Fabric ARCHITECTURE

Tension structure connection details

God is in the details when it comes to tension structure design

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Ludwig Mies van der Rohe got it right when he said "God is in the details." Another well-worn phrase has it that we must sweat the details and the big things will take care of themselves, so with this article we look at tension structure connection details that have proven reliable over time.

The connections are where all the forces that act on and within a tension structure come together, and where the success of the design is made or lost. Problems that occur in a tension structure are most frequently found at the interface between different systems. Tension fabric structures can be described as a convergence of three such systems: a fabric membrane, the supporting structure that anchors and supports the membrane and the tensioned cables that tie the membrane system to the supporting structure. Within each of these three systems is a number of important, crucial connections.

The key to good design practice with tensile structures is to establish appropriate criteria for the connection assemblies. Keep in mind the following interrelated criteria throughout this paper:

- Performance: function, safety and structural behavior
- Constructability
- Cost
- Aesthetics

PERFORMANCE

A strong performance focus is critical to good connection design. Special functional requirements must be carefully articulated:

- Will the connection be subject to extensive movement, out-of-plane movement, vibration, or repeated assembly and disassembly as a temporary structure might be?
- Will the connection be exposed to an extreme environment: extreme hot or cold, a marine environment, high humidity or high industrial pollution levels?
- What amount of rotational freedom is required between joined parts?

Safety issues are largely a function of satisfying code requirements and using appropriate engineering methodologies in a structure's design. Design load requirements and safety factors must be carefully assessed with respect to the structure's application.

Sophisticated fabric tension structures are being used with increasing frequency as permanent architectural structures, often in public buildings. Higher magnitude loads often require a complete reworking of familiar connection details that are used in temporary installations. Engineering analysis by a competent firm experienced in tension fabric structure engineering practices provides the loads and stresses that the structure's connections must be designed to accommodate. Comprehensive engineering analysis is a prerequisite for good connection design. Maintenance is an oft-neglected performance criterion that potentially affects safety, cost and aesthetics. Requirements for maintenance are determined as a direct function of three key issues of connection design: processes, materials and finishes. These will be discussed later in the paper.

CONSTRUCTABILITY

Constructability (the means and methods of fabrication, assembly and erection) is certainly an important design aspect that can affect cost and quality. We've all heard about the wonderful designs that cannot be built. Moreover, a primary objective of good connection design is predictable quality, schedule and cost regarding the fabrication and installation of the connecting components and assemblies. Designs developed without rigorous evaluation of their fabrication and installation requirements will likely result in unanticipated fabrication and assembly problems that can easily affect cost. Good design practice embodies in its product the spectrum of considerations spanning the building process, from concept design through fabrication, assembly, erection and life cycle maintenance.

COST

Cost is usually regarded as an important consideration, and is often the predominant design driver. Connection assemblies for fabric structures typically represent a significant cost center, particularly in permanent architectural applications, which tend to be hardware-intensive (as opposed to software, i.e., the fabric membrane.) A strong focus on connection design will both reduce and control costs, contributing to maintaining the project's budget.

AESTHETICS

Aesthetics becomes a paramount design concern in many architectural applications of fabric structures. Connection detailing represents a prime opportunity for designers to add visual interest and excitement to a fabric design, but aesthetic considerations must start with a rigorous analysis of performance requirements and end with craftsmanship. Much can be done simply with good craftsmanship, but craftsmanship alone will not save a flawed design.

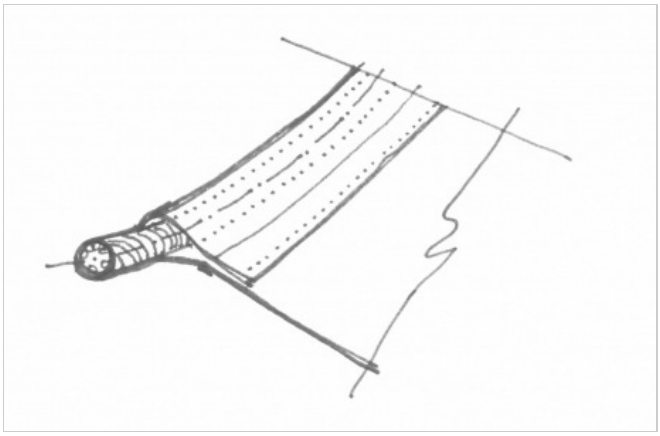
Understand the way in which the forces are moving through the connected components. Tensioned fabric structures are stable

due to their doubly curved forms generated by tensile force equilibrium. Therefore, elements and connections must encourage and follow direct load paths. The displacements of tensioned structures produced by external loads are relatively large compared to those of more conventional construction systems. This quality must be kept in mind throughout all stages of tension structure design. Connections should allow for displacement and rotation. Details should be simple, flexible and in scale with the overall structure and material used.

