fabric ARCHITECTURE

Connections and detailing: Part 1

Well-designed details can make fabric roof construction relatively easy and elegant in appearance.

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INTRODUCTION

This paper addresses an aspect of design that is seldom addressed in tension structures literature: the structural details that fasten the elements of the roof together and provide a means for tensioning the fabric. Details are critical to the performance of any type of structure. In fabric roofs, though, connection details are generally left exposed in the finished structure and are critical to their appearance as well. The elegance and expressiveness of connection details is inextricably linked to the aesthetic success of fabric architecture and necessitates unusually close collaboration between architectural and structural designers.

Most connection design situations provide for more than one technically acceptable solution, and the most successful structures employ connections designed to provide simple and direct load paths and a visual expression of the flow of forces that is intuitively clear to both designer and layman. These structures have a congruity in function and appearance amongst the various connections, and a common vocabulary of design elements that provides clear indication of commonality in function. While the large diameter catenary cables on a structure may require a speltered end fitting and smaller diameter catenaries might more economically use swaged fittings, altering fitting type within the structure implies a variation in function that does not exist and is visually dissatisfying.

In the detailing of connections, the designer is advised to follow what may seem the path of most resistance: solving the design problems of the most complex or heavily loaded connections first, then lightening or simplifying them as required elsewhere. "If the most crucial, difficult detail is not burdened with boundary conditions resulting from other details," notes Jörg Schlaich, one of the masters of contemporary structural design, "it has a chance to become simple."[1]

FABRIC TERMINATIONS

Each of the characteristic fabric termination types—fabric to fabric, fabric to cable, and fabric to rigid support—has particular design requirements and multiple solutions. The most basic connection of all—the joining of two strips of fabric at a seam—is a shop fabrication process discussed in my book. Fabric to fabric connections are also made in the field when the size of shop fabric assemblies must be limited to accommodate fabrication or shipping restrictions or limits on the size of fabric assembly that can be handled during erection.

Depending on the logistics of erection, field seams may be made either on the ground or in place atop the roof's supporting structure. Roped fabric edges secured between clamp plates are used most often (Figure 1), while other roofs, typically smaller, utilize lacing or other simple joining mechanisms between panels.

In many cases, fabric field seams are aligned with cable locations, so that the cable rides directly over a standard double clamp joint (Figure 1). The cable may tend to realign itself to one side or the other of the joint in aesthetically clumsy manner, a problem that can be corrected by periodically substituting an upturned channel for the standard upper clamp plate, or by use of the more elaborate detail shown in Figure 2.

Fabric terminations at catenary cables are most expeditiously detailed by providing a continuous edge cuff through which the cable rides. The cuff material is generally cut at a 45-degree bias to the main fabric panel so it can be curved to fit the line of the cable without wrinkling. Tightly curved cuffs, or those made on stiff fabric, may still wrinkle perpendicular to the cable in an unattractive manner. Closely spaced slits may be made on the inside edge of the cuff to increase its flexibility, like kerf cuts in timber. If the slits are made, another continuous strip of fabric must be sealed over them to provide appropriate reinforcement.

The designer must take care in sizing the cuff so that clevis jaws or other cable terminations will slide through it without binding. These fittings become prohibitively bulky on larger diameter cables so that the one end of the cable is terminated in a threaded "stud end" onto which the clevis jaw is threaded after the cable has been run through the cuff. Alternatively, the edge of the fabric may be secured between clamp plates that are in turn bolted to U-straps which capture the cable—a single-sided variation of the fabric-to-fabric connector shown in Figure 2.

The connection of fabric to a rigid edge support of steel, concrete, or other material can be accomplished in simple fashion with single clamp plates.

