What Structural Engineers Know

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

In the November 2007 issue, I discussed the nature of engineering knowledge and contrasted it with scientific knowledge, noting that neither can be equated with certainty. This month, I would like to examine the types of knowledge that are commonly used by engineers in general, and by structural engineers in particular, in the course of practicing their profession.

My title comes from a book by Walter G. Vincenti, *What Engineers Know and How They Know It* (Baltimore: The Johns Hopkins University Press, 1990). Vincenti used several significant examples from the history of his own discipline, aeronautical engineering, to support his thesis that technology is "an autonomous body of knowledge, identifiably different from the scientific knowledge with which it interacts." He went on to identify six specific categories of engineering knowledge:

- *Fundamental design concepts* – the operational principle of a device and the normal configuration that is commonly agreed to embody it best.
- *Criteria and specifications* – the specific, quantitative objectives for a device that have been derived from its general, qualitative goals.
- *Theoretical tools* – mathematical formulas or calculative schemes, whether grounded in nature or based mainly on successful past experience.
- *Quantitative data* – universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety, etc.
- *Practical considerations* – information learned mostly on the job and often possessed unconsciously, rather than in codified form.
- *Design instrumentalities* – procedures, ways of thinking, and judgmental skills by which the process is carried out.

Vincenti acknowledged that these are not necessarily exhaustive, and noted that there is considerable interaction and overlap among them.

Two professors at Stanford University, Diane E. Bailey and Julie Gainsburg, went on to apply this framework specifically to structural engineering and reported their findings in a 2003 paper, "Knowledge at Work". A copy of "Knowledge at Work" can be found at: (**http://siepr.stanford.edu/programs/SST_Seminars/Bailey_Gainsburg_-_SECOND_DRAFT.pdf**).

They studied three relatively small firms in the San Francisco Bay area that specialized in seismic upgrades, tilt-up construction, and multi-story steel commercial buildings, respectively. Based on their observations, they renamed two of Vincenti's categories – criteria and specifications became *structural systems criteria*, while practical considerations became *rules of thumb and estimates* – and named four additional ones:

- *Appropriate structural elements* – satisfaction of constraints with the selection of particular components.
- *Construction feasibility and ease* – solutions that not only satisfy codes and theory, but also can be built economically.
- *Organization of work* – project management, including the sequence and timing of individual tasks.
- *Engineering politics* – interacting with external parties (e.g. client, architect, other engineers, contractors) and understanding how they do their jobs.

I would argue that these "extra" domains of knowledge could easily be folded back into Vincenti's original scheme – appropriate structural elements are a subset of criteria and specifications, construction feasibility and ease is a practical consideration, and both organization of work and engineering politics constitute design instrumentalities.

In any case, Bailey and Gainsburg used the data that they collected to develop three separate profiles of structural engineering knowledge, each one covering four different project phases: schematic design, design development, contract documents, and construction management. The first profile shows the frequency with which engineers employed knowledge in each of the ten categories. The second breaks down the nature of the knowledge displayed into five types: technical, procedural, social, visual, and financial. The third indicates how much of the observed knowledge was historically established vs. practice-generated.

The results are not especially surprising. The first three phases are dominated by design instrumentalities, appropriate structural elements, and fundamental design concepts, while engineering politics increases over time and is most common during construction. The majority of engineering knowledge is technical, and some is procedural, with relatively little being social, visual, or financial. And more than 70% of engineering knowledge across all phases is practice-generated, rather than historically established.

However, it would be a mistake to conclude, on the basis of this research, that formal education is not terribly important for a structural engineer. As Bailey and Gainsburg point out, learning historically established knowledge "in many senses constitutes the price of admission to the workplace... Familiarity with [it] in all its forms is prerequisite to any further learning that might happen in the course of practice; it serves as the foundation for work." At the same time, "The depth and breadth of [it] in structural engineering no doubt help explain why all such knowledge cannot be conveyed in a four-year university program."

I believe that the observations of Bailey and Gainsburg are highly relevant to both practitioners and academics who are interested in shaping the purpose and content of the structural engineering curriculum in the future. A better understanding of what we know and how we know it should facilitate improvements in how we impart it to each successive generation.▪

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