Art of Approximation

By Dilip Khatri, Ph.D., P.E.

Measure the distance between two points using a ruler, and you may read "12 inches." This implies that the relative accuracy is to the nearest inch. If I write "12.00 inches," then this implies accuracy to nearest 1/100th of an inch. For a foundation, the accuracy of ± ½ an inch may be appropriate. The tools of that construction trade do not have a high level of precision (i.e., a backhoe, shovel, or excavator). In contrast, for an Aircraft Wing on a fighter jet, the accuracy may be measured in Mills (0.001 inches) or 1/1000th of an inch. Understanding the level of accuracy required for a given task involves familiarity and judgment.

Structural Engineers approximate wind and earthquake loads based on data provided by seismologists, then use factors of safety on materials to design buildings that will hold our world's inventory for an unknown period of time, giving our client's a vote of confidence that will assure their tranquility. We represent the trust of society, the honor of integrity, and are responsible for millions of people's lives because our structures store their memories, house their loved ones, and transport the world's treasures across the nation's highways. At both the beginning and the end, it is all based on approximation because engineering is a system of approximations, based on judgment, experience, and past errors that become lessons learned.

Where can a young engineer learn such skills? The first way is to learn from interaction with experienced engineers. Another way is to spend time on construction sites familiarizing oneself with the tools, fit-ups, and methods of the workers. When in doubt, review drawings produced by others and recommended tolerances for construction such as those in ACI 117 or AISC 303. The best learning experience for young engineers is to get construction experience. Work on something "real," build "stuff," get your hands dirty, and immerse yourself in the trades before becoming an "office junky." You will experience how the paper design turns into a real structure.

Masters level students now graduate with extensive training and theoretical background on Finite Element Methods. Feats of analysis that were impossible in earlier generations are now done in matters of seconds using powerful software, hardware, and sophisticated algorithms. No doubt, impressive progress from this author's days when the PC was just emerging on the horizon, and the first four-function calculator was being sold for $100. However, how can we teach the "common sense" and "engineering judgment" to guide us in design, and know that the answers provided by the software are right?

Teaching our engineering students about Strain Energy Density, Non-Linear Dynamic Analysis using the Galerkin Method, Bete Reciprocal Theorem, Heisenberg's Uncertainty Principle, Fourier Transform, Jacobian Matrix, and the Duhamel Integral Formulation are useful tools for engineering analysis. But where's the judgment? Universities cannot teach it because it is not really from textbooks and you cannot learn it from Timoshenko's Treatment on Plates and Shells. You have to "live it" and learn through osmosis with experienced engineers in the profession who have designed many structures over many years.

The profession of Structural and Civil Engineering deserves its own School to match that of other professions: Dentistry, Medicine, Architecture, and Law. We need a practice degree at the Master's Level that is a "Master of Structural Engineering" that teaches Structural Engineering Design and is *taught by Professional Structural Engineers from industry*. These teachers can introduce students to "Instinct," the Engineer's ability to see the structure perform in the extreme event and foresee the failure before it happens, then intuitively design for it so that it does not happen. They can teach scale, both in terms of proportions of members and the production of drawings which describe the structure.

They can teach Judgment, the "common sense" to "feel" the right answer. Yes, "feeling" whether an answer is right is also part of the engineering experience. Our judgment matters because an undersized footing will lead to a sinking building, an over-reinforced concrete roof system will cause sudden collapse when overloaded by snow, and a poorly designed bridge truss will lead to hundreds of deaths. These are skill sets that are best conveyed by practicing engineers or those with extensive design experience. Practicing Engineers have this wealth of experience, accumulated through years/decades of toil working with construction contractors, owners, building departments, and perhaps lawyers on projects that went well, wrong, sideways, and sometimes won an award. All of this matters, because Wins and Losses are both learning experiences that should be shared. Classroom learning is limited to textbooks, charts, tables, graphs, and research papers. There is a boundary to your educational envelope when you limit your circle to only Ph.D. level educators, and you lose the perspective of the real world.

Research is still essential, as are tenured Ph.D. professors, grants, publications, and experimental testing of components and systems. Our profession is being asked to stamp and qualify older structures with retrofit systems that are unproven and be even more economical with designs. We need researchers to help bridge the gaps in our understanding, but we also need them to understand that their students need us too.▪

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