

Tensile Fabric Structures

*Design,
Analysis,
and
Construction*



Edited by
Craig G. Huntington



STRUCTURAL
ENGINEERING
INSTITUTE

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Design, Analysis, and Construction

PREPARED BY
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Preface

Tensile membrane structures are part of a unique technology that gives designers, architects and engineers the ability to experiment with form and create exciting solutions to conventional design problems. These structures are not only visually exciting, but are environmentally sensitive and economically competitive as well. Membrane translucency provides more light than most indoor activities require and creates an attractive "glow at night." The state-of-the art materials, typically PTFE-coated fiberglass and vinyl-coated polyesters, are inherently waterproof and require very little maintenance. Because the materials are lightweight, these structures are extremely efficient in long span applications and are often constructed with substantial savings in the foundation and supporting structure costs. As an added bonus, they do more than just transmit forces to the ground. They serve as the primary architectural form determinant and provide much of the building envelope.

Conventional structures rely on internal rigidity (stiffness) to achieve stability and to carry loads. Fabric structures constructed of elements that have little or no bending or shear stiffness (cables and membranes) must rely on their form and internal tensile forces to carry loads. What makes these structures more complicated to design than their conventional counterparts is that they tend to be highly non-linear in their behavior and their shape is not known when the design begins. The non-linearity is a result of significant changes in geometry that usually occur under load, even though the materials remain, more or less, linearly elastic after the initial set. This change in geometry is a desirable quality, since if properly designed, tensioned fabric structures will increase their capacity to carry load as they deform. In fact, these structures are capable of maintaining a very high ratio of applied loads to self-weight, in contrast to steel or concrete structures of the same spans.

In the last 20 years, great advances have been made in this field. Today we have very sophisticated software for the analysis and design of membrane structures. Not too long ago most computer programs involved with these structures were generated by companies that were very reluctant to share or sell them. At the time of this writing, software that varies in price, capability, and ease of use is available from more than a dozen sources.

This publication describes the materials, design, and behavior of tensioned fabric structures. Chapter 1 reviews the history of the technology. Chapter 2 describes the overall design and construction process and discusses the role of each participant in the project from inception through completion. Chapter 3 treats the properties of various fabrics and films. In Chapter 4 types of loads and their effects are discussed.

The design of a tensile membrane structure can be separated into two distinct phases: shape determination (sometimes called form-finding) and analysis under different loads. Shape determination requires the "design" of a structure whose form is not known in advance; changes in internal pre-stress will change the shape of the overall

structure. Analysis of the system requires the solution of equations for the deformed configuration, a shape that is also unknown in advance. If the stresses in the elements are too high or if the deformations are greater than acceptable, the designer is free to change the shape of the structure by revising the pre-stress or by modifying the boundary conditions. These subjects are discussed in Chapters 5 and 6.

Once the structure is designed, the final steps to its completion are fabrication and erection. Chapter 7 describes the connections between the various materials and the attachments to the supporting structure. In Chapter 8, the non-structural issues unique to tensile membrane structures are presented. Patterning, the process of selecting an arrangement of two-dimensional panels to develop the three-dimensional surface, is discussed in Chapter 9. Finally, the erection of the structure, which requires careful handling of the materials as well as knowledge of the behavior of the structure, is also treated in Chapter 9.

In conclusion, it should be emphasized that this document does not purport to be a comprehensive treatment of the subject. Instead, the purpose of this publication is to assist design professionals and builders in understanding the basic design principles, materials, fabrication methods, and erection procedures utilized with these structures. Experienced designers are presented with ideas that may help them further understand their craft and hone their skills. Novices are offered a wide range of introductory information to assist them in entering the exciting field of tensile membrane structures. Perhaps with both the expert and the beginner, we can inspire the creation of more of these wonderful structures.

The Authors are members of the Tensioned Fabric Structures Task Committee of the Special Structures Committee of the Committee on Metals, 2010.

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This report is an outgrowth of work done by the original ASCE Tensioned Fabric Structures Task Committee which wrote the document, *Tensioned Fabric Structures, A Practical Introduction*, published by ASCE in 1996. R.E. Shaeffer edited this earlier report and also provided the impetus for the formation of a new Task Committee on Tensioned Fabric Structures in 2006. Professor Shaeffer served as Chair of the Task Committee until he was succeeded by Craig G. Huntington in 2008. Members of the Task Committee are as follows:

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The final contents of each chapter represent not only the efforts and expertise of the primary authors, but also extensive input and feedback from other committee members. In addition, a general review of the document for contents and coordination was made by an editing group led by Mark Waggoner that included Maqsood Ahmed, Richard Bradshaw, Wilfred Laufs, and Brian Skourup. Rob Gagich compiled and formatted the manuscript.

The Committee benefited throughout the course of its work from the support of Committee on Metals Chairs Andrea Surovek and Sherif El-Tawil, and greatly appreciates the work done by ASCE staff in preparing this document for publication.

Craig G. Huntington, Editor

Chapter 1

History and Development of Fabric Structures

1.1 Traditional Tent Forms

The tent has been the dwelling in one form or another for most nomadic peoples from the Ice Age to the present. Vegetation permitting, the most common supports for tents were tree branches or the trunks of saplings. The heavier of these were sometimes left behind because of transportation problems. The skin or velum of early tents used animal hides or, less frequently, birch bark pieces or latticed leaf fronds. Later, these were replaced by woven materials such as wool or canvas. Contemporary materials include aluminum, fiberglass, and steel for the supporting elements and highly sophisticated synthetic fabrics for the velum.

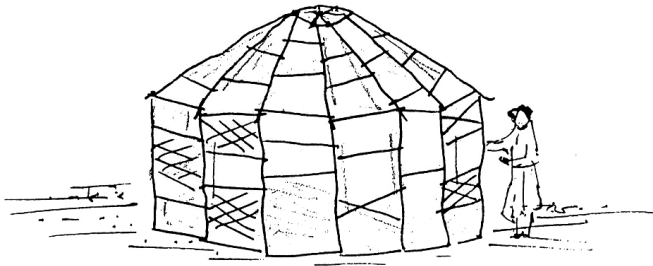


Figure 1-1
Kibitka
(Sketch by the author)

Until quite recently most tents consisted of three basic forms: the conical or tepee shape, the widespread kibitka or yurt that has cylindrical walls and a conical or domical roof as shown in Figure 1-1, and the "black" tent that has the velum tensioned into saddle shapes as shown in Figure 1-2. The black tent gets its name from the goat hair used to weave the velum. (The gable-roofed, ridge-type tent saw little use in ancient times but became a popular and durable military form beginning in the 18th century. It could be considered as an adaptation of the kibitka form to a rectangular plan.)

Of the three basic forms, the conical tepee form is the oldest and saw widespread use across northern Europe, northern Asia, and North America. The conical kibitka shape was prevalent as far back as 2000 B.C., and even now it is used more than any other dwelling form in the world. The same shape executed in vines and straw is found throughout Africa and South America. This tent form developed in a wide band from the eastern Mediterranean region to Mongolia. Its shape has been the one most copied or adapted for later tents. For example, a parasol roof shape derived from the