Smaller Internal Forces Example: Alloz Aqueduct

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Concept:

By reducing the internal forces in a structure, the structure becomes stiffer.

Structure:

The Alloz Aqueduct is an aqueduct in the northern Spanish region of Navarre, 25km south west of Pamplona.

The aqueduct crosses the River Salado, a small river known locally for its high salinity. To prevent water contamination an aqueduct was built spanning 1340 feet or just over 400m designed by a famous Spanish engineer called Eduardo Torroja.

Figure 1 - Alloz Aqueduct

A major design factor with aqueducts is seepage, causing structural damage and loss of flow. For this particular project economy was also a major design issue, due to the economy of post civil war Spain. Torroja's task was to design a structure that satisfied the economical constraints and was as efficient as possible.

Torroja designed a simple structure as seen in Figure 1. It involves post-tensioned, u-shaped, concrete channels supported by two-pronged forks. The span between successive supports was 62 feet or just under 20m. The design incorporates the two main design factors with these supports.

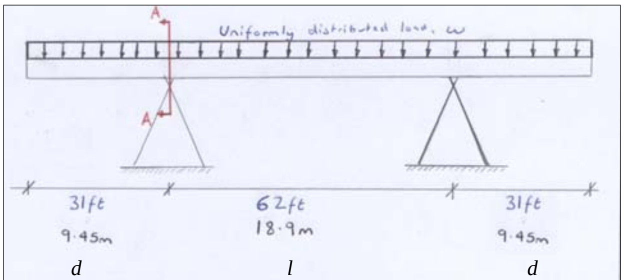

Figure 2 – Simplified side elevation of Aqueduct

As can be seen in Figure 2 the aqueduct was constructed in sections 124 feet long or just over 37m. The two supports are arranged so that in essence each section is a simply supported beam with two overhangs at each end, each half the simply supported beam span, essentially an overhang:span:overhang ratio of 1:2:1. This decreases the bending moment in the viaduct, hence making it stiffer and less material is needed. This can be proved for any equally distributed load as with a steady flow in an aqueduct:

Moment at centre span of simply supported beam (maximum bending moment):

$$M_{\max} = \frac{1}{8}\omega.l^2$$

Moment at support for an overhang of a simply supported beam:

$$M_{\sup port} = -\frac{1}{2}\omega.d^2$$

If $d = \frac{l}{2}$

$$M_{\sup port} = -\frac{1}{2}\omega.\left(\frac{l}{2}\right)^2 = -\frac{1}{2}\omega.\frac{l^2}{4} = -\frac{1}{8}\omega.l^2$$

Hence the bending moment at the centre of the span between supports is:

$$M_{centre} = M_{\max} + M_{\sup port} = \frac{1}{8}\omega.l^2 - \frac{1}{8}\omega.l^2 = 0$$

Hence in Torroja's viaduct there is no positive bending moment but only negative as shown in Figure 3.

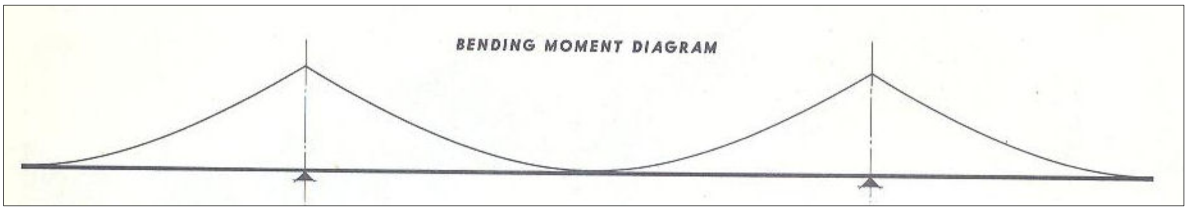

Figure 3 – Bending Moment diagram over a single section of the viaduct

This aids the structure in two ways. The channels are in tension over their entire length. This suits the design as each channel section has post-tensioned steel cables running through the top edge of the channel, as seen in Figure 4. This is where the tension in the channel is highest. Seepage in concrete viaducts is usually caused by tension cracks in the bottom of the viaduct. If there is no tension in the bottom of the channel, seepage is more unlikely.

If the maximum bending moment lies over the support this means the reinforcement can be increased over the support and decreased in the centre span. Torroja used 4 post-tensioned cables over the supports and 2 in the centre span, using less steel.

The self balancing overhangs cause the viaduct to be stiffer and more efficient in its function and as a structure. Torroja reports no seepage occurred over the entire length of the viaduct. The deflections of the spans, potentially damaging to gravity driven water flow, are rendered negligible by the overhangs.

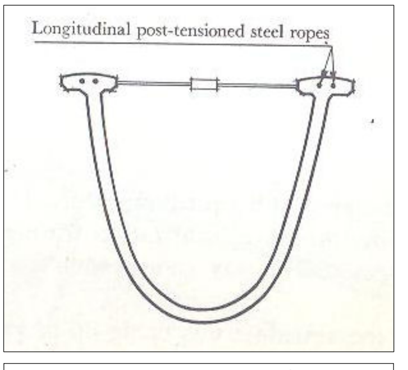

Figure 4 – Section A-A of Channel

References:

Figure 1 courtesy of Structurae.de found at http://en.structurae.de/photos/index.cfm?JS=52586. Picture taken by Yoshito Isono.

Figure 3 and 4 from Page 60, *The Structures of Eduardo Torroja*, Eduardo Torroja 1958

The Structures of Eduardo Torroja, Eduardo Torroja 1958

Seeing and Touching Structural Concepts, Tianjian Ji and Adrian Bell, 2008

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