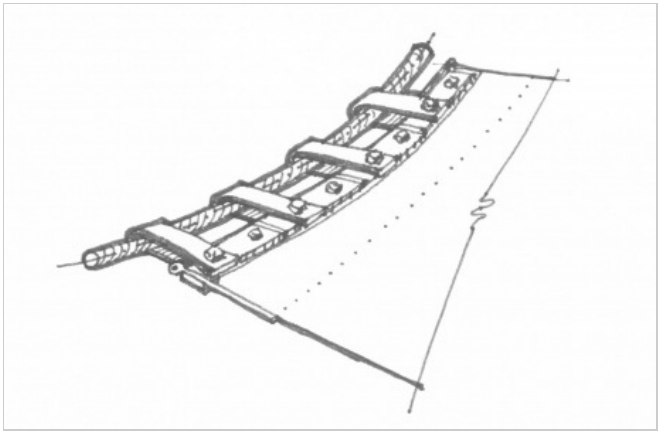
Overall, be certain that you truly understand what your connection design will look like when built. Computer renderings are helpful, but full-scale mock-ups are by far the best format for determining issues of form and proportion, as well as fit and function. Spend as much time as you can afford looking at other fabric structures, drawings and photographs of built connection details, keeping in mind what works visually and what does not. Do this, and you should soon recognize tension structure connections that work well both functionally and visually.

INTERACTIVE FEATURES

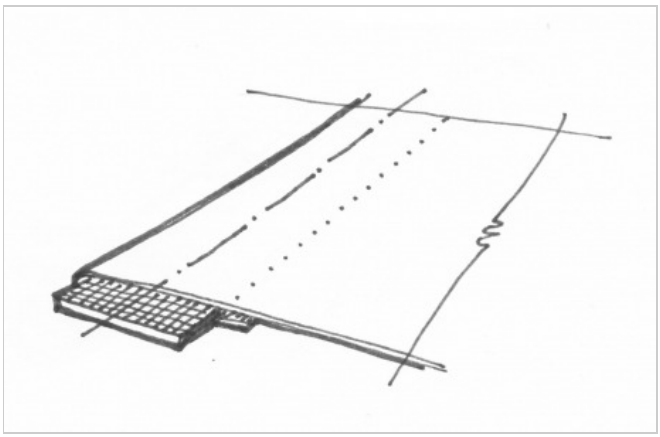
Continuing Education Test



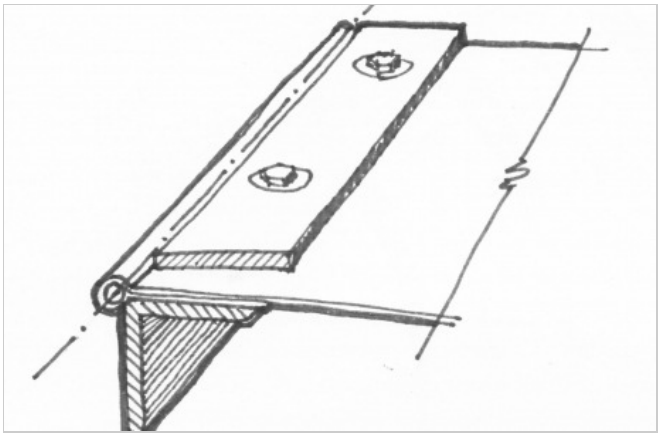
Fabric pocket with cable. Used with PVC-coated polyester fabric or PTFE-coated fiberglass fabric (must be restricted by the length of the fabric seam. If the forces get too large, it would be better to use the edge cable with clamps method, shown next.)



