Tension Elements in Lightweight Structures

Peter Lim
Spacetech Pty Ltd, Melbourne

1. INTRODUCTION

Linear or two dimensional elements in tension are utilised by cable (or tension) structures as their primary load carrying elements. The tension elements are required to work in harmony with the compression and bending elements. This subsequently leads to a visual and architectural expression of how the forces are being carried by the structure. This type of structures have been executed by some of the leading architects of our era.

This paper provides a brief overview of the various types of tension elements readily available for this type of construction. An in–depth study and treatment of the various elements and issues raised are provided in the references.

2. CABLE ELEMENTS

The development of high tensile steel cable has made it possible to transmit large axial forces in tension at a relatively low cost. The use of cables in modern suspension and cable stayed bridges are obvious examples of the economical way in which these large loads can be supported by the use of tension members.

The cable roof structure at the North Carolina State Fair Arena in Raleigh USA (1952) was the achievement of Mathew Nowicki and Fred Severud and represented one of the first buildings using cable elements.

There are various types of cable elements used in the construction industry today. This paper will limit its discussion to the 2 major ones, namely:–

- Galvanised and stainless steel cables & fittings
- Polyaramid ropes & fittings

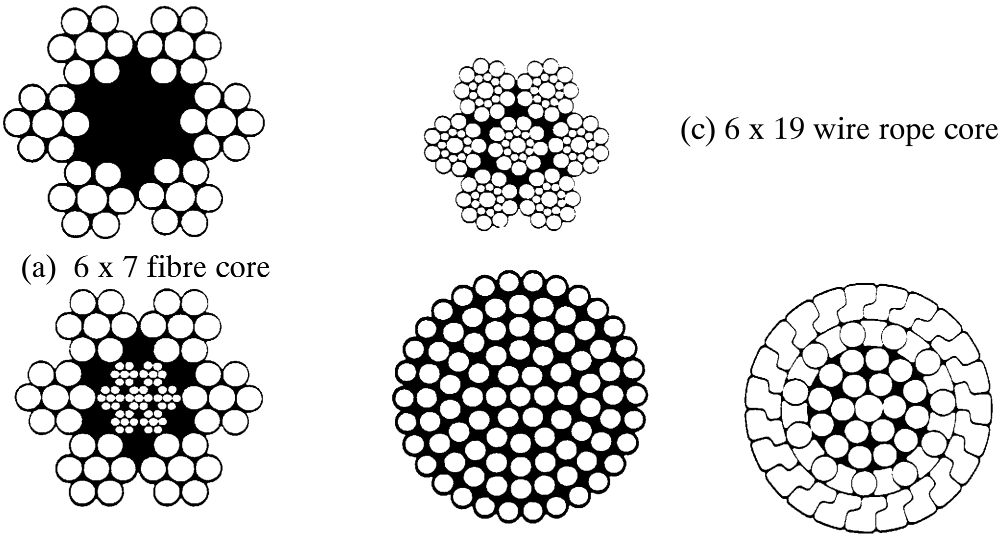
2.1. Galvanised and stainless cables & fittings

Wire ropes comprises of a number of high tensile steel wires spun together to form six strands, which in turn are spun together around a fibre or wire core to form a cable. There are many different variations to the wire construction and each is designed for a particular application.

For example, hoisting ropes have a fibre core and usually ungalvanised and heavily greased. This type of ropes although are flexible but are not used in the construction of tension structures because these cables have a tendency to stretch as the fibre core reduces in diameter. The possibility of a partial collapse situation of the cable increasing in length has lead to cables composed solely of steel to be used in long term structures. Rigidity is also more desirable than flexibility in structural applications.

Single strand wire ropes which are composed of layers of wires built up around a central king wire are known as spiral strands. This is commonly used in the construction of cable type structures. For some smaller applications, the use of a six stranded cable with an independent wire rope core is suitable, but for most heavier application, the spiral strand or lock coil cables are used.

Lock coil strands use one or more interlocking wires on the outside of the cable to produce a smooth external finish.



