Transactions on Engineering Sciences vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3533

Experimental study and numerical modelling of inflated fabric panels

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Abstract

An experimental and numerical study of inflated fabric panels is presented. The panels are made of two coated linen cloths connected by yarns in order to ensure a perfect flatness. They are submitted to medium pressures and to bending loads. The shape of the deformed panels is linear between points of loading. It seems therefore that the panels behave as tight yarns, but a yarn model gives valuable results on the deflection when the pressure is low, but very bad results for higher values of this pressure. A beam model is not suitable to calculate deflections because of less curvature, but gives a correct answer for the limit load of the panels. Modelling of these structures suppose computations with hypothesis of large displacements and following forces. Strength abilities of the structures are given by buckling conditions of cloths.

1 Introduction

The aim of the study is to develop computation methods for large size inflated structures submitted to medium pressures because such methods do not exist yet. Inflated structures are generally studied at low pressures (lower than one bar). The work introduced here is devoted to a kind of structures called panelled fabrics submitted to pressures varying from one to several bars in order to ensure their strength behaviour. The first results can be found in Wielgosz[1] and this paper is devoted to add experimental data and to refine the numerical study. The panels are made of two linen cloths connected by yarns. The ends are sewn and the

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panels are coated in order to ensure their airtightness. The behaviour of the structures depends on the inflation pressure which leads the clothes and the yarns to be prestressed. The panels are very light, easily transportable and extremely strong. The tested panels are simply supported "beams". The shape of the deformed panels submitted to bending loads is linear between points of loading. Simplified models like a tight yarn model or a beam model are unable to give a right answer to the behaviour of the panels. A yarn model gives valuable results on the deflection when the pressure is low, but the results are very bad for higher values of this pressure. Nevertheless the main interest of these fabric structures is to be used at high pressures. A beam model is not suitable to calculate deflections because of the less of curvature, but gives a correct answer for the limit load of the panels. The real behaviour of these structures is obtained with following hyphotheses: cloths are membranes in tension and allow large displacements, connecting yarns are non linear bars and the pressure is replaced by following forces applied normally to the cloths. Numerical computations have been done with CASTEM 2000[2]. Meshing must be very fine just about the loading point and the supports. Strength abilities of the structure are given by buckling condition of cloths.

2 Experimental results

A section of the panels made of two coated linen cloths (polyester) connected by yarns is shown on figure 1 and provides from Tissavel's tract.

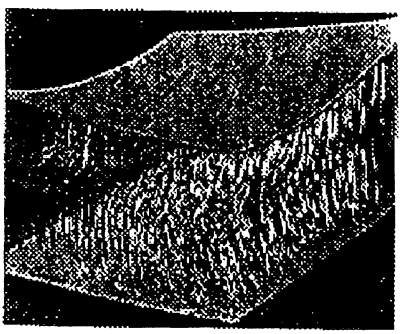

Figure 1 : cross section of the panels

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The yarns density is enough to ensure the flatness of the fabric structure. Its behaviour depends on the inflation pressure which leads the cloths and the yarns to be prestressed and then to support local compression loads.

2.1 Bending shape

Many panels have been tested and the results are given for two of them with dimensions 200x25x5 and 200x45x6 cms. They are simply supported "beams" loaded by a concentrated force and the length between the supports is about 160 cms. The inflation pressure will vary up to 4 bars. The shape of the deformed panels submitted to a bending load is shown figure 2.

