Prestressing in Simple Structural Applications

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Concept: **Prestress**
Structures: **A Dome Tent and Other Everyday Examples**

In many cases, a structure's integrity, stability and security may be based on applications of prestressing. Prestressing can be defined as the internal creation of permanent forces within a structure, structural arrangement or structural elements before they are loaded, for the purpose of improving or defining its performance, under variable service loads, in respect to a desirable outcome.[1] The desired effects might include reducing unwanted stresses by redistributing internal forces hence allowing lighter structures; reducing displacements; avoiding cracks by inducing permanent compression on members; generating particular shapes of tension structures; and stiffening a structure or structural element. The main applications of the concept come in forms of pre-tensioning, post-tensioning and pre-compressing.[2]

From ancient structures such as the Colosseum in Rome, which uses pre-compression, to modern structures such as bridge-decks, which use pre-tension, this concept is widely employed to solve structural problems.

Figure 1: A Dome Tent and its Parts

A rather unusual application of pre-tensioning is that used in a dome tent. Such tents usually imply the use of two or more poles – fibreglass tubes or metal alloy rods – that are installed on the exterior or interior of the fabric, running from one side of the rectangular floor to the diagonal opposite side in a smooth curve, crossing at the peak. The ends of the poles are fitted into sockets in the four corners of the rectangular fabric floor. In this example the poles are at the exterior and are held by fabric pole sleeves or clips; see figure 1. ***A video is provided as well***.

Aluminium alloys poles are normally used to provide added durability. The aluminium alloy poles are comprised of several sections that have sockets on each side appropriately for

[1] Nilson, 1987
[2] http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/

assemblage. An internal elastic cord running the entire length eases the process as it keeps the parts from mixing up, but, most importantly, provides added pre-tensioning when the pole is assembled. The elastic cord at its two states can be seen in figures 2 and 3.

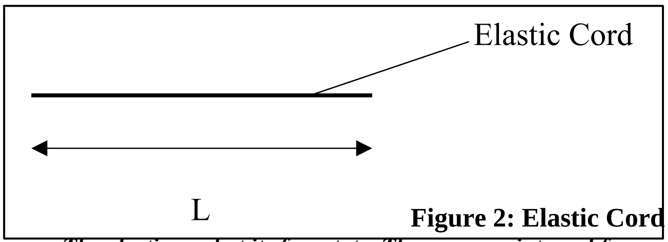

Figure 2: Elastic Cord
The elastic cord at its free state. There are no internal forces.

The dome tent is able to stand up due to pole tensioning. The poles are bent into a curve and stresses are produced before any loads are applied. The poles have the tendency to straighten up in their normal position due to the internal 'pulling' of the elastic cord as well as the effect of the aluminium alloy which is ductile and elastic: overall there is an internal tension within the members or, said otherwise, the members are pre-tensioned. Figure 4 presents the pole-cord interaction before bending.

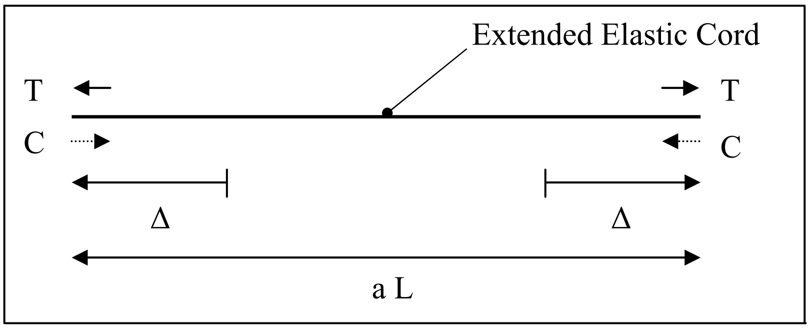

Figure 3: Extended Elastic Cord
The elastic cord when extended. A tensile force is applied to extend the cord, resulting in an internal compressive force. The length of the cord is now equal to L + 2Δ = a L. Any application of this cord will

The poles are fitted into the external pole sleeves which form part of the fibre. The fabric produces an external uniformly distributed load on the poles which acts downwards, inducing an outward force of the pole members at their ends, which also have a moment at each end due to their bending. At the same time, the fibre expands in response to the poles' tendency to compress, but its expansion is not enough to relieve the stresses within the poles. The forces within the fabric, which acts as a tie, keep the poles bent. This occurs because the fibre, which is in tension, is stronger than the pole acting in tension; the resistance within the fabric in response to the tension it experiences is provided by the shear force of the fabric's matrix. Figure 5 illustrates the above.

