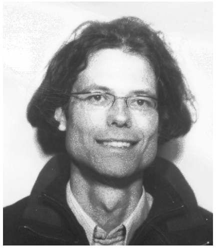
Adaptable Tensairity



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ABSTRACT

The new structural concept Tensairity® [Tens 2005] is a synergetic combination of a pneumatic structure and a cable-strut structure. The main function of the pneumatic structure is to stabilize the cable-strut structure. Tensairity structures have a multitude of very interesting properties. The beam or shell like structures are very light. Compact transport and compact storage is possible as well as fast and easy deployment. Furthermore, new lighting possibilities and special forms can be realized with Tensairity. Tensairity is ideally suited for a variety of applications ranging from roof structures, foot bridges to temporary structures as advertisement pillars. Furthermore, one of the most outstanding properties of Tensairity is that the structure is adaptable. The load-deformation response of such a Tensairity girder can be controlled by the air pressure which allows the girders to adapt to changing load conditions.

1 The Tensairity principle

The fundamental Tensairity beam consists of a cylindrical airbeam, a compression strut tightly connected with the airbeam and two cables spiraled around the airbeam and attached at each end with the compression strut [Fig. 1]. While the cables are pretensioned by the airbeam, the buckling problem in the compression strut is avoided due to the stabilization by the airbeam. As for a beam on an elastic foundation, the buckling load in the compression strut of the Tensairity girder is independent of its length but depends on the pressure of the airbeam [Luchsinger *et al.* 2004a]. Since there is buckling free compression in Tensairity, the cross section of the compression strut can have minimal dimensions leading to the light weight property of the new structural concept. Furthermore, the pressure in the airbeam is solely determined by the load per area and independent of the span and slenderness of the beam [Luchsinger *et al.* 2004a]. Therefore, the synergetic combination of an airbeam with cables and struts is ideally suited for wide span structures.

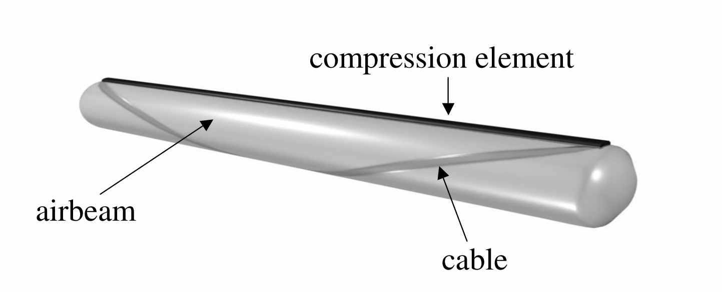

Figure 1. The basic set up of a Tensairity girder.

The cylindrical shape was the first Tensairity form investigated. Further studies have revealed, that spindle shaped Tensairity girders are more efficient [Pedretti *et al.* 2004, Luchsinger *et al.* 2004b]. Spindle shaped Tensairity beams are the focus of current research [Luchsinger *et al.* 2005] and recent applications of Tensairity such as the roof over the parking garage in Montreux, Switzerland [Fig. 2] rely on the spindle shape. This membrane roof is supported by 12 Tensairity girders with a span up to 28 m. Intensive use of the intriguing lightning possibilities of Tensairity was made by the architects in the roof in Montreux. Spotlights with color changing capabilities are mounted on each end of the The light shines through the glassy end plates into the pneumatic structure and illuminates the Tensairity girders from inside in a surprisingly homogeneous way. The color of each Tensairity beam can be dynamically changed and controlled by software and interesting light patterns over the whole roof structure can be realized.

Figure 2. Tensairity roof structure in Montreux, Switzerland (Luscher Architectes SA).

2 Adaptiveness and Tensairity

The basic concept of Tensairity which is pressure induced stabilization is a common in nature, too. The green tissue of plants is stabilized by the cellular pressure turgor. This becomes most obvious when plants start to wilt due to a lack of water and thus to a reduced turgor. Being adaptable to changing environmental conditions is an important advantage of living systems. The underlying common principle of pressure induced stability in nature and Tensairity [Luchsinger *et al.* 2004c] may give hints about the adaptability of Tensairity structures. Indeed, the deformation and load bearing capacity of a Tensairity structure can be controlled in a very simple way by the air pressure.