(a) 6 x 7 fibre core

(b) 6 x 7 wire rope core

(c) 6 x 19 wire rope core

(d) spiral bridge

(e) lock coil bridge cable

Figure 1 – Typical cross section of various type of cables

The following tables are examples of various lock coil strands and spiral strands. The data was obtained from British Ropes Limited but most of the major suppliers would have similar cables.

Diameter (mm)	MBL (kN)	Weight (kN/100m)	Steel Area (mm^2)	Elastic Modulus (kN/mm^2)
25.0	557.2	2.99	374	169.7
30.5	795.6	4.54	546	169.7
31.1	910	5.48	678	169.7
42	1500.9	8.48	1033	169.7
45.9	1805.0	10.15	1240	169.7
66.0	3747.4	21.11	2570	157.9
75.0	4846.1	27.35	3330	157.9
86.4	6131.3	35.89	4330	147.2
102.0	8524.9	49.97	6020	147.2
116.0	10486.9	66.01	7862	147.2
127.0	13371.0	78.33	9450	147.2
137.0	15068.2	89.10	11015	147.2

Table 1 – Spiral strand bridge cables (British Ropes Limited)

Diameter (mm)	MBL (kN)	Weight (kN/100m)	Steel Area (mm^2)	Elastic Modulus (kN/mm^2)
24.0	509.0	3.06	373	158.4
35.8	1106.8	6.58	802	158.4
38.8	1314.5	7.92	966	158.4
48.0	2001.3	12.57	1530	158.4
51.5	2452.5	15.08	1840	158.4
63.2	3492.4	21.42	2610	158.4
73.6	4708.8	29.69	3617	158.4
87.2	6553.1	41.14	5012	158.4
99.0	8721.1	51.89	6320	158.4
101.5	9035.0	56.20	6900	158.4
116.0	12390.0	75.96	9251	158.4

Table 2 – Lock coil bridge cables (British Ropes Limited)

From the tables, it can be seen that in the bigger sizes, greater than 90 mm, the higher steel area ratio to strand area ratio gives the locked coil construction type cables some advantages in terms of breaking load to diameter of strand.

The requirements for individual projects vary greatly and therefore one needs to consider all the various types of cables and construction prior to selection. In most cases, the designers usually specifies a MBL (minimum breaking load) that the cable needs to achieve but other considerations, including

- type of construction of cables;
- corrosion requirements;
- stretch/strain characteristics and requirements.

also need to be included in the specifications so that the appropriate cable is used.

Three major factors that affect the life of a cable are:–

(a) fatigue

(b) dynamic behaviour; and

(c) corrosion

The tension fatigue life of cables has been the subject of much research over the years. (Ref. 5) On the basis of this, most designers tend to limit the maximum tension in a cable to approximately 40% of the MBL for long life structures. For temporary structures, with a life of up to ten years, 50% is acceptable.

Generally the internal damping of cable cladded net structures or tensile membrane structures are high, so one would not expect a large number of cycles at high loads.

Corrosion of bridge cables has also been researched extensively. In a recent paper (Ref 5), it was concluded that cables systems should be designed for ease of inspection and replacement. Generally, in a cable at the end of its design life, wire breaks can be seen and the cable should be replaced. Particular attention should be paid to socket detailing to avoid corrosion fatigue. Galvanising when correctly carried out should give corrosion lives of 50 years.

Most cables are made from galvanised wire to reduce corrosion. In some instances, the cables are filled with zinc paste. The use of plastic sheaths over the cable is doubtful if water and other corrosive agents enter into the sheaths. The resulting corrosion in these instances can be worse that unsheathed cables. Visual inspection of any problems with the cables are also made more difficult. However, filled strand or lock coil cables with shrunk on polypropylene or polyurethane sleeves could lead to greater corrosion resistance.

Stainless steel offers total corrosion but one needs to be aware that in some instances, where air is excluded, intercrystalline corrosion will occur. The cost factor associated with stainless steel (especially in the larger diameter cables) are also another factor why we do not see much application in large structures.

