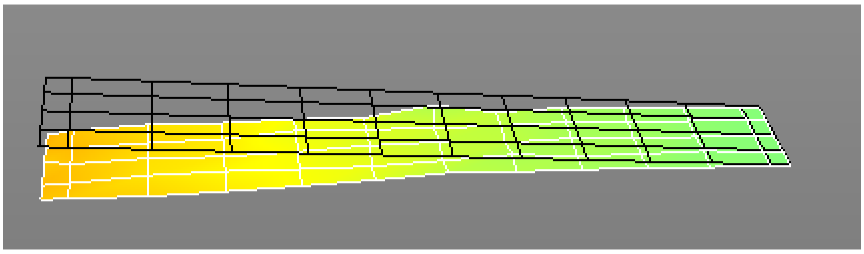


Fig.7: Test result of the first order mode of the ETFE inflated beam

It can be seen that the test results of the 1st order frequency is very close to the FEM results of the 1st order frequency when considering added mass of outer air through comparing values in Table 1 and Table2, the differences within 5% between them. The test results of first order frequency also have 20% differences with the FEM results of the 1st order frequency when not considering added mass of outer air. The tested first order mode of the ETFE inflated beam is coincided with the FEM result comparing Fig.6 and Fig.7.

4 AIRSHIP ENVELOP INFLATABLE BEAM

The dimensions of the airship envelop inflatable beam are shown in Figure 1(unit is mm), the thickness of ETFE coated fabric is 380μm. The airship envelop fabric is non-isotropic material, the elastic properties of the airship envelop fabric were measured in house with our biaxial test rig[3], the E-modulus in warp is E_{Warp} =0.947kN/mm^2, the E-modulus in weft is E_{Weft} =0.895kN/mm^2, and the Poisson's ratio is 0.36. The nonlinear load bearing capacity of inflated beam was analyzed when a homogeneous load was applied on loading belt, three points are selected to record load-displacement curves of them, positions of three points are also shown in Fig.8.

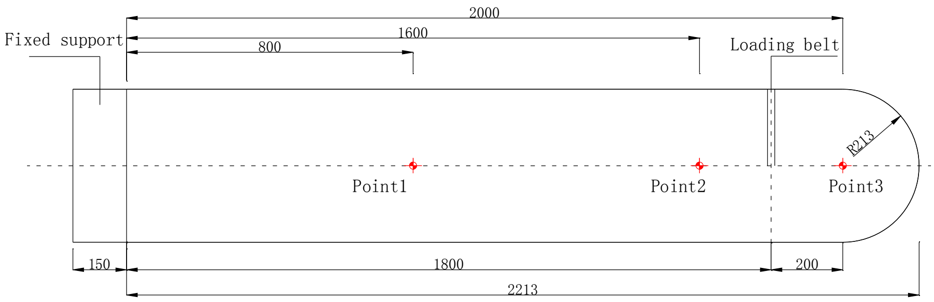
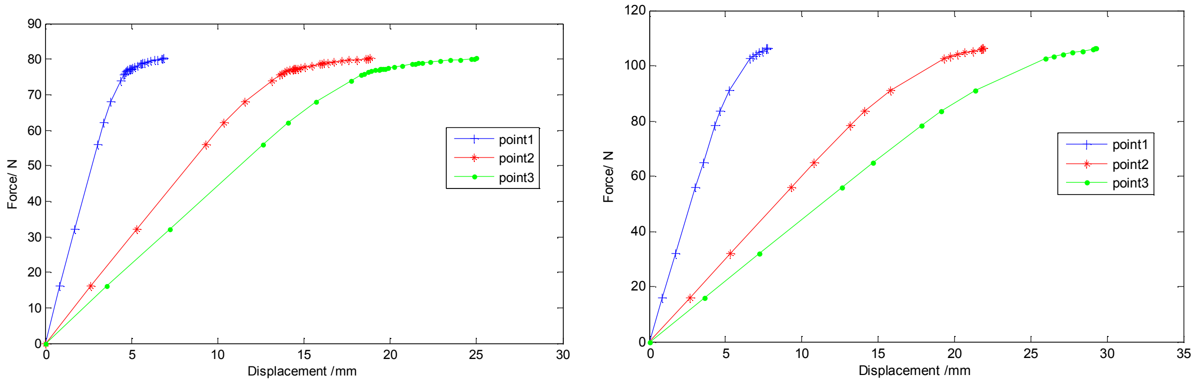


Fig.8: The airship envelop inflated beam and point layout

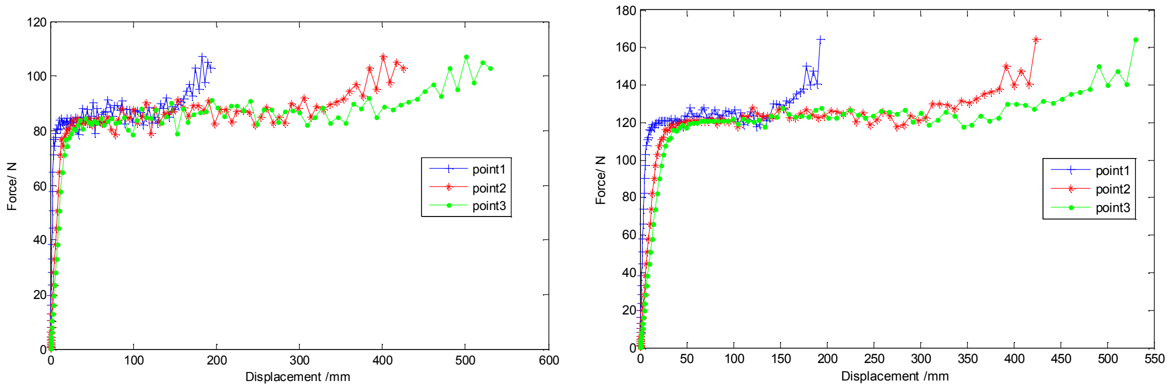
4.1 Static load bearing capacity analysis