Catenary edge terminations are characteristically used around the perimeter of open-sided structures while rigidly clamped edges are almost universally used to provide a direct interface between the fabric roof over an enclosed space and the supporting walls or other conventional construction. On some structures, designers wish to maintain the "free" form of the roof by allowing its edge to spill over the top of the wall and terminate at a catenary edge. The interface between the rigid wall and the flexible and curving roof becomes more problematic in such designs. On some, designers have addressed the issue by providing a fabric skirt that "returns" from the underside of the primary membrane to the top of the wall. Others, such as the Denver Airport Terminal, link the underside of the membrane to the top of the wall with continuous inflated fabric tubes that are able to flex upward and downward as the membrane deflects under load. (Figures 3 & 4).

CABLE TERMINATIONS

The primary detailing problem of cables used in tensioned fabric roofs is the method of termination at their two ends. Terminations may be either fixed or allow adjustment in cable length, and they may allow the cable to articulate through angle changes about one or both axes. The different mechanisms used vary in their adaptability, economy, and visual elegance. In general, terminations are designed to develop the full tensile strength of the cable.

The most economical termination, admirable for its easy field application, is a looped cable eye formed by a thimble and secured by U-bolted clips (Figure 2). Such terminations may be adjusted for length prior to installation, and they allow the cable to articulate about both axes. Their application is limited by their inelegant appearance and potential for improper installation, but they are well suited to temporary structures or those with limits on budget or need for sophistication. Their appearance is enhanced when a swaging sleeve is substituted for the cable clips. These sleeves may be shop or field applied on cables of up to 30mm diameter.

Cable eyes may be interlocked with one another to splice two or more cables together, and one or more cables can be linked with shackles to provide attachment to lug plates welded to the supporting structure. The thimbles used in cable eyes force the cable to a tight bending radius, and the designer must reduce the allowable cable capacity appropriately, generally 10 percent for cables of 25 mm or greater diameter and 20 percent for smaller cables.

Speltering or swaging of stud end, jaw end, or eye end terminations provides reliable fixed length cable terminations that are generally both more expensive and more sophisticated in appearance than eyes. Spelters are formed by pouring molten metal inside a tapering sleeve as required to fix a cable whose wire ends have been spread open inside the fitting. While speltering may be accomplished in the field, it is generally done in the shop, where work is faster and more accurate. In swaging, the fitting is clamped tightly onto the end of the cable. Smaller swages can be made in the field, though shop work is again preferred.

Both spelters and swages are available with stud ends (threaded termination that provide adjustment in length), jaw ends (which attach to a single lug plate with a pin), and closed ends (an eye which may be secured between a pair of plates or onto a clevis). Stud ends may be either fixed or allowed to rotate, depending on how they are attached. Jaw and closed ends allow rotation about a single axis in line with the center of the pin or eye hold, while toggles are sometimes added to permit rotation about both axes.

In addition to stud ends or adjustable toggles, cable length variation may be provided by splitting the cable into two segments joined by a turnbuckle. Turnbuckles, like cable eyes, are inexpensive, adaptable connectors that typically have a busy and workmanlike visual character that may be poorly adapted to more elegant “high-end” structures. Just as speltered or swaged terminations provide a tidy alternative to eyes, conventional turnbuckles are sometimes replaced (at increased cost) by pipe turnbuckles.

The choice of cable termination must be coordinated with the design of the elements to which the cable attaches. Closed eyes may be knifed between and connected to a pair of plates while jaws connect to a single plate. The greater simplicity of the latter connection accounts for a much wider use of jaw ends.

The lug plates to which jaw or eye termination are attached must be sized with thickness adequate to prevent tearout of the connecting pin. Typically, doughnut-shaped “boss” plates are welded to each side of the lug plate to match its thickness to the width of the jaw and prevent bending of the pin.

For all but the lightest cable forces in combination with stout mast walls, special care must be taken to avoid excessive local bending in the mast wall resulting from lug plate forces normal to the mast axis. In some designs, it is sufficient to knife the lug plate all the way through the column so that both walls of the column are engaged in resisting local bending. In more heavily stressed connections, however, designers provide circular ring plates around the mast to which the top and bottom edges of the lugs are welded. (Figure 5). Where possible, the holes for cable pins on the lug plates are laid out so as to bring all cable centerlines to a common workpoint at the centerline of the supporting member, thereby avoiding unnecessary bending moment in the member. There is both economy and a handsome and sturdy honesty to cable terminations that follow these simple principles (Figure 6).