The simplest and cheapest type of end termination is a swaged Talurit eye made round a thimble. This would connect onto the pin of a shackle.

Swaged end terminations are the neatest type of fitting. The swaging process is usually carried out using a hydraulic press and can achieve a guaranteed 95% of the cable's minimum breaking load.

However, hot poured zinc (or alternatively cold poured polyester resin) socket terminations still have to be used for large cables (exceeding 50 mm). The swaged end terminations is more predominant in the smaller size cable fittings.

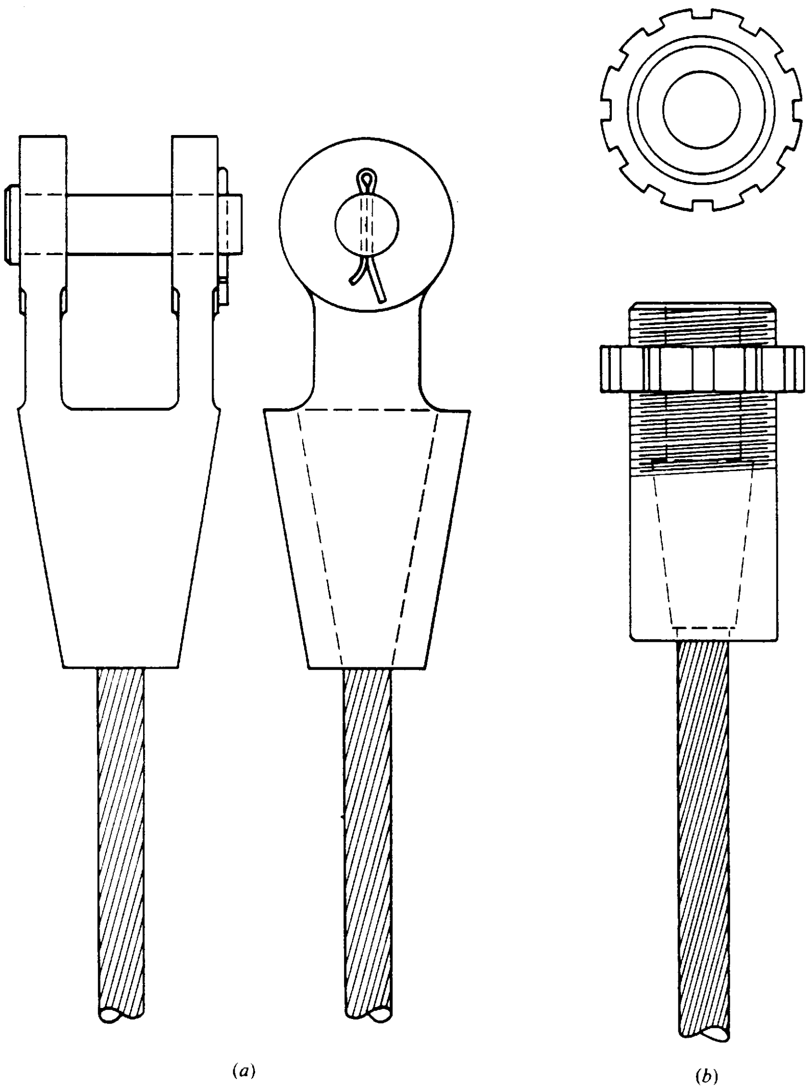


**Figure 2 (a) Socket terminal with pin connector
(b) Socket terminal with screw thread**

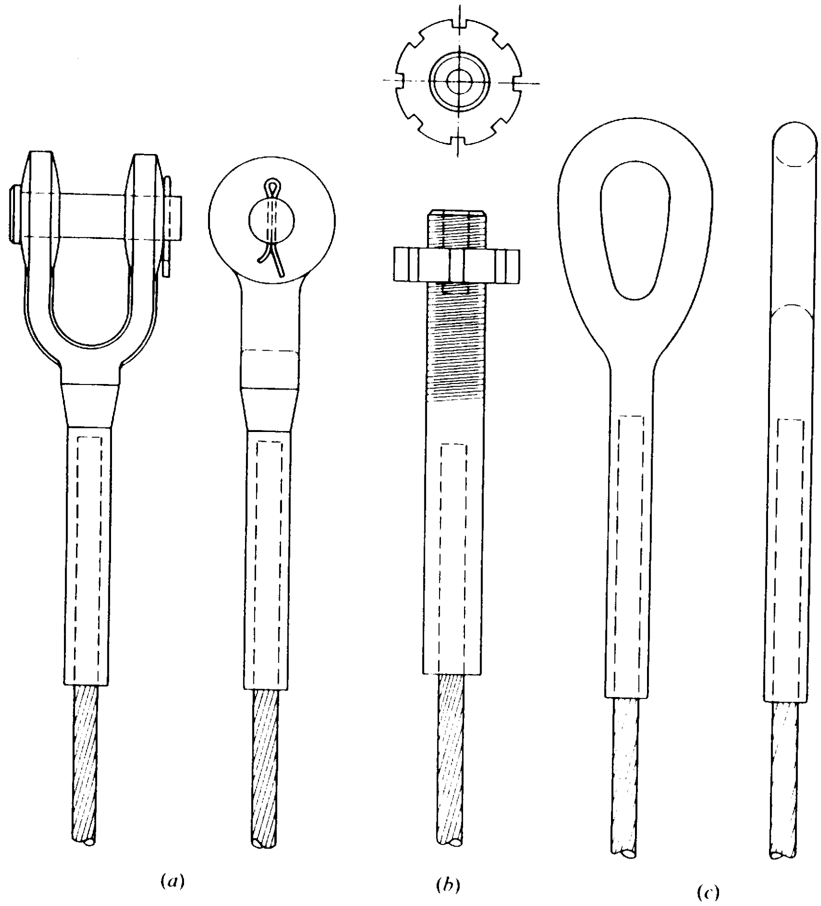


Figure 3 (a) Swaged terminal with clevis fork and pin connector
(b) Swaged terminal with screw threaded end
(c) Swaged terminal with closed eye end

2.2. Polyaramid ropes & fittings

25 years ago, a new range of polyaramid materials was developed. These are usually known by their trade names of Kevlar (trade name of DuPont); Twaron (trade name of Enka) and Tecnora (trade name of Teijin). These materials are produced in the form of fine filaments, which are then given a surface coating and supplied as tow, each containing about 1000 filaments loosely twisted together.

The yarns are produced in different grades depending on the heat treatment they receive during production. Unlike other materials, the heat treatments affects the elastic modulus but the ultimate strength remains unchanged.

Properties	Kevlar 29	Kevlar 49	Prestressing steel wire
