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Experimental and numerical investigation of a tensairity arch

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ABSTRACT

The Tensairity principle is a recent concept for lightweight structures. Until now, mainly linear beam elements have been developed and investigated. To broaden the range of Tensairity applications, Tensairity arches are investigated experimentally and numerically. This paper focusses on the validation of the numerical approach for Tensairity arches. The results shows that a good agreement is found between the numerical and experimental approach when the manufacturing imperfections are included in the numerical model. This paper also documents a basic parameter study on the validated numerical model to prove the usefulness and effectiveness of this numerical approach. Finally, the Tensairity arch is upscaled to spans of 8 m where it is compared to other inflatable arches currently used. These results clearly show the added advantage the Tensairity principle can bring for inflatable arch structures.

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1. Introduction

Inflatable structures have been used in civil engineering projects for several decades. Their lightweight, flexibility and mobility, make these structures an excellent building component for engineers and architects alike.

Research on the topic of inflatable beam elements states that the load response of an air-inflated beam - in short ‘airbeam’ - is similar to that of a pretensioned beam [1]. The internal over pressure will pretension the membrane and will introduce radial and longitudinal tensile stresses in the hull of the airbeam. Under vertical distributed loading the upper surface of the airbeam will be compressed while the bottom surface will be tensioned. As a consequence the longitudinal stresses will be reduced at the compressed side of the beam and eventually create wrinkles when the influence of the external loading becomes too high. This development of wrinkles is solely dependent on the internal pressure and the radius of the airbeam [2]. Thus to increase the load bearing capacity of an airbeam, larger airbeam sections and/or higher internal over pressures must be used, but this considerably increases weight, size and cost. To counter the limited load bearing capacity, modifications have been made by several researchers to the standard air-inflated beam [3]. One of these concepts is Tensairity [4].

Tensairity is a combination of slender struts, cables and an airbeam under low pressure. The struts are firmly connected to the membrane at the compressed side of the airbeam while the cables are placed at the tensioned side. The purpose of the airbeam in the Tensairity system is twofold. First, it will provide a physical separation between tension and compression so that only axial forces remain in the struts and cables. And secondly, the inner pressure of the airbeam will pre-tension the cables and will stabilize the slender strut against buckling [4]. Some existing structures built with this principle are a car parking roof in Montreux (Switzerland) [5], a skier bridge in Lanslevillard (French Alps) and a tennis court cover in Rouhampton (United Kingdom). Because the technology is fairly new (2004), research mainly focussed on linear Tensairity beams. Already a good understanding of the structural behaviour has been attained through experiments, finite element simulations and analytical models [6–8]. Up to now, we know that the Tensairity principle provides a linear beam which is ten to one hundred times stronger than a simple airbeam with the same dimensions and pressure [4].

The principle of Tensairity can also be applied to other structural elements, such as arches. However, the expertise about Tensairity arches is still very limited [9,10]. The first paper concerning Tensairity arches reports the comparison between several experimental and numerical tests [9]. Scale models of five meter span were built to understand the structural behaviour of Tensairity arches. These tests then finally led to the development of a 10 m model. The experimental tests were verified with numerical models under both symmetric and asymmetric loading. Good correspondence between experiment and numerical prediction was found for asymmetric loading, while manufacturing errors or

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a slight unbalance in the applied loads lead to discrepancies in the symmetric case.

This paper will document the validation of the numerical modelling of Tensairity arches. Both experiments and numerical simulations are performed on a Tensairity arch with 2 m span. The numerical model is adjusted such that a good agreement is found with the experiments. This numerical simulation method will facilitate the calculation for all future Tensairity arch projects. The paper concludes with a first basic analysis to increase the stiffness of the Tensairity arch based on the validated numerical model and a comparison of the Tensairity arch with currently used inflatable arches.

2. Experiments

2.1. Design of the arch

The experimental model has a parabolic shape and a length to height ratio (L/H) of 3, with a span of L=2 m and a height of H=0.66 m (Fig. 1). Previous research already stated that this L/H ratio is the most optimal for parabolic arches subjected to a uniform distributed symmetric loading [10,11]. The cross-section of the Tensairity arch is constant along its length and has an inner diameter of d=10 cm. The hull is welded airtight and fabricated with a Riverseal 202 material which is a double PU coated nylon fabric. Two slender aluminium struts are firmly attached both at the top and bottom of the airbeam. The total cross-section of each strut is 30 mm by 6 mm. However, the struts are divided in three parts: one upper large part of 30 mm by 3 mm and two smaller part of 15 mm by 3 mm. The connection is designed in such a way that the membrane is pinched between both struts, as shown in Fig. 1. An M3 screw locks both struts, and thus fixes the connection between membrane and struts.