In some structures, the confluence of cables at the top of a mast makes it difficult either to provide the required clearances for cable terminations or to avoid a cluttered appearance. In order to address these problems, we raised the workpoint for the straight guy and tieback cables 600 mm above that for the catenary and radial cables that lie in the plane of the fabric (Figure 7) in the Weber Point Canopy of Stockton, California, that we engineered for contractor Sullivan & Brampton. The double workpoint came at high cost, though, as the resulting bending moment made it necessary to increase mast diameter from 355 mm to 508 mm.

With large cables or geometries that provide very acute angles between cables and masts, lug plates can become high in both their real and visual mass. Refinements sometimes yield connections that are more elegant, more directly expressive of the flow of tensile forces, and that begin to share some of the voluptuousness of the membrane forms themselves. Simple curvature in the edges of lug plates accomplishes this, and further lightness is sometimes achieved by cutting openings in the interior of the plate at areas of low stress. Such paring away of form complicates design and fabrication without offering any compensatory technical advantage. Contemporary plasma cutting technology minimizes the additional cost associated with such work, however. Further refinement of cable termination form is achieved when steel castings are substituted for welded plates. Castings gain in economy at heavily loaded connections or where the roof configuration permits substantial reuse of casting forms.[2]

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References

1. Ito, Judge. 1991. “Cable Stayed Bridges: Recent Developments and Their Future,” Elsevier, 58.

2. Huntington, Craig. G. 1993. ”Methodologies and Technologies for Tensioned Structures,” l’Arca, July/August, 82–83.

Figure 6: There is both economy and a handsome and sturdy honesty to cable terminations that bring all cable centerlines to a common workpoint at the centerline of a supporting member.

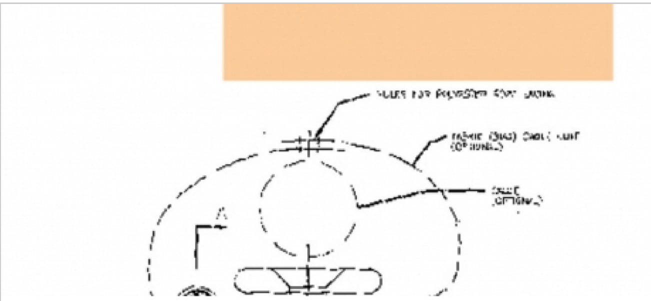

Figure 1: Fabric field joints can be made by sandwiching two fabric roped edges between clamp bars. The joints are made to align with a cable where possible, as shown here.

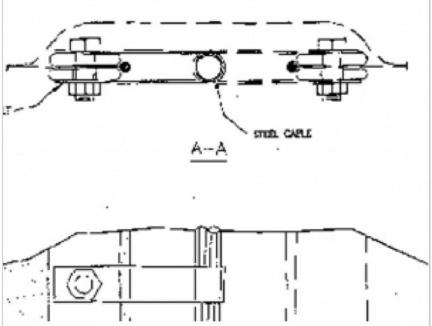

Figure 2: U-bolting clamped fabric is a means of providing both fabric field seams and fabric terminations at catenary cables (the undashed portion of the figure).