Ultimate Strength (kN/mm2)	2.760	2.760	1.860
Youngs Modulus (kN/mm2)	62	124	200
Specific gravity	1.44	1.44	7.86

Table 3 – Properties of polyaramid fibres

From the table, Kevlar is at least 50% stronger than steel. The high strength/weight ratio is a major factor in consideration of its application in lieu of steel cables.

The most common method of aggregating the fibres together is using a parallel lay rope technique. The individual fibres are kept together by means of a polymeric sheath extruded over the core bundle. In some cases, it is possible to incorporate a resin or thermo–plastic filler. During fabrication, if it is required to eliminate the inter–fibre air voids, these resins can be used. Parafil ropes are examples of ropes made in this way using high strength Kevlar 49 fibres. These ropes are known as Type G Parafil ropes.

The most common method used for anchoring parallel fibre ropes is the internal wedge (or spike). The gripping force is produced by radial forces between the spike and the external body, so all the fibres are anchored. The length of the spike can be chosen to ensure that the transverse stresses are within the capacity of the fibres. Once the load is transmitted through the terminal body, similar end termination as cables (clevis forks, threaded end and closed eye ends) can be attached. The terminal body, spike and end terminations are usually made from an aluminium alloy.

One property that most engineers need to note is that Kevlar’s thermal expansion coefficient is negative, so the fibres shorten as they get warmer.

