Design Revolutions

By Jon A. Schmidt, P.E., SECB

In the May 2009 issue, I summarized several key ideas from William Addis's book, *Structural Engineering: The Nature of Theory and Design*. This month, I would like to share some additional thoughts from the same text, specifically regarding the history of engineering science and how it relates to the history of structural engineering practice.

The typical approach to these subjects is to focus on the developments that served as stepping stones to today's understanding. As a result, concepts that are now known to be "incorrect" are often overlooked or simply ignored, even though they were quite useful at one point in time. This leads to the common assumption that a sharp distinction must be made between how engineering was done before and after it became "grounded" in science. The problem is that different historians assign different timing to this alleged transition – from as early as the 16th century to as late as the mid-1800s – and whatever date we use, we implicitly devalue the engineering achievements of earlier ages.

Addis believes that this way of thinking is mistaken. He advocates applying to the history of engineering the insights of Thomas Kuhn into the history of science, as published in his landmark 1970 book, *The Structure of Scientific Revolutions*. Kuhn suggested that, rather than maintaining a slow and steady pace of continuous progress, scientific development proceeds in two radically different modes:

- "Normal science" happens during periods when the scientific community shares a dominant "paradigm" consisting of "beliefs, aims, theories, textbooks, vocabulary, experimental apparatus and procedures, and the very research problems themselves."
- "Scientific revolutions" are triggered when anomalies – new phenomena that do not "fit" within the current paradigm – accumulate until "a radical new way of looking at the world" is proposed and, eventually, adopted.

Addis first shows how this kind of pattern is evident in the history of engineering science, most notably with respect to the bending of beams, and then goes on to explore various "design revolutions". As he is careful to point out, they are not necessarily associated with corresponding revolutions in engineering science; in fact, some of them happened long before "engineering science" even existed as a defined discipline. Examples include:

- The ancient Greeks "made use of numbers, simple proportions and geometry" to create "rules based on precedent in nature, especially on the 'design' of the human body." The straightforward Doric and more complex Ionic orders differed not only in appearance, but also in how the various parts of a structure related to one another.
- Gothic cathedrals sprang up quite suddenly in 12th century France. The secretive trades responsible for their planning and construction developed clever techniques for describing and justifying their designs, such as using circles to generate various arch profiles and rotating squares to create different tower plans.
- Trusses were originally conceived as little more than beams propped by diagonals rising from each end support, and even cross-braced and lattice trusses were initially modeled as beams of similar overall dimensions. Some designers used truss members to stiffen arches, and others used arches to stiffen trusses. The familiar simplification of assuming all pinned joints and only axial forces in each member did not come along until the middle of the 19th century.
- Plastic design emerged in the United Kingdom in the 1930s largely because of a growing dissatisfaction within the structural engineering community of that country with the elastic methods that had been employed for the previous hundred years or so. Efforts to "improve" existing specifications only resulted in more complexity – a phenomenon well-known to us today. The solution did not become apparent until someone was able to look at the problem in an entirely different way. Of course, here in the United States, the corresponding "paradigm shift" – from ASD to LRFD – is still in progress.

The notion of design revolutions is yet another way of acknowledging the non-deterministic aspect of engineering in general, and structural engineering in particular. The same kind of outside the box thinking that we use to conceive unique solutions to our clients' specific problems can help us occasionally take a new look at ourselves and how we do our jobs in general. A major failure is not necessary to prompt a change in paradigms; as Addis notes, "some of the most significant revolutions in engineering design have come about by careful thought and testing by means of experiment." After all, design procedures are human inventions that must be "engineered" – and, from time to time, "re-engineered" – to suit the ever-evolving needs of our profession and our society.▪

Your Turn Do ancient structures, such as the pyramids, qualify as great engineering feats, despite the lack of "scientific" understanding on the part of those responsible for them? What are some additional examples of design revolutions in the history of structural engineering? Besides the shift from ASD to LRFD, and perhaps the transition to BIM, are there any underway right now? Please submit your responses and see what others have had to say by clicking on the "Your Turn" button at **www.STRUCTUREmag.org**.

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