Engineering Models

By Irfan A. Alvi, P.E.

Generally speaking, structural engineers first gain confidence that we can know the true behavior of structures during our engineering education, when we become exposed to the sophisticated and beautiful theories of structural mechanics. But as we progress to design, we notice overt approximations being made for loading conditions, distribution of loads through structures, material behavior, ultimate strengths, etc. Evidently, *models* are being used; in fact, our interactions with reality are always mediated by models. These models may be conceptual, mathematical, computational, or physical; regardless, all such models are simplifications of reality, serving as incomplete and approximate representations. To reduce the extent of this simplification and distortion, a potential strategy is to make models more complex. However, complexity provides no guarantee of accuracy and can sometimes even backfire, since more complexity also means more things that can go wrong. By contrast, the principle of Occam's razor advises that we should "keep it simple," which supports using simpler models. Clearly, balance between simplicity and complexity is needed, tailored to fit each situation.

This highlights the fact that our models are developed and used for diverse *goals*, such as explaining structural behavior, developing intuition, instructing in academic and professional settings, predicting particular structural behaviors, designing structures, and experimenting and collecting data. Such diverse potential goals make it clear that there will rarely be a single model that is always best for a given structure. Instead, a variety of models can typically be developed to serve particular goals; and, if there are multiple goals, there will likely be tradeoffs in trying to achieve them. These considerations indicate that a model is essentially what Billy Vaughn Koen defines as a *heuristic*: "anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible."

Since models are developed to achieve specific goals, the adequacy of models needs to be evaluated with respect to those goals. For example, a model intended for instructional purposes should be conceptually clear, whereas a model intended for prediction should be quantitatively accurate. As a result, no standard and objective means for evaluating models can be prescribed; instead, judgment is generally necessary. If we do focus on predictive accuracy, because models are always incomplete and approximate representations, we must contend with uncertainty. In that regard, we rarely get feedback on how well our models represent the specific full-scale structures that we have designed. And factors of safety prevent models from truly being "put to the test," so uncertainty remains even after a long history of experience, whether successful or not.

With respect to their origin, models are both discovered and created. On one hand, models are based on objective empirical phenomena and aim to represent them, so discovery is involved. On the other hand, we choose the form and goals of our models, so a creative and subjective element is also involved. In this regard, Herbert Simon noted that humans have "bounded rationality," being subject to limited availability of information, limited cognitive capacity, and limited time to complete tasks. An implication is that, rather than optimizing or striving for "perfect" models, in practice we "*satisfice*," continuing our efforts only until "good enough" modeling results have been achieved, again echoing Koen's idea that models are heuristics.

In a similar vein, Daniel Kahneman and Amos Tversky, among others, have revealed a variety of biases in human cognition which often lead to decisions with suboptimal outcomes. Many of these biases apply to modeling, such as *confirmation bias* (selective emphasis on evidence which confirms a model), *loss aversion bias* (giving irrationally greater preference to avoiding losses as compared to acquiring gains, which can result in excessive model conservatism), *overconfidence bias* (unwarranted faith in one's cognitive abilities, which can lead to overconfidence in models and associated risks), and *recency bias* (using a particular model because it was used recently, despite overall experience supporting a different model). The existence of such biases may be disconcerting, but conscious search for their presence during modeling can at least help to correct for them.

Considering the factors described above, evaluation and validation of models is clearly a challenge. However, some pragmatic suggestions can still be offered, such as: develop and apply a strong understanding of structural mechanics; treat models as "guilty until proven innocent"; explicitly identify, in writing, the assumptions underlying a model and what the model leaves out; evaluate models against your experience, intuition, and judgment, using visualization tools where applicable; to check a model's robustness, perform a sensitivity study, varying parameters around "best estimates" as well as testing what happens when parameters are taken to extreme values; to increase predictive accuracy, average results from multiple diverse models; when using computational models, do not use them as "black boxes"; perform equilibrium checks and test models with simplified load cases; investigate discrepancies between results from different models of the same structure until they can be credibly explained; and, conduct independent peer reviews and checks of models.

Overall, perhaps our most central conclusion is that, due to unavoidable uncertainties, we do not and cannot fully know what we are doing when we model structures. Furthermore, safety factors shield us against structural failure even when our models may be quite faulty, thereby possibly fueling overconfidence. With this in mind, consider reducing safety factors with great caution, only when a clear ability to reduce uncertainty enables extra confidence to be placed in models. Conversely, when modeling atypical structures, or in other circumstances when uncertainty or risk is increased, be ready to increase safety factors and generally apply more conservatism than required by codes. In short, be aware, and be humble!▪

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