Disadvantages of this material is its brittleness, worse creep and worse stress rupture behaviour than steel cables. The apparent higher costs of these ropes are also another factor against the polyaramid ropes. However the advantages of lightweight, lack of corrosion are factors that could lead to savings in the overall cost of the structure need also to be considered.

At the moment, most applications using these ropes have been in the yachting industry. These ropes were used extensively in the Australian Bicentennial Travelling Exhibition structures. In order to assist with the installation/dismantling process at each site, the catenary cables of the structures were not removed on dismantling and thus a more lightweight and flexible cable was required in lieu of steel.

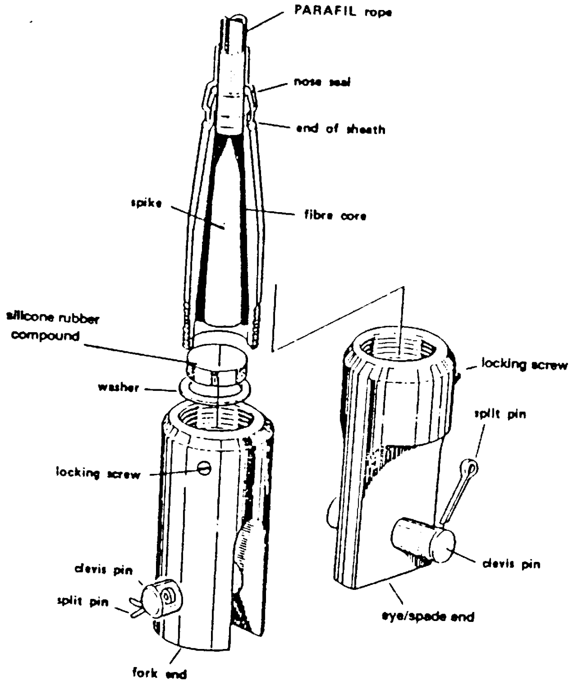


Figure 4 – Termination of Type G Parafil rope

3. RODS

In recent years, quite a few new companies have evolved, producing tension rod system. The rods are made from high tensile strength steel. End fittings are provided with a threaded hole into which the rod are screwed in. End fittings are usually cast items.

High strength tensile steel prestressing bars and rods used primarily for prestressed concrete construction, are also finding applications in lightweight structures as substitutes for cables.

There are several disadvantages with the use of cables, especially in the design and construction of cable–stayed roofs.

(a) Cables have a low modulus of elasticity, therefore if it is used at its full strength, the strains in the ties will be 3 or 4 times greater than if a solid section of the same area were used.

(b) Cables are supplied galvanised and greased. Over time this grease will be eroded away and the galvanising has a limited life. As discussed in the earlier section, there are various methods of protection in the form of polyethylene sheath or elastomeric coatings or encased in resins. After a period of 20 years, the maintenance costs may be high. In comparison, rods or tubes can be provided in a painted finish. Maintenance costs may be lower than using cables.

(c) Cables fittings are available with off the shelf fittings and in some cases may be too bulky in appearance and an alternative used.
There is no clear cut decision on whether to use rods or cables but there are instances where rods are used or preferred in lieu of cables. The rods should be regarded as another option to be consider in the design stage.

4. CONCLUSIONS

There is a wide range of cables, polyaramid ropes and rods available and offers considerable potential to architects and engineers to include tension elements in their designs and construction.

5. REFERENCES

1. H.A. Buchholdt. Introduction to Cable Roof Structures. Cambridge University Press 1985.
2. C.J. Burgoyne. Polyaramid ropes for tension structures. 1st Oleg Kerensky Memorial Conference Proceedings. pp 71–79. 1988.
3. Norseman Terminals Limited. Catalogue. 1988.
4. J. A. Thornton. The design and construction of cable stayed roofs. The Structural Engineer Volume 62A. No. 9 pp 275–284. 1984.
5. G. P. Tilly. Performance of bridge cables. 1st Oleg Kerensky Memorial Conference Proceedings. Session 4. pp 22–28. 1988.
6. VSL Prestressing Australia Pty. Ltd. Catalogue. 1988