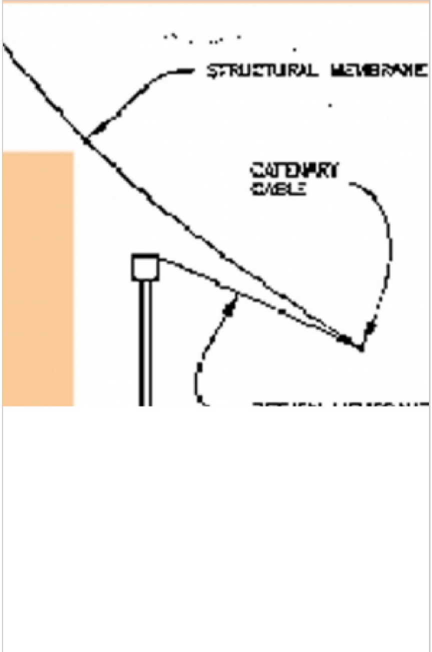

Figure 3: The gap between a “free” fabric edge and the perimeter wall can be closed by a return membrane which must accommodate expected movements in the catenary cable.

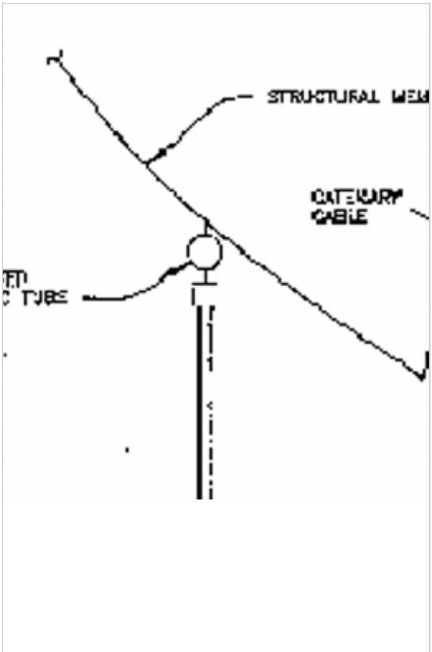

Figure 4: Inflated fabric tubes provide an alternative edge closure.

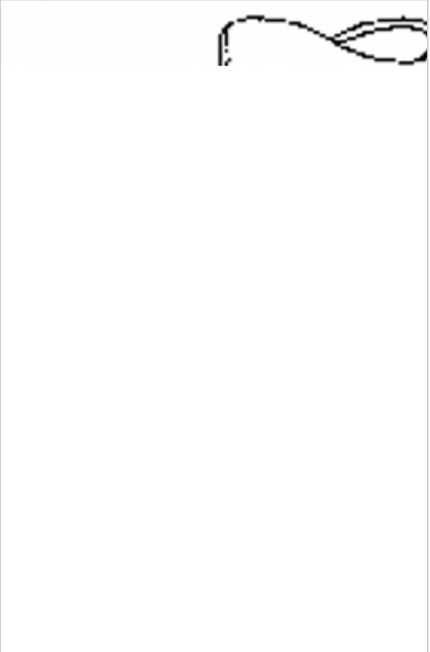

Figure 5A: In designing face-welded gussets, cable force “F” is resolved into axial (Fa) and lateral (Fv) components resisted through bending of a single mast wall.

Figure 5B: Knifing the gusset through the mast effectively halves sidewall bending.

Figure 5C: Sidewall bending is eliminated with ring plate designs.

Figure 7 : Masts are analyzed by resolving cable forces into axial and shear components at the mast centerline.

Boss plate: Doughnut-shaped plate attached to a cable ear plate to reinforce the pin hole and allow a thinner plate.

Cable eye w/thimble: Device used in a simple cable loop end to secure the cable and bear against the pin.

Catenary cables: The cables that form the boundary edges of a uniformly stressed fabric structure and which are restrained only at their end points.

Clevis: Device used with a cable stud end or a threaded rod to form a pinned connection that is somewhat adjustable.

Radial cable: Cables that converge upon a central mast or mast ring.

Speltered end: Type of cable fitting in which the strands of the cable are opened inside the fitting and molten lead is poured into the fitting to secure the cable.

Swaged end: Type of cable fitting in which a sleeve fits over the outside of the cable and the sleeve is compressed around the cable to form a tight fit.

COMMENTS

There are not yet any comments.

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