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Working With Uncertainty …

There is a common perception that structural engineers are no-nonsense professionals living in a black-and-white world. With great precision, they solve problems that have but one correct answer. This is not entirely accurate. Here is an artfully-crafted definition that you have probably never seen:

> ***"Structural engineering is the art of molding materials we do not wholly understand, into shapes we cannot fully analyze, so as to withstand forces we cannot really assess, in such a way that the community at large has no reason to suspect the extent of our ignorance."***

Versions of this definition have been circulating within the structural engineering community for nearly fifty years. While identification of the author remains something of a mystery, the terms "we" and "our" reveal that the writer was a structural engineer. The definition is both humorous and humiliating, yet it endures because it reveals certain truths. This can best be illustrated by example.

Materials we do not wholly understand: Archeologists have discovered concrete in the ruins of ancient cities dating back to 6500 BC. Way back then, concrete cracked. Now, more that 8,500 years later, concrete still cracks. There are many reasons for this and structural engineers generally understand all of the reasons. In mainstream design practice, they can usually limit the severity of concrete cracking. However, they can rarely eliminate it. Reinforced concrete has been used since 1848. Reinforcing with deformed steel bars (rebars) greatly improves concrete strength: rebars are strong in tension, while concrete is strong in compression. Rebars often need to be spliced to reach full design length, but minimum splice lengths remain elusive after more than 150 years of research and practice. Fifty years ago, the code addressed splices in a single page. The criteria were simple: minimum splice lengths ranged from 20 to 36 rebar diameters depending on rebar strength and location. Today, the code addresses splices in 30 pages. The criteria are complex, and they continue to change every few years with each code revision.

Shapes we cannot fully analyze: Before computers, structural engineers would analyze structures assuming the connections between beams and columns were either rigid or pinned, based on the relative amount of rotation expected in each joint. These assumptions were necessary to meet the limitations of classical analysis techniques. Even with the powerful computer analysis methods available today, however, these limitations generally persist in mainstream design practice. Nearly all connections are actually semi-rigid, meaning that some joint rotation takes place, but this is usually addressed only in research.

Forces we cannot really assess: Structural engineers design for a host of loads and load combinations. The most enigmatic loads are those caused by environmental conditions. For the most part, structural engineers use static approximations for the forces due to dynamic phenomena like wind, snow, and earthquake. Fifty years ago, the code addressed loads in just a few pages and the criteria were simple. For example, wind pressures were usually 20 pounds per square foot. Today, the code addresses loads in a 608-page document. The criteria for wind are complex and require 117 of those pages. The code continues to evolve with frequent revisions, and structural engineers strive to follow all criteria to the letter. The same cannot be said of Mother Nature.

The extent of our ignorance: Before computers, structural engineers used slide rules for all of their calculations. This limited their results to three significant figures. They rationalized that this was more than sufficient, because they knew that their incomplete understanding of materials, shapes, and forces did not justify higher accuracy. To assure safe design, the code incorporated various factors of safety. Computers now provide calculations with very high precision. Fortunately, most structural engineers continue to think in only three digits, realizing that much remains unknown. To assure safe design, the code now incorporates load and resistance factors, an improved approach to the older factors of safety. This allows structural engineers to acknowledge their ignorance, appropriately address it, and continue to produce economical and timely designs that place public safety ahead of all other concerns.

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