Structural Engineering Is More than Just Meeting the Building Code

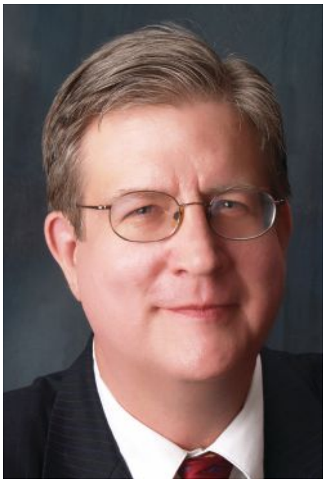
by Dr. William D. Lawson, Murdough Center for Engineering Professionalism, Texas Tech University

EDITOR'S NOTE

This is the latest in an ongoing discussion in ASPIRE® *about what we can learn regarding professionalism and ethics from the collapse of the Florida International University (FIU) pedestrian bridge and the subsequent National Transportation Safety Board (NTSB) investigation. In the Summer 2020 issue of* ASPIRE, *we invited Dr. William D. Lawson to write an article on engineering responsibility, and in that article he included a lengthy quote from Dr. J. Greg Soules on structural engineering judgment. We were very impressed by Dr. Soules's comments and found that every sentence was significant and worthy of further discussion. So, as part of the continuing discussion in* ASPIRE *of the FIU tragedy and what we should learn from it, we invited Dr. Lawson to interview Dr. Soules to expand on the thoughts Dr. Soules had shared. Their conversation is presented here and reflects Dr. Soules's experience, which has been with buildings rather than bridges.*

About Dr. Soules

*J. G. (Greg) Soules, PhD, PE, SE, PEng, is a senior principal structural engineer and the technical authority for seismic and wind engineering for CB&I Storage Solutions, a division of McDermott International, in Houston, Tex. His responsibilities include the supervision of design engineers, management of engineering for large projects worldwide, and development of CB&I Storage Solutions engineering standards on aboveground storage tanks and on the application of wind loads, seismic loads, and building codes to tank and vessel designs. He is the past chair of the Energy Division of the American Society of Civil Engineers (ASCE), current vice chair of the ASCE/SEI 7 Main Committee (*Minimum Design Loads and Associated Criteria for Buildings and Other Structures*), and chair of the ASCE/ Structural Engineering Institute (SEI) National Technical Program Committee for the ASCE/SEI Structures Congress.*



J. G. (Greg) Soules, PhD, PE, SE, PEng

Dr. Soules earned BS, MS, and PhD degrees in civil engineering from Texas Tech University and an MBA from the University of Houston. He is a fellow of the American Society of Civil Engineers, a fellow of the Structural Engineering Institute, a licensed professional engineer in 23 jurisdictions, and a licensed structural engineer in eight jurisdictions. Dr. Soules was presented the Stephen D. Bechtel, Jr. Energy Award by ASCE in 2010. He joined CB&I Storage Tank Solutions in 1980.

Q This interview came about, in part, as a response to your comments quoted in my Summer 2020 Perspective article on the role of engineering judgment relative to the FIU pedestrian bridge collapse. I would like to further explore those themes with you. As we begin, please share some about your technical experience portfolio, types of projects, geographic scope, etc.

A I have been a structural engineer with CB&I Storage Solutions (originally Chicago Bridge and Iron Company) for more than 40 years. In that time, I have designed structures and foundations for the oil and gas, bulk material, water and wastewater, and aerospace industries worldwide. My technical expertise is primarily in the areas of plate and shell structure design and behavior, wind design, and seismic design.

In his "Board Member Statement" on the FIU pedestrian bridge collapse (the statement was reproduced following the Perspective article by Freeby and Nickas in the Spring 2020 issue of *ASPIRE*), NTSB vice chairman Bruce Landsberg states, "A bridge-building disaster should be incomprehensible in today's technical world" and "the science should be well sorted out by now." Does Mr. Landsberg's statement align with your experience? How so?

Unfortunately, Mr. Landsberg's statement does not align with my experience. Most structural failures occur during construction. The commentary (Section C1.3.1) to ASCE/SEI 37-14, *Design Loads on Structures during Construction*, states, "During erection of a structure, the permanent lateral load-resisting system is generally not complete. Also, other elements of the structural system that are essential to the overall performance of the structure may not be in place or may only be partially secured. As such, the structure may be vulnerable to severe and widespread damage should a single, local failure or mishap occur." The determination of construction loads is not always straightforward. Both the structural engineering profession and the construction industry promote innovation, so it is not uncommon for a new structural system or a new construction method to be employed. Because of innovation, the science may not always be well sorted out. In many of these cases, engineering and construction professionals rely on their judgment, which in turn is based on their professional experience. Professional judgment, while a key tool used by engineers and constructors, is not perfect. There is also the human factor to deal with. Humans make mistakes, whether in a design office or in the field. Human error cannot be completely eliminated. Please do not take my comments as excusing incompetence or gross negligence. I am simply pointing out that the individuals who engineer and build structures are not perfect.