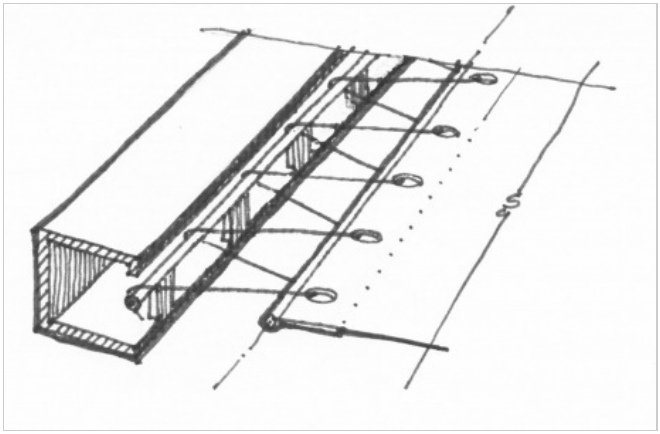
Edge cable with clamps. Used mainly for PTFE-coated fiberglass fabric, but also for PVC-coated polyester fabric when edge spans are longer than 20m.



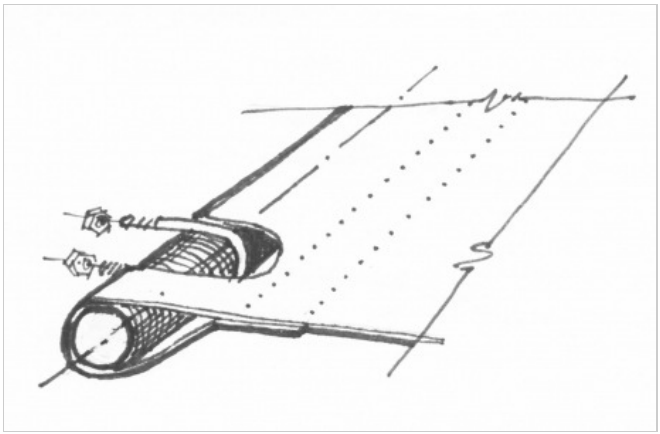
Belts. Can be stitched or welded along the edges and used with PVC-coated polyester fabric. Used mainly for retractable roofs, umbrella-shaped designs and temporary structures.



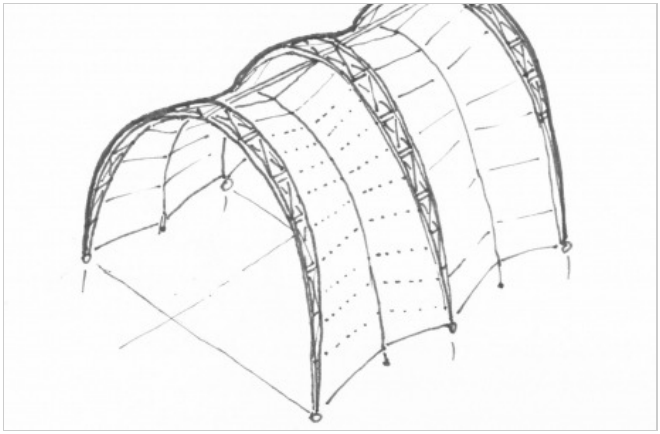
Clamped edge with plates. Used with both PVC-coated polyester and PTFE-coated fiberglass.



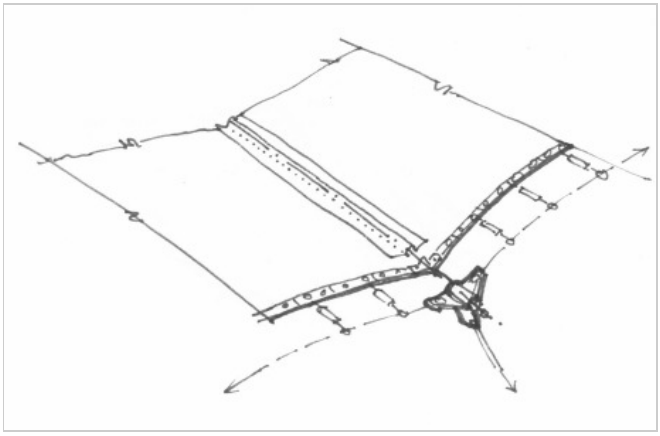
Channel (with grommets) and lacing. Used with PVC-coated polyester fabric where the edge has grommets spaced at frequent intervals. Rope is laced through the grommets and to a tie rod within the channel.