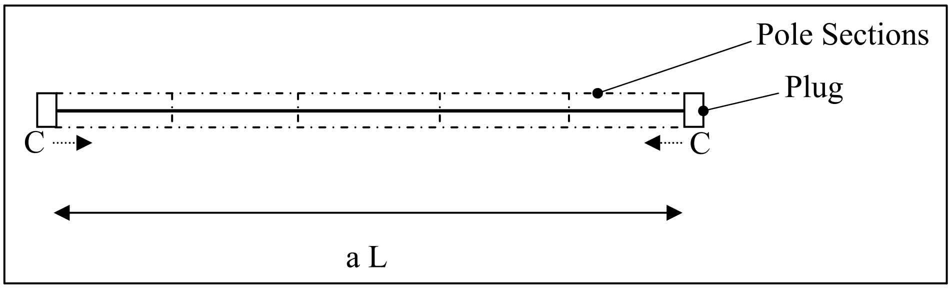

Figure 4: Elastic Cord and Metal Pole
The elastic cord as seen within the aluminum alloy rod or pole. As shown, the plug forces the existence of a pre-tensile force as it pulls to extend the cord, whilst the cord has a natural tendency to compress in response to this deformation. The pole is comprised of sections that fit within each other.

The equilibrium condition is achieved at a point where the poles are bent and the dome-shaped fibre is expanded. Hence the fibre prevents the poles from pulling up into their previous unbent state whilst expanding enough to produce a living space within the tent. The whole arrangement ultimately produces a freestanding structure which does not need guy ropes or tents for structural integrity; however, the tent should be pegged into the ground to withstand wind loads. Figure 6 presents pictures of the pole – sleeve pole interaction and a closer view of the dome tent.