The slender struts are bent from a straight element in the arched position and then fixed to the membrane. Due to the cutting pattern of the airbeam, the arch will obtain its final parabolic shape. The cutting pattern of the airbeam is constituted of 10 segments. The fibre orientation for each segment is such that one direction follows the shape of the arch and the other is aligned with the hoop stresses. Both top and bottom strut are fixed to hinged supports. The total weight of the model is 3.5 kg.

2.2. Test rig

A test rig has been designed to investigate the load bearing behaviour of the Tensairity arch (Fig. 2). The Tensairity arch is hinged in the plane of the arch at both supports (number 1 in Fig. 2). The internal pressure of the arch is regulated with a pressure gauge and kept constant before and during the test (number 4 in Fig. 2). A distributed load is approximated by adding weight to seven loading points, positioned 25 cm (projected distance) from each other (number 3 in Fig. 2). These loading points are attached to the upper strut of the Tensairity arch and are placed in such a way that the ropes of the loading point don't interfere with the airbeam.

The spatial displacement of the arch under loading is measured at both the upper and the lower strut with a 3D digital image correlation system (Limess Vic 3D). Each loading point and some other additional critical points have a set of markers attached to them (number 2 in Fig. 2). All markers are positioned in the same plane as the neutral axis of the arch. They are also placed on a

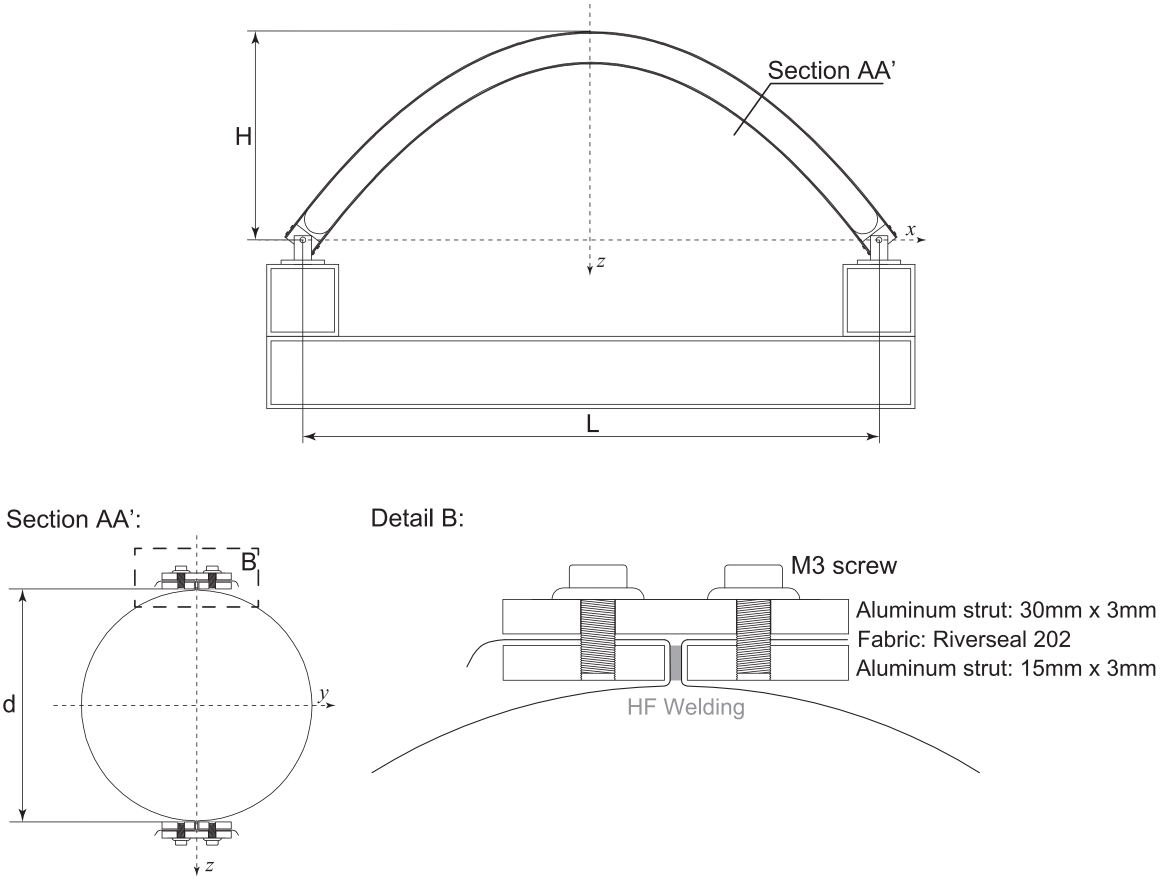

Fig. 1. The experimental model has a span of L=2 m, a height of H=0.66 m and a constant cross-section with a diameter of d=10 cm. The slender struts are held together by M3 screws and are made out of aluminium with a total section of 30 mm × 6 mm.

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