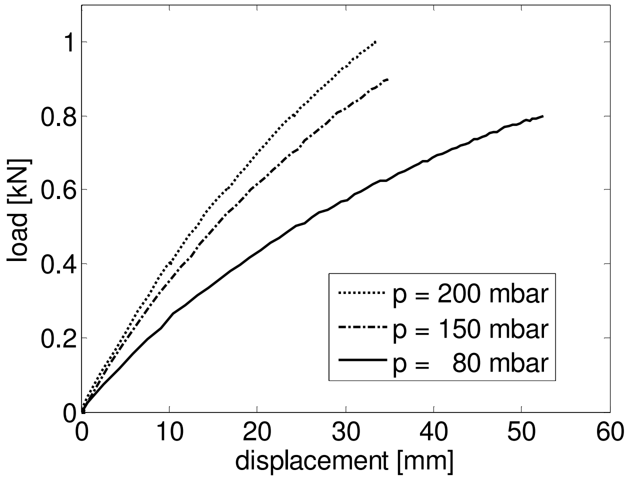

Figure 3. Experimental load-displacement response of a simply supported Tensairity beam for three different pressure values.

The experimental load-displacement response for a simply supported spindle-shaped Tensairity girder with 5 m span and a central diameter of 0.5 m is shown in Fig. 3 for three different pressure values. A central load is applied and the displacement of the Tensairity girder at the load input is shown. Obviously, the displacement decreases with increasing pressure and the Tensairity structure gets stiffer with increasing pressure. The decrease of displacement is a non-linear function of the pressure. For very high pressure values, the displacement of the Tensairity girder is dominated by the strain in the tension and compression element which is to a good approximation independent of the pressure.

The controllable adaptiveness of Tensairity structures to changing load conditions is interesting and probably the most outstanding feature of Tensairity compared to conventional trusses or girders. In fact, in so called intelligent or smart structures, a girder is made adaptable by cutting it into pieces, connecting the parts with hinges and adding a lot of actors and control units to the system. The structure is made intelligent by adding an external device. In Tensairity, the adaptability is an inherent feature of the structure itself and follows from its design and concept. A multitude of inherent features is typical for synergetic structures, where the new properties are not attained by adding different materials or components but by combining them. As a consequence, Tensairity girders can be viewed as a machine, where energy is converted into work. The energy in form of the compressed air is used to lift a weight.

The machine aspect of Tensairity structures can give a different look on civil engineering structures. In civil engineering, the girder for e.g. a roof structure is designed to withstand the total load which is the sum of the dead load and the live load. While the dead load is constant, the live load is often variable and can depend on wind and snow conditions. In light weight structures, the live load normally dominates the dead load and thus mainly defines the design of the structure. Such a girder is therefore designed for a maximal live load which is normally given by the building regulations. Most of the structures never experience the maximal load during their life time. The price for a nevertheless relative security is that most structures are under almost all conditions way to strong and way too heavy. A Tensairity girder can be adapted to the current load situation simply by pressure variation. This enables an important safety concept for Tensairity. The idea is to design the Tensairity structure in such a way that the load-bearing capacity of the bending stiff elements in the girder is large enough to carry the dead load of the structure even with zero overpressure. This can easily be realized in spindle-shaped Tensairity girders, where the upper and lower chord can be made identical to carry both compression and tension. The role of the compressed air is then to guaranty the stability of the structure under changing live load conditions. In a structure like the parking garage in Montreux, the maximal live load is in the order of a factor 10 higher than the dead load. Thus the philosophy, inherent structural integrity for dead load, adaptiveness to live load can have a real impact on the design and weight of the structure. Since such designed structures do not fail even with zero overpressure under the dead load plus eventually some predefined value of live load, they are not prone to vandalism. Even in case of a complete pressure loss in the Tensairity girder due to a damage in the membrane, there is in almost any case enough time to evacuate people from the building and to take measure to restore the structural integrity, since high live load events are very rare. And since an unusual pressure loss can be even detected by the naked eye, problems with the structural integrity of Tensairity are easy to detect. This is in striking contrast to many conventional structures, where a structural failure often comes completely unexpected. Another possible advantage of the adaptiveness of Tensairity is in scaffolding for e.g. bridges, where the deflection of the scaffold can be kept constant under increasing load by increasing the pressure.