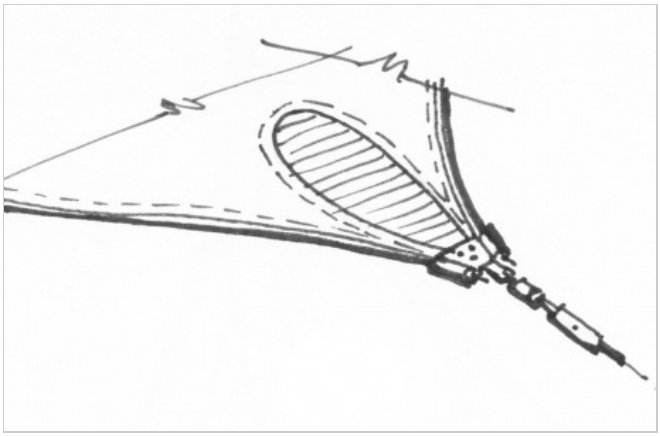
Tube in cable pocket. Used for PVC-coated polyester fabric. Forces travel perpendicularly to the tube and movement prevented along the length of the tube.



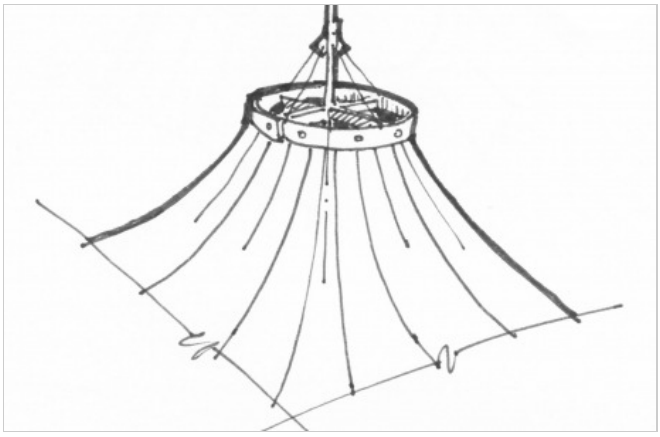
Arches are used to help shape the fabric roof surface and promote double curvature.



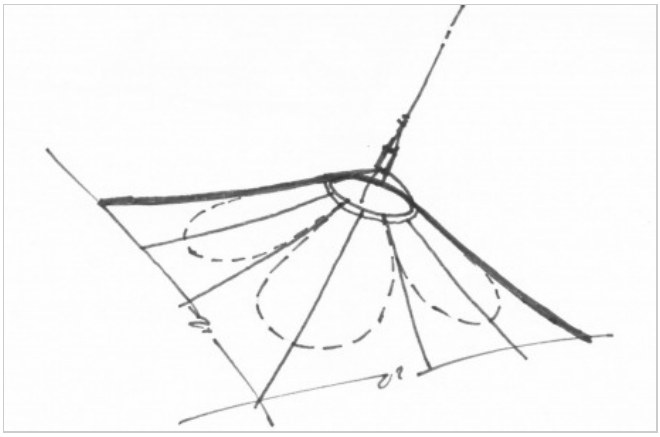
Ridge & valley cables help promote double curvature with cables running in parallel to create a “wave” shape. Cables must be adjustable in length to allow fine-tune tensioning.



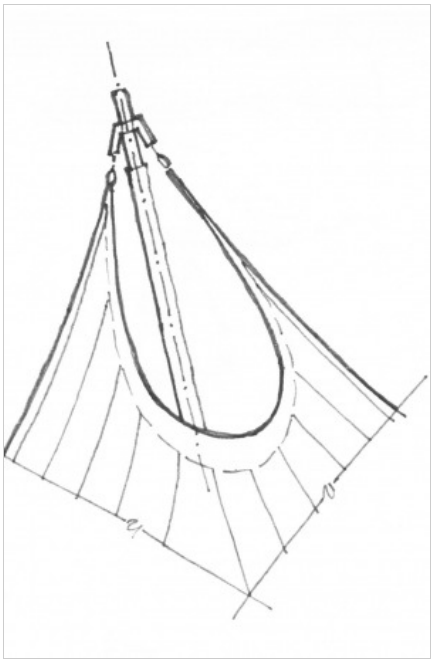
Eye cables are cable loops lying within the membrane plane and are used to relieve forces at stress points.