Please tell *ASPIRE* readers about ASCE 7, and your role there. In what ways does the ASCE 7 Committee inform and improve structural engineering? To what extent has the FIU pedestrian bridge collapse influenced or otherwise affected the work of the committee?

ASCE/SEI 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, is the primary document used in the United States (and many international locations) to determine loads used in the design of new structures—live and dead loads, wind loads, seismic loads, etc. I currently serve as the vice chair of the ASCE 7 Main Committee for the 2022 cycle. I will serve as chair of ASCE 7 for the 2028 cycle. ASCE 7 is specified for use in the *International Building Code*, which is the basis for virtually every state and local building code in the United States. A few structures, such as bridges, are outside the scope of ASCE 7 because they are covered by other nationally recognized standards (AASHTO for bridges [the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*]).

[Many] structural engineers use ASCE 7 every day. It provides minimum prescriptive loads and requirements for a wide range of structures, but not all structures. Please note that I stated *minimum* loads and requirements. No building code can cover every possibility for every type of structure. We rely on the skill and judgment of professional engineers to supplement the loads and requirements given in ASCE 7 [and other design specifications]. It should also be noted that the structural engineering profession is moving in the direction of using performance-based design. Basically, in performance-based design, the building code will specify the level of performance required and the structural engineer will use his or her knowledge, judgment, and creativity to meet the specified performance goals. This is in stark contrast to our current prescriptive codes that spell out minimum requirements to meet these performance goals, which often stifle innovation and creativity. [See the Professor's Perspective in this issue of *ASPIRE* for additional insight regarding prescriptive and performance-based design.]

The FIU pedestrian bridge collapse, as with any failure, impacts the structural engineers who serve on the ASCE 7 committee. The collapse, however, did not affect the work of the committee. The collapse occurred during construction of a bridge. The scope of ASCE 7 does not include construction loading, nor does it include bridges. As mentioned in a previous response, ASCE 37, *Design Loads on Structures during Construction*, is the standard that addresses loads during construction. This document recognizes that "many elements of the completed structure that are relied upon implicitly to provide strength, stiffness, stability, or continuity are sometimes not present during construction." I chaired the environmental loads chapter (Chapter 6) of this document during the 2014 cycle. The members of this committee take any construction failure to heart and such events do impact the committee's deliberations.

Clearly you possess deep and broad expertise in the structural engineering discipline. From that perspective, please comment on the observation, "When a [structural] engineer 'follows the code,' engineering judgment is already handled and thus does not come conspicuously into play (very much)."

The "code" represents a set of minimum requirements. The code by itself is not sufficient to ensure a safe structure. It takes the skill and judgment of highly trained engineering and construction professionals to properly implement and supplement these minimum requirements. The code does often address areas where its committee members see deficiencies in professional practice. Sometimes, we end up stifling innovation and creativity to protect the public from a few bad actors. In any case, a "code-compliant" structure is not always suitable for its intended use, nor is it necessarily a guarantee against failure.

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You have asserted that "the codes are minimum requirements and that engineering judgment is very necessary in the design of safe structures." But is this an accurate way to characterize day-to-day structural engineering practice? Do not many, perhaps most, structural designs for buildings and other structures specifically (and only) follow the code? Is this not why we have design codes in the first place?

Day-to-day, structural engineering involves a lot more than simply complying with the requirements in the 402 pages of ASCE 7-16 and other associated documents of technical authority. Determining the best structural system that meets a client's needs, that is constructable, that is economical, and that is safe requires extensive use of the engineering skills learned in school and in practice and requires extensive use of professional judgment. I personally would not want to work in a building that simply met only the requirements in the code.

As a professional business, structural engineering is not immune from market competition. Owners, for example, might seek an engineered design that is both technically sound and cost effective. In such a case, is it a stretch to believe owners might view the definition of "technically sound" as equivalent to "meeting code," even to the extent that if the engineer were to design beyond code, this would be seen as expensive overdesign?

This question is more about the professional relationship between the owner and his or her structural engineer than it is about "meeting code." In the best relationships, the structural engineer provides a structure that meets the owner's needs. Such a structure is always beyond code in some respects. There are, of course, owners and developers who want the least-expensive structure possible. Some engineers will provide a purely "code-compliant" structure. In many of these cases, the engineer may find himself or herself in court in a few years defending a "code-compliant" structure. Minimum code requirements are insufficient by themselves.

Under what circumstances is the structural engineer justified in going beyond code-mandated minimums? More specifically, what are some of the primary factors you recognize as indicating a project or application may require more than "strictly following the code"?