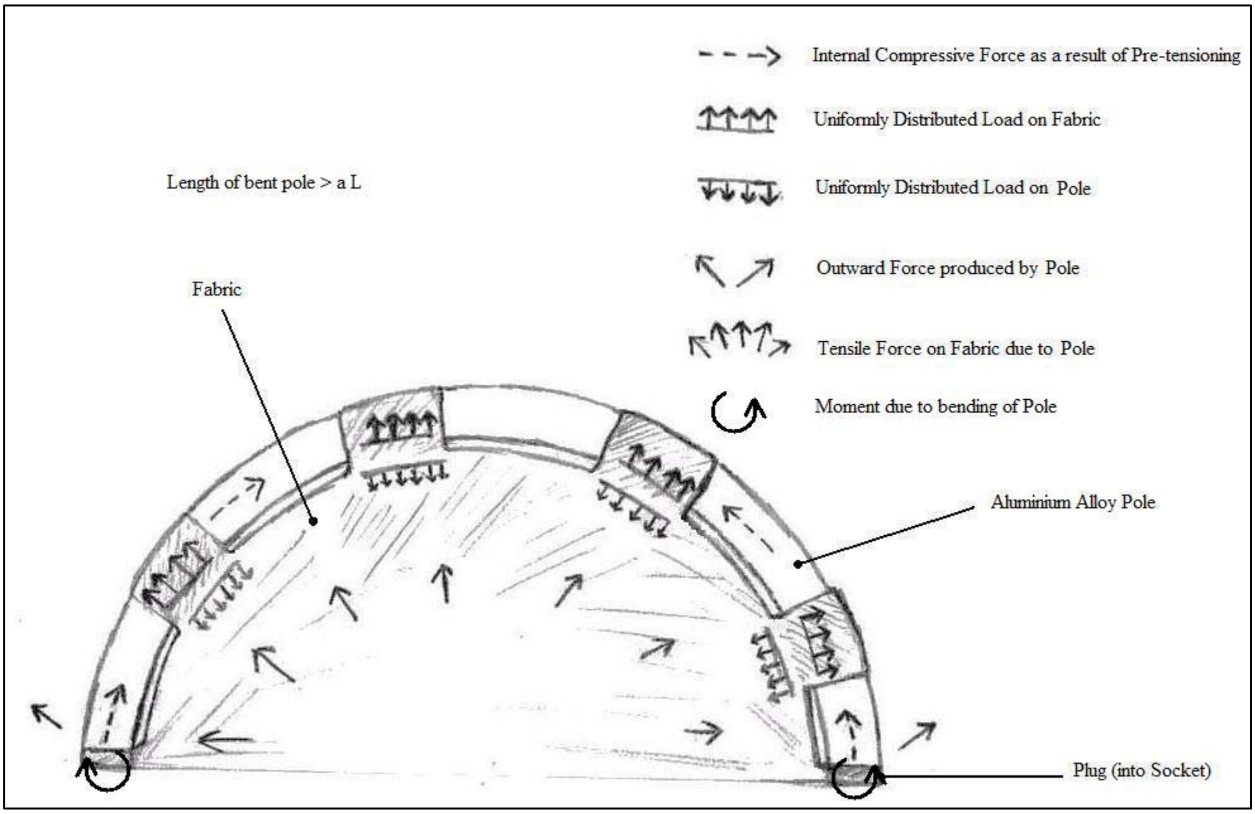

Figure 5: 2D Aspect of Metal Poles and Fabric

The aluminium alloy rod as fitted into the sockets at both ends and as placed within the pole sleeves. The internal compressive force of the metal rod in combination with bending resistance produces the forces shown above, ultimately making the fabric stand up. The exterior part of the pole is in tension whilst the interior/inner part of the curve is in compression. Note that that length of the smoothly bent pole is bigger than when not bent, hence the pre-stressing forces within are larger.

If pre-tensioning within the poles did not exists, the whole structure would not be able to be freestanding. It would have needed vertical supports to stay in shape. It is made obvious that without the prestresses within the poles, the whole structure is rendered unusable.

Figure 6: Sleeve – Pole Sleeve Interaction and Dome Tent

Left: The forces acting on the fabric and the pole are shown at a point where the pole is held by a pole sleeve.

Top: Dome tent, close-up.

Supplementary Examples

Prestressing is an engineering concept widely used in applications we come across every day. The following pictures and their explanations show how useful this concept is.

Figure 7: Portable Rail

Here a rail used in retail stores and elsewhere is demonstrated. The belt stays up due to internal tension. A mechanism inside one of the two poles pulls the belt, whilst the belt is firmly attached to the other pole. This pre-tensioning gives a result that would otherwise look like the rail on the left.

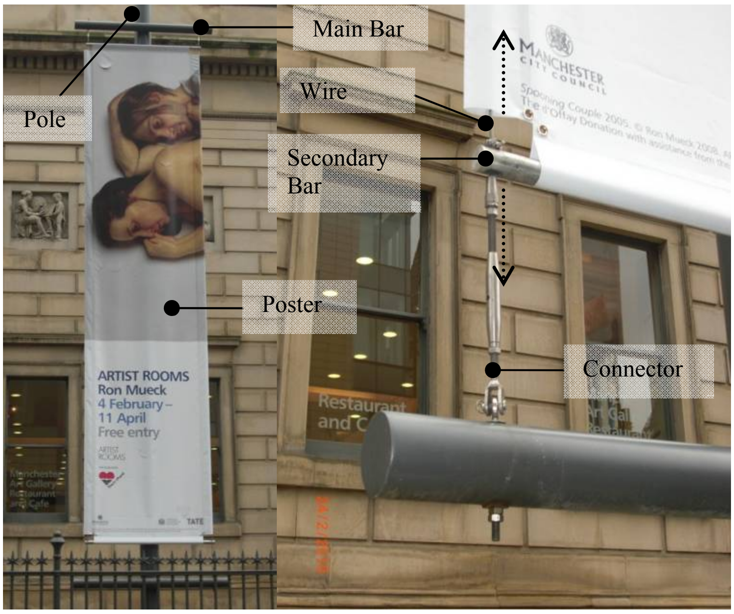

Figure 8: Stretched Poster (Left)

Here, the poster is supported using metal wires that span it vertically, whilst supported on secondary metal bars that span it horizontally, which in turn are supported on the main metal bars top and bottom; the main bars are held by the pole. Using the screw mechanism, the wires that run along the poster are tightened: they are pre-tensioned. In addition, the screw mechanism tightens the grip on the horizontal (secondary) bars that run along the poster at its top and bottom, resulting in a uniformly distributed force pulling the poster up and down. Therefore, the compressive force due to self-weight and the reaction of the poster to stretching are counterbalanced and a resulting tensile force exists within the cable and the connection to the main bars. This pre-stressing counterbalances the effects of lateral loads (wind) as it does not sag. In case where the wire was let in its free state and the metal bars were not tightened on the connections, the banter would rock with the effects of the wind whilst sagging, just like a flag.