The wrinkles are easy to be formed when bending is applied on the inflated beams, the simulation by the FEM of inflated beams adopting implicit and explicit methods. FEM calculations were conducted at air pressures values of 3000 and 5000pa, the load-displacement behavior of airship envelop inflated beam adopting implicit scheme is shown in Fig.9, and the load-displacement behavior of the airship envelop inflated beam adopting explicit scheme is shown in Fig.10.



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa

Fig.9: Analytical load-displacement behavior of the airship envelop inflated beam adopting implicit method



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa

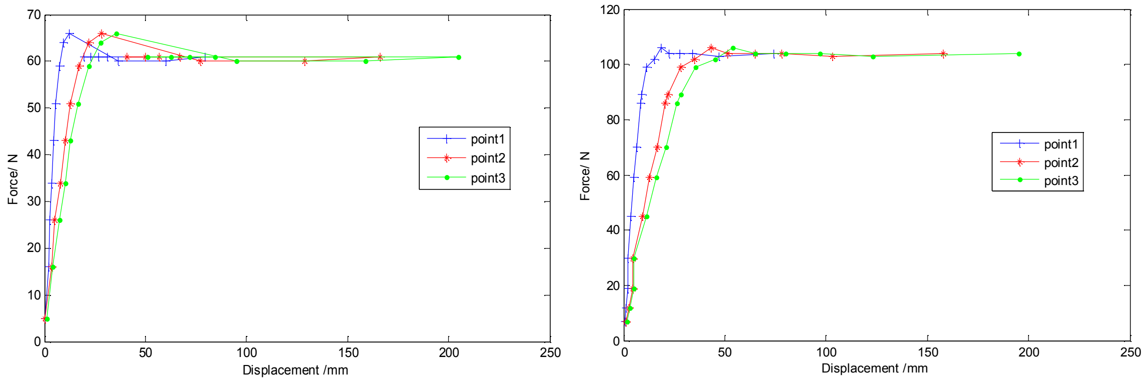
Fig.10: Analytical load-displacement behavior of the airship envelop inflated beam adopting explicit method

Seen form Fig.9 and Fig.10, the calculation is not convergent when the airship envelop inflated beam was bended at certain degree adopting implicit schemes, the calculation can continue to destination when adopting an explicit scheme. The calculated results using an explicit scheme do not tally with that using an implicit scheme.

4.2 Experiment of static load bearing capability

The full-scale inflated beam was fabricated and the deflections of three points under bending are measured. An experiment of airship envelop inflated beam under bending is shown in Fig.11. The experimental displacement-force curves of three points for air pressure of 3 and 5kPa are shown in Fig.12.

Fig.11: Experiment of the airship envelop inflated beam under bending



(a) Inner pressure=3000Pa (b) Inner pressure=5000Pa
Fig.12: Experimental load-displacement behavior of the airship envelop inflated beam

The deflection calculated of airship envelop inflatable beam has deviations between calculated and experimental results comparing Fig.9, Fig.10 and Fig.12.

4.3 Theoretic analysis of dynamic properties

The frequencies and modes of beams are conducted by FEM for two cases, viscosity acting force of outer air is not considered for one case, while viscosity acting force of outer air is considered for another case. The frequencies of ETFE inflated beams were calculated using added air mass when considering viscosity of outer air.

The FEM results of first order frequency for two cases at pressure values of 3, 4 and 5kPa are shown in Table 3, there are about 37% differences between values in two cases.

Table 3: Test results of the 1^{st} order frequency

Inner Pressure (Pa)	The 1^{st} order frequency (Hz)	
	Not considering added air mass	Considering added air mass
3000	15.30	11.20
4000	15.36	11.25
5000	15.39	11.28

4.4 Test of dynamic properties

The frequencies and modes of beams are tested using laser vibraometer, the test results of first order frequency value at pressure values of 3, 4 and 5kPa are shown in Table 4.

Table4: Test results of the 1^{st} order frequency

Inner Pressure (Pa)	The 1^{st} order frequency (Hz)
3000	10.13
4000	10.38
5000	10.50

The test results of first order frequency have 10% differences with the FEM results of the 1st order frequency when considering added mass of outer air, and the test results of first order frequency have 50% differences with the FEM results of the 1st order frequency when not considering added mass of outer air. The tested first order mode of the ETFE inflated beam is coincided with the FEM result.

5 CONCLUSIONS

- The load-displacement curve of inflated beam in bending is obtained and compared with the experimental data. The deflection calculated of ETFE inflatable beams show excellent coincidence with measured curves, but the deflection calculated of airship envelop inflatable beam has deviations between calculated and experimental results, which indicate that the static capability of inflatable tube is sensitive to the elastic parameters of fabric, and the material nonlinearity of the airship envelop fabric is the major factor[4].
- The structural vibration behaviors of inflated beams are analyzed, the first order frequency of inflated beams reduced 25%-40% when taking into account of added mass of outer air, so the influence of outer air on inflated beams is not be overlooked. The first frequency and mode of ETFE inflated beam showed good correlation with experimental results, but the first frequency of airship envelop inflated beam has difference with experimental result.

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