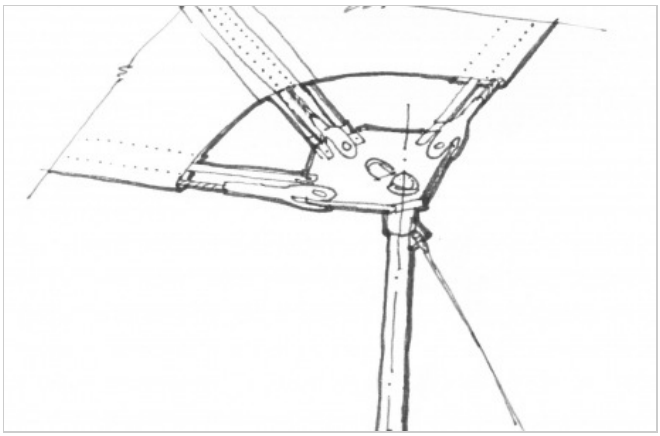
Bale rings are a good way to control stresses in fabric roof at high or low points. Used at high points they must be covered to make the structure watertight. If used at low points, they can be used to gather rainwater and snow for redistribution on site.



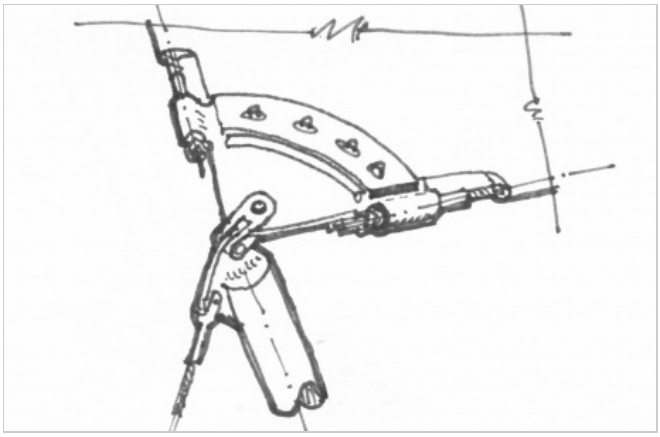
A “butterfly” is a series of cable loops that lie within the membrane plane to help relieve stresses. They can be beautiful, but also expensive to detail. Forces come together and are transferred to a point connection where the cable loops converge.



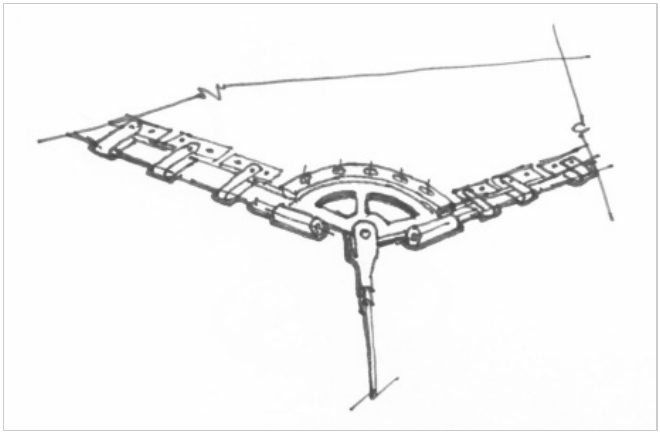
A single cable loop can reduce stresses, much as with the butterfly form. Seldom used for permanent structures that must provide waterproof shelter.



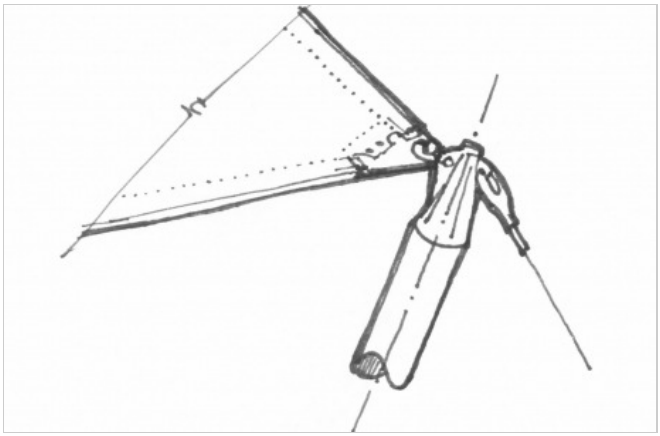
Corner plate apart from fabric (cables have separate adjustability.)



