Indestructible bridges could be reality

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A bridge demonstrating the optimal arch. Credit: Professor Wanda Lewis

A new generation of indestructible bridges could be possible, thanks to research from the University of Warwick.

Emeritus Professor Wanda Lewis in the School of Engineering has taken a design process called 'form-finding', inspired by the natural world, to another level.

Form-finding enables the design of rigid structures that follow a strong natural form - structures that are sustained by a force of pure compression or tension, with no bending stresses, which are the main points of weakness in other structures.

This could, for the first time, lead to the design of bridges and buildings that can take any combination of permanent loading without generating complex stresses.

Such structures will have enhanced safety, and long durability, without the need for repair or restructuring.

For 25 years Professor Lewis has been studying forms and shapes in nature: the outlines of a tree or a leaf, the curve of a shell, the way a film of soap can suspend itself between chosen boundaries. In all of these natural objects, Professor Lewis observed that they develop simple stress patterns, which help them to withstand forces applied to them (such as wind hitting a tree) with ease.

Professor Lewis has been developing mathematical models that implement nature's design principles and produce simple stress patterns in structures. The principles behind her mathematical models are illustrated using physical form-finding experiments involving pieces of fabric or chains, for example.

A piece of fabric is suspended, and allowed to relax into its natural, gravitational, minimum energy shape; then that shape is frozen into a rigid object and inverted. She finds the coordinates of this shape through computation by simulating the gravitational forces applied to the structure. This produces a shape (a natural form) that can withstand the load with ease.

Professor Lewis argues that "nature's design principles cannot be matched by conventional engineering design."

While classical architectural designs are appealing to the eye, they aren't necessarily structurally sound: "aesthetics is an important aspect of any design, and we have been programmed to view some shapes, such as circular arches or spherical domes as aesthetic. We often build them regardless of the fact that they generate complex stresses, and are, therefore, structurally inefficient," says Professor Lewis.

The question of how to build the optimal arch has been argued through history. In the seventeenth century, Robert Hook demonstrated to the Royal Society that the ideal shape of a bridge arch is that resembling the line of an upside down chain line - the catenary form. The only other form proposed by classical theory is the inverted parabola. Each of these shapes can only take a specific type of load without developing complex stresses, which are points of weakness. Professor Lewis' pioneering 'form-finding' process fills the gap in classical theory, offering a new mathematical solution in the pursuit of the optimal arch subjected to general loading.

The work on discovering the optimal arch has been published in the *Proceedings of the Royal Society A*.

More information: W. J. Lewis, Mathematical model of a moment-less arch, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science* (2016). DOI: 10.1098/rspa.2016.0019

Provided by University of Warwick