The structural engineer must understand the needs of his or her client. Serviceability of the structure over its life usually requires more than just meeting minimum code requirements. While the codes require that serviceability be considered, specific requirements are usually few and far between in the code. Serviceability is often specific to the use of the structure, its occupants, and its owner. An owner may decide that a structure is so important to his or her business and livelihood that the structure must be designed for higher environmental loads or more-restrictive drift limits or other requirements that minimize damage and downtime. The codes have life safety as their goal, not economic or functional recovery.

Knowing you face a unique design situation is one thing. Getting the owner or decision maker on board with paying the premium is something else. What experiences in your education and your career prepared you not only to recognize unique or special factors, but also to be able to persuasively (and successfully) advocate for autonomy in your design practice to address these factors—this in the face of ever-more competitive business and/or public opinion pressures?

It takes time to develop a relationship with a client. You have to learn the client's needs and be able to explain how the "added" cost of some feature of the structure meets those needs. An engineer will not come out of school with the skills or experience to persuade a client to do the "right thing." A young engineer will need to develop these skills working with more experienced engineers. For example, I have clients who have extensive internal standards to provide them with structures that meet their needs. My own company has extensive standards to help fill in the gap when a client thinks he or she only wants the "minimum." In these cases, the engineer must help educate the client in what the client's needs really are. These skills take time to develop, so the best outcomes occur with long-term, repeat clients.

You mention that you know a "growing number of younger [structural] engineers who believe they can analyze any problem (correctly) with today's software." Further, these same engineers "accept the software defaults for modeling as gospel—they basically substitute a programmer's judgment for their own when they do this." What is it about using software that prompted you to single out this aspect of the challenge of cultivating sound engineering judgment in structural engineering? Please elaborate.

I have seen a lot of young engineers misuse software that they did not fully understand. They wasted time analyzing and designing a member that they could have done using half of a page of calculation paper instead of the 100-page output from the analysis program. As a profession, structural engineers rely on very complex software to design a wide range of structures, from the average "box" structure to very unique structures such as the Burj Khalifa. The more complex and powerful a software package is, the easier it is to make mistakes. It is interesting to note that a favorite problem on the 16-hour structural engineering license exam is to give the candidate the output from a commercial structural analysis program and ask the candidate to find 10 things wrong with the model. I firmly believe that the initial design of a structure should be done with pencil and paper and then verified using a computer model. Many experienced structural engineers would say you should be able to rough out the initial design on the back of an envelope. To be able to rough out a design takes both engineering judgment and experience.

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Turning our attention to the FIU bridge collapse, the NTSB report indicates all parties—the design-builder, the designer, the construction project administrator/inspector, the owner/construction manager, and the state transportation agency—showed poor engineering judgment and response to precollapse cracking. But unforeseen structural response is not unheard of in structural engineering practice. From your experience, how does an engineer handle complex situations where you see movement, cracking, deflection, etc., that is unexpected?

Unexpected behavior of a structure is always a bad sign and should be dealt with immediately. The engineer must determine the cause or, at the very least, treat the symptoms of the problem. There is never enough time to carry out a full-blown "research project" to determine every aspect of the unexpected behavior. Safety of the construction personnel always dictates a quick response. But there are also cost and schedule pressures that demand a quick response to the unexpected behavior. When unexpected behavior occurs, the structural engineer must step up and say "stop." This is never easy in the schedule-driven projects we all work on. It is even harder for a young engineer to do. The engineer of record (EOR) has a responsibility to intervene when such a problem comes up. The pressures can be significant on the EOR. The EOR probably works for a large company, so he or she must report to a boss. The client has a need to use the structure to make money, and the construction company may be under liquidated damages. Given these kinds of pressures, delays are rarely tolerated. The EOR, as I said, must step up and say "stop." He or she (in reality, a team) must rapidly investigate the unexpected behavior and determine a path forward (a plan to correct the unexpected behavior). If the EOR is young and relatively inexperienced, he or she should [seek to] bring in the engineers with gray hair. There is no shame in doing so. This may require delaying the project, reinforcing a deficient portion of the structure, correcting quality issues on the site, etc., etc., etc.

In closing, what lessons learned have you taken from the FIU pedestrian bridge tragedy? Is there anything you say, or do, differently now?

Inasmuch as I am not directly involved with the project or failure investigation, I cannot address specifics of the FIU pedestrian bridge collapse. More broadly, and as I've noted, most structural failures occur during construction. Unexpected behavior must be identified and reported immediately, and action must be taken immediately, even when the action is unpopular with the participants and adversely impacts the project. In my career, I have investigated failures, some with loss of life. Some of these failures were caused by engineering errors, fabrication errors, or construction errors. In all cases, solutions must be found quickly and a plan developed to implement the solutions. I cannot say this is "new knowledge," but the FIU pedestrian bridge collapse does serve as a strong reminder to the structural engineering profession about the importance of this type of response.