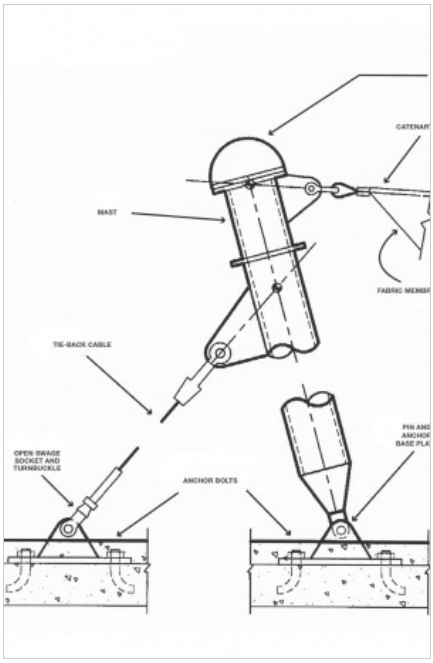
Corner plate clamped to fabric (cables are adjustable.)



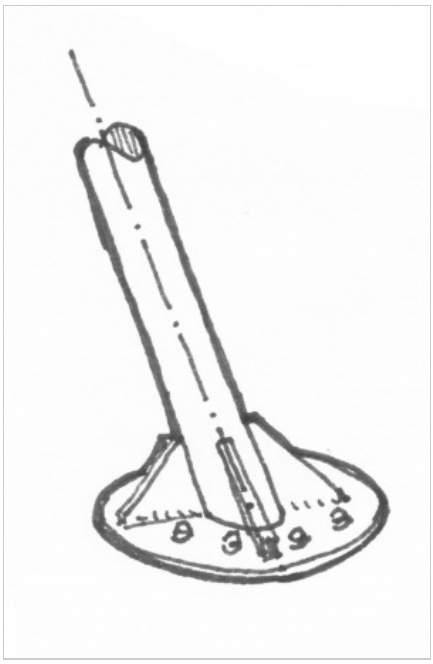
Corner plate with keder/fabric edge (cables adjustable or fixed length.)



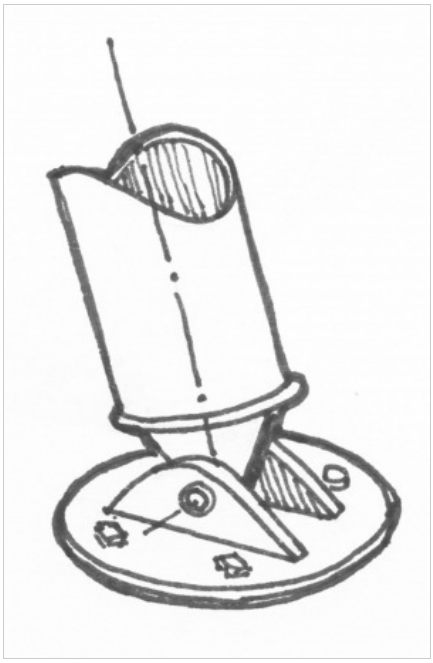
Corner plate with connecting belts.



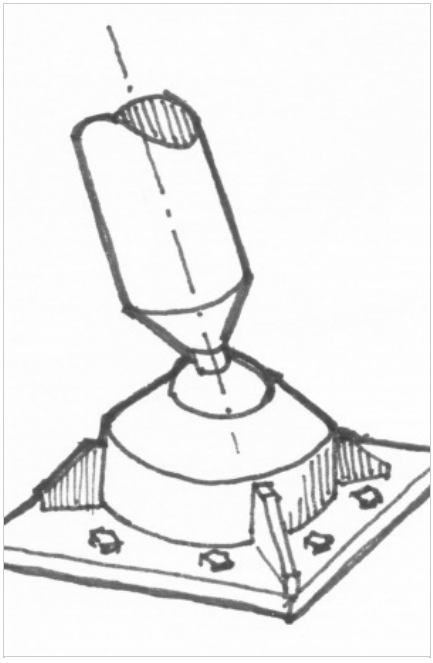
Masts are tall, linear structural elements (usually of steel) used to hold up the fabric membrane and cable elements of a fabric structure. They are frequently fastened to the foundations with hinged base plates.



