You Can Never Know Too Much

Learn why "we've always done it that way" isn't a good basis for engineering decisions.

BY R. SHANKAR NAIR, PH.D., S.E., P.E.

R. Shankar Nair is senior vice president of Teng & Associates, Inc. in Chicago. He is a member of the United States National Academy of Engineering and a recipient of AISC's Lifetime Achievement Award.

CONSIDER THE STORY OF CHRISTOPHER COLUMBUS'S DISCOVERY OF AMERICA. Contrary to what generations of schoolchildren have been taught, Columbus was not out of step with the conventional wisdom of his time in believing that the earth was round. Most European navigators and geographers in the late fifteenth century knew that. They also knew that Asia was out of reach by sea to the west: The range of a ship in those days was about 3,000 miles, and the distance to Asia was much longer than that. Columbus, however, was a bad geographer. He calculated the distance to Asia as 2,500 miles, which placed it within reach, and he persuaded a royal patron that he was right and everyone else wrong. So he sailed west to Asia and stumbled on the New World.

There may be a lesson in this for engineers. I am not suggesting that we should practice engineering by serendipity. Rather, the lesson is that being successful is not the same as being right. Columbus succeeded but he was wrong, twice over: He was wrong in that he did not know there was another continent between Europe and Asia, and he was wrong about the distance to Asia. He shared the first mistake with his contemporaries but the second was uniquely his. The two mistakes together led to his success.

One cannot leave the Columbus story behind without a small detour into the issue of who (other than the indigenous population) really discovered America. Yes, it is possible, indeed likely, that Scandinavians and maybe even Chinese visited America before Columbus did, but it was Columbus's voyage that set in motion the colonization of the New World by Europeans and the creation of America as we know it. So in terms that really matter—that is, in engineering terms—Columbus discovered America. Possible earlier visits by others are little more than historical curiosities.

The examples of success through compensating errors in engineering are many. So it is important that we not assume that just because something works, or worked in the past, it is correct. This message came home to me recently when I was studying the evolution of the skyscraper.

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The first skyscraper, the 10-story Home Insurance Building in Chicago, was built in 1885. In just 28 years, skyscraper technology progressed to the 60-story Woolworth Building in New York. And in 1931, just 46 years after the first skyscraper, we had the Empire State Building.

This upward progress, with a doubling of building height about every 15 years, was brought to a sudden halt by the Depression, which had already begun when the Empire State Building was completed (leading to jokes about the Empty State Building). The Depression was followed by war and tall building construction did not start up again in any strength until the 1950s, after a quarter-century interruption.

As it turns out, it was a good thing skyscraper construction came to a halt in 1931, for the structural design of that first generation of skyscrapers—from the Home Insurance Building to the Empire State Building—was wrong.

Most of these were "portal frame"-type structures that depended on rigid beam-to-column connections for lateral stability and resistance to lateral load. And most or all of the columns, interior and exterior, were part of the lateral load-resisting system. There is nothing wrong with this concept, but we know now that the beam-to-column connections were actually far from rigid. And a comprehensive analysis of the structural frame of almost any first-generation skyscraper using today's technology (including accurate modeling of connection flexibility) would reveal several deficiencies: The design wind load was much too low, the frame is deficient in lateral stiffness, and column axial forces due to wind are completely different from what the designer anticipated.

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But these buildings are still safe, for two main reasons. First, the partition wall construction of the time added considerable stiffness and damping to the structure. Second, the weight of the walls, cladding, and floor systems was so great that column design was controlled by gravity loads—it didn't matter that the calculated wind-induced column forces were wrong.

But imagine what might have happened if the first-generation buildings had continued to double in height every 15 years, without the interruption caused by economic depression and war. It would not have been long before the errors in the design overwhelmed the compensating factors. (And when lightweight partitions and floor systems came into use, the compensating factors would have disappeared altogether.) There may not have been a collapse, but we almost certainly would have seen an unserviceable skyscraper, with grossly excessive lateral deflections and movements due to wind.

This disaster was prevented by the quarter-century hiatus in tall building construction after 1931. By the time tall building construction resumed, engineers knew of the defects in first-generation skyscraper technology and had the tools to do better. The first post-World War II building to approach half the height of the Empire State Building was the Torre Latinoamericana, completed in 1956 in Mexico City. This was a correct structural design by almost any standard, completely different from that of the first-generation buildings. The seismic design was by Nathan Newmark, and it has survived two major earthquakes with essentially no damage.

The building profession was not always so fortunate as to have its march toward disaster halted by an external event. The history of construction is replete with examples of technology that "worked" for a time, though it was wrong, and then failed catastrophically.

The Gothic cathedrals of Europe are magnificent and inspiring structures, but their designers really didn't know how they worked, even after hundreds had been built over a period of centuries. We know now that while the designs were generally very conservative, there were elements that were marginal. So when a designer stepped out of the box of what had been done before, or when conditions changed in ways that he did not understand, the result could have been disastrous. Witness the multiple, serial failures of the cathedral at Beauvais, all caused by design mistakes that no competent structural engineer would make today.

Bridges—which are pure structures in a way that buildings aren't—were not immune to this syndrome. One of the worst bridge failures was that of the Tay Rail Bridge in the United Kingdom in 1879. Surprisingly (to us today), it failed not because it could not handle the railway loading but because of wind load. Bridge designers had paid little attention to wind loading until then, and for "typical" bridges this had not got them in trouble. On the unusually tall Tay Bridge the oversight proved fatal.

Structural design today is rational in a way that it wasn't a few generations ago. Given enough time and resources, we could use the basic principles of physics and engineering to design any structure to any required level of safety and reliability. It would, in fact, be possible, though certainly not practical, for a building code to state simply that structures shall be designed and constructed such that the probability of failure (perhaps defined in various different ways) is not greater than X per year or Y over the anticipated life of the structure. The rest would be up to the designer.

Of course, in the real world, time and resources are not unlimited. And so we use codes and standards and specifications that provide standardized loadings and relationships between design variables and structure capacity or behavior, all directed at attaining the required level of safety and reliability without the engineer having to work out the entire design from first principles. And as researchers discover new modes of failure and aspects of behavior, the codes and standards and specifications get longer and more complicated. (The first AISC specification was 13 pages long.)

The ongoing refinement of design specifications makes some engineers very unhappy. Indeed, any time a new specification provision is proposed there will be someone who asks: Where are the buildings that have fallen down for want of this provision? But that is the wrong question. Any change that reflects a better understanding of how structures behave is to be welcomed. History teaches that ignorance masked by past success cannot be relied upon to remain dormant; it can jump up and bite someday. We cannot assume that we will always be lucky, like Columbus, and that all our mistakes will be cancelled out by other offsetting mistakes.

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But there is hope for those who long for shorter specifications and fewer rules. Most specification provisions today are intended to compensate for limitations in our methods of analyzing structures. Specifications grow as we learn more about structure behavior; they can shrink as more aspects of behavior are captured by our methods of analysis. At present there are only a few hints of this shrinkage (as in simpler stability design provisions applicable when more advanced analysis techniques are employed), but it is happening, and it will accelerate. And we can all look forward to the day when we know so much and analyze structures so well that codes and specifications will merely spell out standards for safety and reliability. MSC