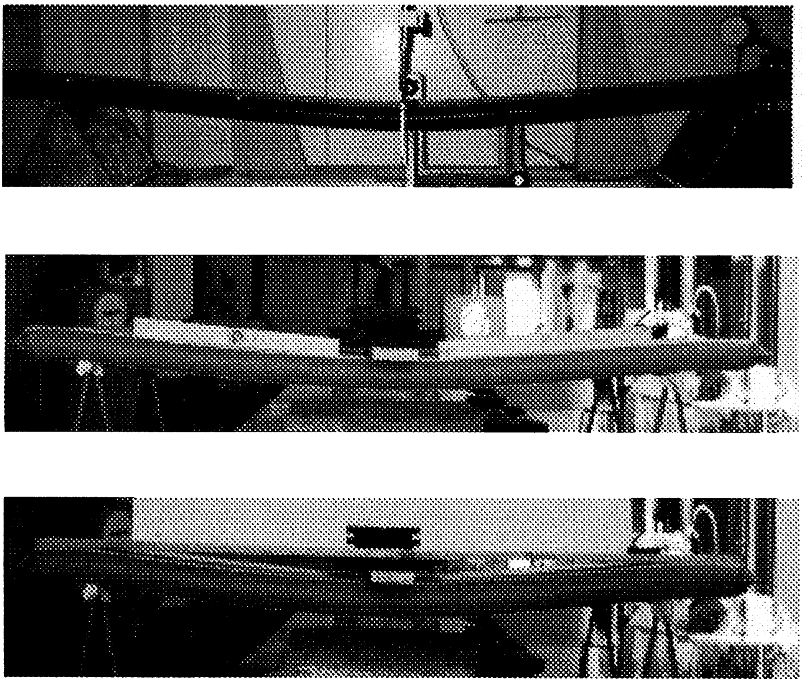

Figure 2 : deformed shape of the panels

Light boards have been set on the grey panel in order to show that this shape is quasi linear between points of loading and that the free ends of the panel remain almost straight. In fact, light curvatures appear near

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loading areas (supports and loading point). The panels have therefore a tight yarn behaviour and not a beam behaviour.

2.2 Limit load

The limit load F_l is a linear function of the applied pressure. The limit load results for the two "beams" (black and grey) is given table 1.

p (bar)	1	2	3	4
F_l (daN)	9	19	28	38
F_l (daN)	23	45	66	88

Table 1 : Experimental limit load as a function of the pressure

The weight of the grey panel is only about 4 kgs and its limit load is about 88 daN when the pressure is equal to 4 bars. Given that the maximum pressure can reach 20 bars (maximum pressure admissible by the yarns), one can realise the strength abilities of these structures: they can support up to a hundred times their own weight.
Another remarkable property of this panel is that "shakedown is reversible": after loading the panel up to its limit load and unloading, it comes back to its initial shape without any damage.

3 Modelling of the behaviour of the panels

We will first show that very simple models like yarn or beam models can't give good results on the deflection or on the limit load. Numerical modelling must be used to obtain accurate results.

3.1 Simplified models.

3.1.1 Deflection.

Given that the shape of the deformed is linear between points of loading one can try to use a tight yarn model. Unfortunately, a comparison between experimental and theoretical results shows that the yarn model

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gives valuable results on the deflection when the pressure is low, but the results are very bad for higher values of this pressure (cf figure 3).

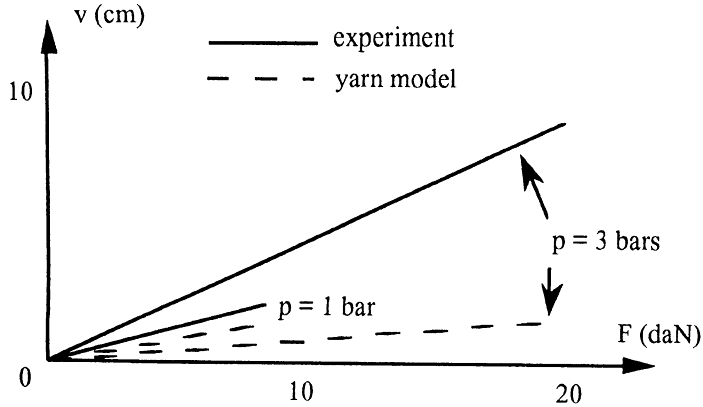

Figure 3: experimental and tight yarn deflections for two pressures

Moreover many other reasons plead against the use of this model: the two clothes are not differentiated, their stress is supposed to be constant and the connecting yarns are not taken into account.
A beam model cannot be developed to calculate values of the deflection: the momentum of the external load is linear between points of loading, but the curvature is equal to zero; we can't therefore define the flexural rigidity of the beam and it's also very difficult to modelize the transfer of the shearing stress by the connecting yarns.

3.1.2 Limit load.

A beam model can be used to calculate the limit load of the fabric structure[1] because the yield mechanisms of beams satisfy linearity between plastic hinges. One can show that the theoretical limit load is given by:

$$F_l = \frac{p\, b\, h^2}{l} \qquad (1)$$

where p is the pressure, b the width, h the height and l the half length between supports. Theoretical values of the limit load are close to experimental results and are obtained within 20% error as shown table 3 for the black panel.

p (bar)	1	2	3	4
Ex load (daN)	9	19	28	38
Th load (daN)	7.8	15.6	23.4	31.2

Table 3: Theoretical and experimental limit loads

The result is very interesting because it shows that the limit load is proportional to h^2. Given that the process of weaving can give heights up to 20cm, we can assert[3] that a "bridge" with 2m width, 10m length built with one of these panels submitted to a pressure of 10 bars, can support a light vehicle which can take away the bridge after crossing!