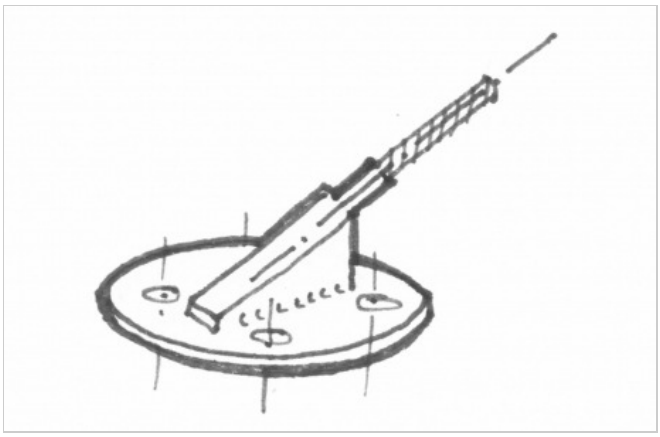
Moment resisting mast base plate. The lowest cost method, but all converging forces must be absolutely accurate and fabrication must meet high tolerances, ultimately a trade-off in cost.



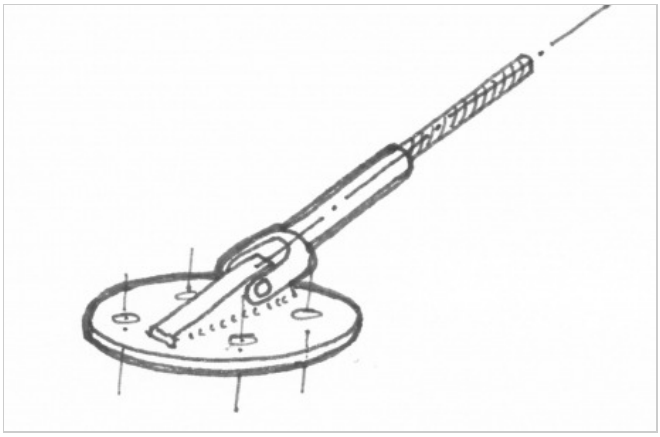
Single hinge mast base plate. For use when tangential forces are simple and direct.



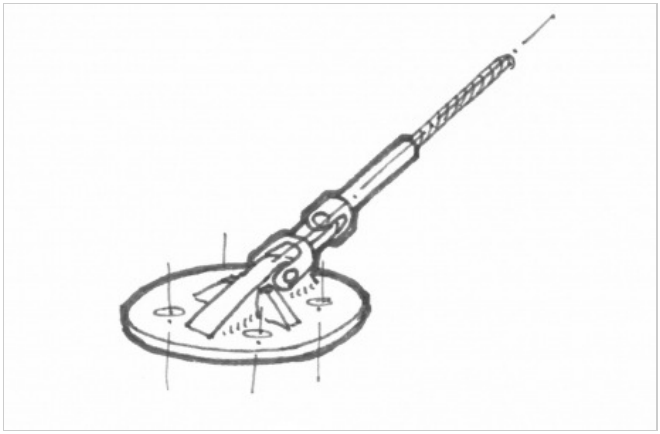
Ball & socket mast base plate. For use when tangential forces are complex and unpredictable.



Moment resisting cable base plate. Lowest cost method, but see mast moment resisting base plate above.



Single hinge cable base plate.



Double hinge (w/extra toggle) cable base plate.

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LEARNING OBJECTIVES

After reading the article you will be able to:

1. Understand the importance of designing connections that safely address all structural interface systems used in fabric tensile structures.
2. List all the possible groups of connection details used for transferring loads from one interface system to another.
3. Learn design criteria for designing successful tensile structure connection details.
4. Recognize aesthetic opportunities in the design of fabric tensile structure connection details.

COMMENTS

Comments are the opinion of individual posters and do not reflect the views of Fabric Architecture or Industrial Fabrics Association International.

Adriaan
May 3, 2010
10:07 am CDT

Details

Who is the author of this article as I am very intressted in dusicussing some further details and elaboration on this topic? Specially with a focus on PTFE coate Fibre Glass membranes.

Abbie Yarger
May 6, 2010
11:12 am CDT

Re: Details

Editor's note:
The article is a compilation of several articles published in *FA* over the past 20 years, and edited down by myself to condense it to essential information. So, in a sense, *Fabric Architecture* magazine is the author. I would be glad to discuss anything regarding the article or detailed points within the article.
- Bruce N. Wright, AIA, editor of *Fabric Architecture* magazine