Figure 9: Rocking Hammock

As any other hammock, for this portable unit to have any functionality, one must be able to lie on it whilst the hammock remains stable supporting ones mass. In order to achieve this, the fabric is tensioned (pulled) and wrapped around the metal beam at the edges. The fabric has a pre-tensioning force within; the force resulting from the mass is applied vertically, resulting in forces that act opposite to the pre-tension forces. The balance is such that the mass remains suspended on the fabric, whilst the fabric is tensioned. The pre-tensioning means that the overall resulting forces on the member are much smaller. In any case where the fabric was not pre-tensioned, the mass would sink when applied.

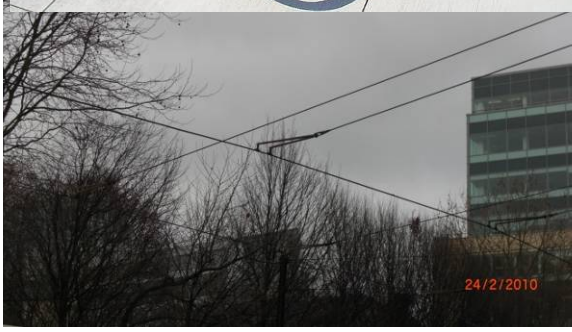

Figure 7: Tram Cables

The cables needed for the trams of Manchester to operate are suspended from poles and from other cables that in turn are supported on buildings nearby. The whole arrangement works by pre-tensioning the cables so that they can remain suspended. Cables are not able to withstand compressive forces so they must be tensioned. In this way wind loads do not affect the cables. If pre-tensioning did not exist, the cables would be let free to rock about

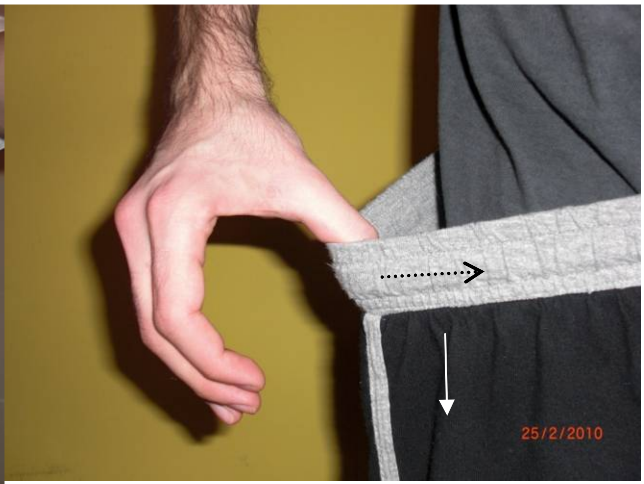

Figure 10: Clothing Examples
Pre-tensioning clothes is a concept widely used every day. As seen at the top, some clothes such as sweat-pants have elastic cords running around the hoop to tighten around ones thighs. The belt used in pants has a similar application. If the pre-tension did not exist, the effect of the elastic cord and the belt would not apply and the pants would not hold up.

Braces are another example of pre-stressing in clothing. They are place on the front and back of the pants, running through ones shoulders. The result is an expansion of the braces which now are in tension. The grip on the pants and the fact that the braces run through the shoulders results in a pre-stressing force within the braces which, ultimately, resists the downward force of the weight of the pants. In other words, the braces have a tendency to compress before they are loaded (tensioned). The point where the forces balance is the point where the pants rest.

Bibliography

1. Nilson, Arthur H. [1987]. *Design of Prestressed Concrete*. Massachusetts, USA: John Wiley & Sons.

2. Structural Concepts Website: [http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/]; cited: 24th February 2010.

3. Photographs and Videos of Dome Tent and Poles: Black's Outdoors, Deansgate; cited: 24th February 2010.

4. Photographs in Figure 9: [http://www.backyardcity.com/images/wti/Rocking-Hammock-1.jpg]; cited: 24th February 2010.

5. Photographs in Figure 10: Home; cited: 25th February 2010.

6. Photo in other Figures: Manchester City Centre; cited: 24th February 2010.