3.2 Numerical modelling.

We suppose that cloths are membranes in tension, that the connecting yarns are non linear bars and that the pressure can be replaced by following forces. The problem is studied with the hypothesis of large displacements and with following forces applied normally to the clothes. The equations of this kind of problem and their discretized form lead to solve the following incremental system

$$(K_1 + K_2 - K_3)\,\Delta U = P - R \qquad (2)$$

where K_1 is the classical stiffness matrix, K_2 is the non linear geometrical matrix, K_3 is the non symmetric matrix providing from following forces. ΔU is the vector of incremental displacements, P is the vector of external loads and R is the vector of internal or resisting forces. All computations have been done with CASTEM 2000[2]. The cloths are replaced by plate finite elements and the yarns by non linear bars. Meshing must be very fine just about the loading point and the supports because of the sudden discontinuities of forces at these points. The constitutive law is obtained from experimental data on polyester.
A comparison between theoretical and experimental values of the deflection is shown figure 4. Numerical results are very close to experimental ones. The theoretical deformed shape shows linear parts slightly shorter than those obtained by experiment and also local curvatures near the loading point and the support.

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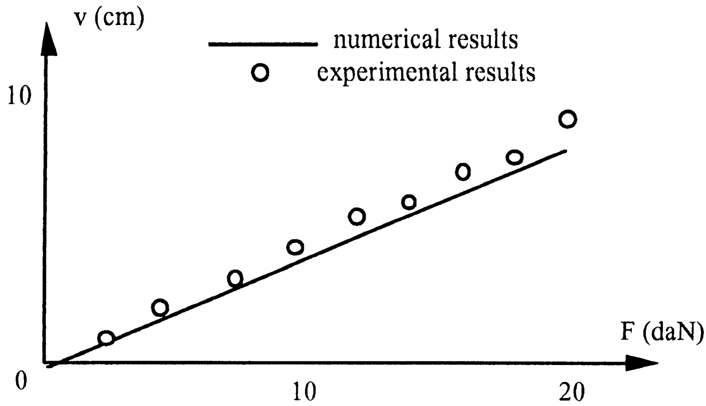

Figure 4 : theoretical and experimental values of the deflection

On figure 5 one can see that the normal stress in the connecting yarns is constant between loading points with sudden discontinuities at these points.

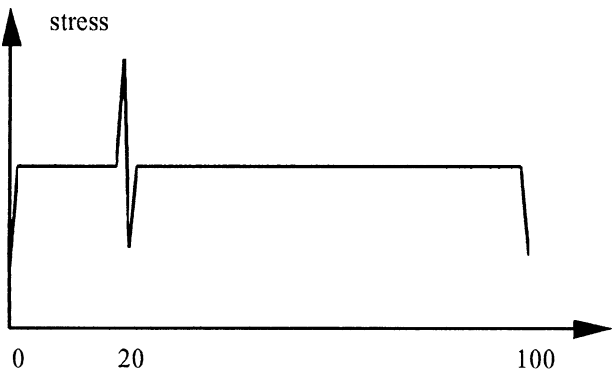

Figure 5 : normal stress in the connecting yarns

The theoretical values of the normal stresses in the cloths are given in figure 6 for a value of the load close to the limit load. One can see that the stress in the upper cloth decreases as soon as we draw nearer the loading point and foretells the buckling of this cloth.

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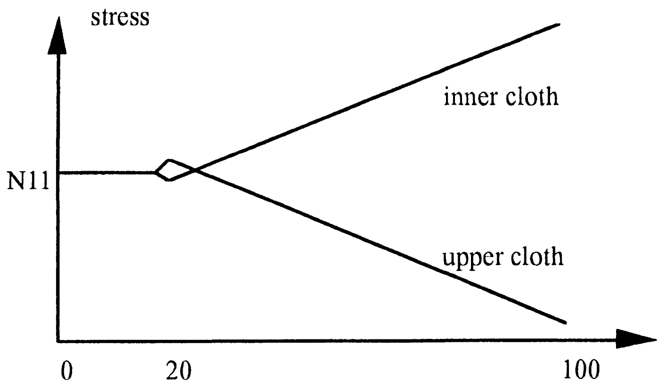

Figure 6 : normal stresses in the clothes

Strength abilities of the structure are therefore given by buckling conditions of the upper cloth and allow to give better results on the limit load that the simplified model as shown on table 4.

p (bar)	1	2	3	4
Ex load (daN)	9	19	28	38
Th load (daN)	8.2	17.3	26.3	35

Table 4: Theoretical and experimental limit loads

4 Conclusion

These first experimental and numerical results on the modelling of the behaviour of fabric panels show that it is now possible to compute this kind of inflated structures and therefore to foresee the building of light, easily transportable and extremely strong fabric structures. Their industrial application can be very numerous: crossing and provisional structures, light roofs,.... One have now to work on the reliability of such structures in order to prove that they can be used by industry.

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