Building Design Collaborator or Implementing Technician?

By Julie Mark Cohen, Ph.D., P.E., SECB

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On April 29, 2021, I attended a virtual meeting of SEAoNY's President's Breakfast Roundtable: *Engineering Post-Pandemic*. In my assigned break-out room, I listened to the attendees talk about the push for "sustainability" and, to achieve this goal, "optimization" of structural framing. This article discusses the evolution of engineering over the past decades and notes the consequences of misunderstanding "optimization." It reiterates my observation that a lack of 3-D structural framing systems resulted in damage to many structures during the 1994 Northridge earthquake. These structures were pulled apart in the same manner as they were designed – that is, as a collection of two-dimensional vertical and horizontal planes of framing.

The 1960s brought us:

- The first civil engineering papers were published on the optimization of the physical infrastructure for electric power transmission.
- The widespread introduction of master's degree programs in structural engineering.
- The continuation of the post-war construction boom.
- External pressures on structural engineers from tight budgets and short schedules were unprecedented.
- Changes in structural safety criteria in codes from allowable stress design to ultimate strength design for concrete and load and resistance factor design for steel.
- The disproportionate progressive collapse of London's 22-story Ronan Point residential building in May 1968.
- Education of university structural engineering students was conducted under the umbrella of ASCE (1950-1982), which required general education courses in place of practice-relevant courses in related engineering fields.
- In most cases, structural engineers collaborated with architects during schematic design and, often, conceptual design.

During the 1970s:

- Bay sizes of office buildings of all heights were increased, up to 30 feet by 40 feet, to provide building owners with the flexibility of larger open spaces for tenants.
- Often, the floor framing spanned large distances from the center core to the exterior walls.
- Architecturally, individual offices were replaced with cubicles to take advantage of open floor plans. The expectation was that each tenant could change the layout of their cubicles as needed. In reality, cubicle partitions were rarely moved, showing that the arguments about needing large open spaces did not necessarily hold true at the expense of more columns and full-height walls, which could have been constructed without interfering with office activities and communications.

By the 1980s, the following occurred:

- Textbooks continued to emphasize the design and analysis of 2-D planes of structural framing, with little emphasis on 3-D framing. As such, the notion of 3-D structural framing design and optimization never penetrated structural engineering education, research, or practice.
- Master's degree programs geared for practitioners were commonplace.
- Recessions came and went as in previous decades, but external financial pressures that shaped the design decision-making of structural engineers were omnipresent.
- Structural failures were increasing and recurring, more and more without recognizing and using well-established knowledge published in various documents in structural engineering and related engineering fields. For example, knowledge on fatigue and fracture dates back to at least the late 1800s, but little, if anything, appears in structural steel design textbooks. Also, the following failures due to fatigue and fracture at geometric discontinuities in steel structures have rarely, if ever, been mentioned in structural steel design textbooks: 1943 Liberty Ships, 1954 Comet De Havilland airplanes, 1967 nonredundant Silver Bridge, 1979 Kemper Arena, 1980 Alexander L. Kielland semi-submersible offshore drilling platform, etc.
- The standards for structural engineering education (in the same format as prior decades) were transferred in 1983 to the oversight of ABET (an engineering accreditation entity) with ASCE's guidance. However, no successful attempts were made to establish structural engineering as a separate undergraduate degree program. Undergraduate students interested in structural engineering were therefore unable to take many relevant courses but instead were required to take many non-engineering courses that subtracted from the engineering education.
- The collaboration of structural engineers with architects was waning due to architects' perceptions (often relayed to them in undergraduate university education) questioning the need for participation early on by structural engineers compounded with budgetary constraints of owners.

The 1994 Northridge earthquake brought dozens of examples of structural engineers having minimized locations of lateral load resistance. However, many of them referred to this design decision as having "optimized" the sizes. This is not correct. Optimization requires a *3-D structural framing system*. Optimization includes simultaneous assessment of (1) structural efficiency, which includes, in its simplest form, uniformity and regularity of horizontal and vertical framing (i.e., stress and deformation) with minimal use of abrupt stress-flow physically-adjacent lateral load-resisting and gravity-supporting framing, (2) 3-D system reliability which includes but is not limited to structural redundancy and alternate load paths, and (3) cost of materials and labor. Instead of 3-D structural framing systems, the result was a lesser number of moment-resisting frames with very large columns and beams and the cost savings of fewer un-tested welded beam-to-column connections. Again, this is minimization, not optimization. "Size effects" and risk-laden extrapolation to larger sizes, as well as evaluation of test results, are essential parts of the overall failure story, as noted in the Federal Emergency Management Administration's (FEMA) FEMA 355E, *The State of Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*.

That is, structural engineers have been failing to understand the difference between structural optimization and minimization. Lateral load-resisting framing members became relatively large while gravity load-carrying framing was smaller, resulting in an inefficient distribution of structural resistance and abrupt changes in resistance (often not tested). Minimization was shown to affect structural performance adversely.

By the early 2000s, structural engineers rarely, if ever, participated in the conceptual design and even the schematic design of buildings. In 2018, Angie Sommer, S.E., summed this up as follows: "We [structural engineers] come on usually after a building is somewhat formed and we are working with the architect and the owner to figure out how we can fit [structural framing] into the allotted spaces." This lack of early-on participation in the design process has also been observed in university education. "Design" courses either do not include architecture students or, if they do, they mimic practice with little, if any, early-on collaboration between structural engineering and architecture students.

At the SEAoNY meeting, the New York City structural engineers in attendance presented an argument that optimizing structural framing by providing larger open spaces for building owners, an architectural requirement, promotes sustainability by increasing longevity. They claimed that this would provide alternatives for the buildings' future use. If this was optimizing, why did it take until 2021 to do this? Why has no one questioned the viability of the "open space" concept? This sustainability, however, minimizes the locations of lateral load resistance and also minimizes locations of gravity load-carrying framing.

As a result, the possibilities are lessened for structural redundancy and alternate load paths unless something costly is introduced, such as using multiple, deep transfer trusses or deep beams, thus increasing the heights of the buildings. In addition, risk is introduced by using larger connections and other sub-assemblages that likely have not been tested. (Analyses without experimental data do not validate anticipated performance.)

Clearly, over time, the role of most structural engineers has shifted from building design collaborators to becoming implementing technicians. However, structural failures have increased in the same time period, at least 40 percent of which have been caused by recurring shortcomings in engineering design decision-making (i.e., cognitive errors). Are these failures not as important as "sustainability"?

The trajectory is undeniable. Is it acceptable?▪

References are included in the online PDF version of the article at **STRUCTUREmag.org**.

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