Prestress In Tied Arches

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The concept

Prestress is the method of inducing a stress in a structural element to enhance its loading capacity. Prestress is usually induced in a material that has a high compressive strength in relation to its tensile strength, so that the member is kept in compression and the loading capacity is maximised. The method usually involves threading steel cables through concrete members and tensioning the steel at each end to compress the concrete. The method can be used on a more global scale through, for example, the tensioning of large and slender arches, by joining the ends with steel cables.

The model

The prestress concept can be demonstrated with a very simple model using just a ruler, string, some blue tack and a set of weights. A ruler is used to span between two supports and a weight is applied. As can be seen, the weight causes a deflection that would be considered unacceptable in engineering. However, to increase the strength and hence reduce the deflection of the ruler, a string is attached at each end and a weight hung from it. The string is brought into tension, which causes the ruler to change to an arch shape. When a load is applied to the arch, there are both vertical and horizontal forces at each end. The chairs provide a vertical reaction while the string provides a horizontal reaction. Now, over twice the original load can be applied without any noticeable deflection, all because a string is keeping the ruler in an arch. The blue tack is used just for lateral stability.




Fig. 1: A ruler spanning between two chairs; **Fig. 2:** A load applied causing major deflection; **Fig. 3:** A tied arch using string and a weight to produce tension; **Fig. 4:** The ruler now holds twice the original

weight with no apparent deflection. The blue arrows show compression, the red arrows show tension and the green arrows show vertical reactions.

The everyday object

The bicycle wheel is a very apt example of prestress in everyday life. The wheel is comprised of a rim, a hub and a number of spokes. On its own, the rim would deflect inwards at the top and bottom and outwards at the sides under load. In order to reduce deflection, the rim is stiffened by adding spokes, which connect the rim to a central hub. The spokes are then tensioned using a spoke wrench, which draws the spoke into a threaded hole in the rim. Now, when the wheel is under load, the rim does not deflect outwards at the sides as the pre-tensioned spokes resist the horizontal forces.

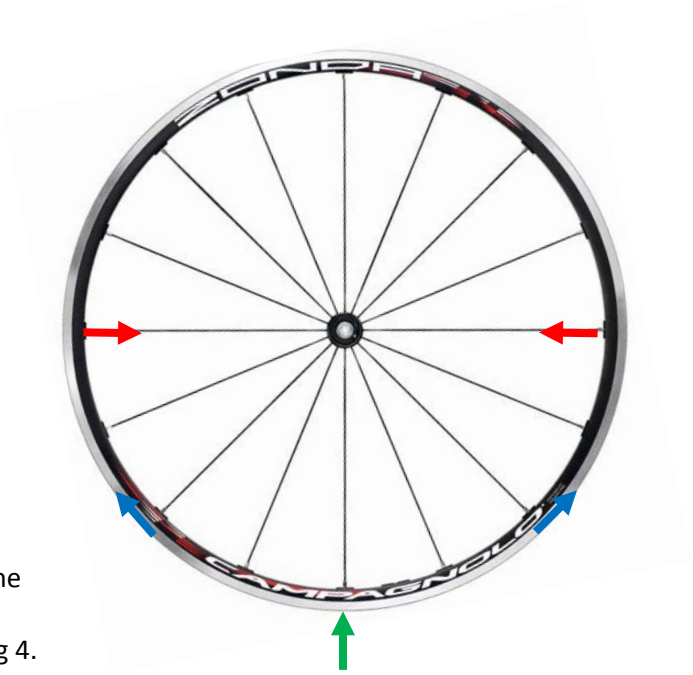

Fig. 5: A bicycle wheel showing the actions and reactions as in Fig 4.

The structure

The Lupu Bridge, spanning 550m over the Huangpu River in Shanghai, China is the world's longest arch bridge, and is a perfect example of prestress in structural engineering. Because of the length, the deck would not stand up on its own, so an arch was constructed to hold the deck in place. This posed problems because of the very soft soil on the riverbanks. The arch would tend to spread outwards under load as the soil would not be able to resist the movements. The designers decided to place eight steel cables running along the deck, connecting the ends and creating a tied arch. The horizontal forces are now primarily taken by the cables, allowing a very slender and elegant structure to be created.

Fig. 6: The Lupu Bridge in Shanghai, China – an example of prestress.

References

Fig. 5: http://www.wiggle.co.uk/images/campag-zonda-wheelset-zoom.jpg
Fig. 6: http://www.jinliansteel.com/upload/zhanshi/2009317109232201327.jpg