3 Tensairity actors

The adaptiveness of Tensairity enables to use the structure as an actor, where the machine character of this new structural element becomes most obvious. One possible design of a Tensairity actor is a cantilever as shown in Fig. 4. The Tensairity cantilever is similar to the set up of Fig. 1. However, the compression element lies at the lower side of the airbeam and the two cables spiral only half way around the airbeam. The compression element is made flexible to a certain amount to increase the range of lift of the actor. In Fig. 4 on the left, the load still touches the ground and the overpressure in the actor is almost zero. In Fig. 4 in the middle, the pressure is increased and an intermediate state of the lift process is shown. Finally, the Tensairity cantilever reaches its final straight position for a higher pressure value as shown in Fig. 4 on the right. By releasing the pressure, the load will drop down again under its weight. The lift process is therefore reversible and cycles can be driven. An interesting feature of the actor is, that the highest pressure is needed for the straight position, where the bending moments due to the load are maximal and the forces in the compression and tension element are maximal, too. As the pressure is needed for the stabilization of the compression element against buckling, the stabilization effect increases with the increasing force on the compression element during the lifting process. The Tensairity effect adapts in a constructive way to the changing load conditions.

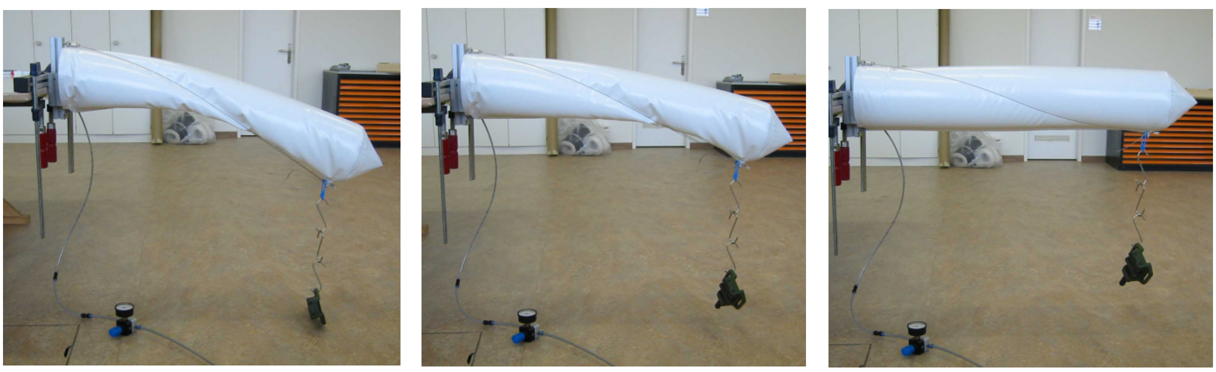

Figure 4. Demonstration prototype of a Tensairity actor. The load is lifted by increasing the pressure in the Tensairity cantilever.

4 Conclusions

The new structural concept Tensairity unites a wealth of interesting and important features. Light weight, fast and easy set up, compact transport and storage volume as well as thermal insulation are among this list. First applications in civil engineering as a roof over a parking garage or a bridge with over 50 m span demonstrate the feasibility and reliability of the technology. One further important feature of Tensairity is the adaptiveness. The deformation of a Tensairity girder for a given load can be varied simply by changing the air pressure of the structure. Tensairity is a machine and not a beam. This inherent property can be used e.g. in civil engineering, where the stiffness of the structure can be easily adapted to changing live load conditions. On the other hand, the machine like character of Tensairity allows the technology to be used as an actor. A first demonstrator based on a Tensairity cantilever shows the feasibility of the concept. To think about structures in terms of machines and not beams is something which most structural engineers are not used to. This thinking can open the path to completely new concepts and a different understanding of the functionality of structures. The synergetic structure Tensairity has the potential to realize such concepts.

References

Tensairity® is a technology of the Swiss company Airlight Ltd developed in close collaboration with prospective concepts ag. Recently, the research activities of prospective concepts have been transferred to the Center for Synergetic Structures at the Empa. For further information about Tensairity see www.airlight.ch.

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