TBD

by Charles Hoes

The September 2, 2021 edition of *The New York Times* "The Morning" included an interesting article concerning the collapse of the Champlain Towers South Condo in Miami that resulted in the deaths of 98 people. After seeing multiple news accounts, I couldn't help but wonder what in the world went wrong? Is there an important system safety lesson to be learned? If so, what might it be? The International System Safety Society (ISSS) is supporting a National Institute for Occupational Safety and Health (NIOSH)-sponsored effort to explore ways to better implement "safety through design" for construction projects. The *Times* article provided a few enticing tidbits that might be worth mulling over regarding improving safety through design.

My first reaction was that perhaps it was the aftereffect of using a type of high early strength concrete, such as Portland cement, that was popular in the late 1960s because it gains strength quickly, maximizing the probability of passing the required 28 strength tests, and potentially enhancing the profits of contractors by reducing the risk of concrete failing the tests a month after it was placed. I researched this material for my father (who was a county road inspector) around 1968 because he had become concerned about its potential for long-term deterioration in strength.

Portland cement achieves substantial strength within the first few weeks but takes many years to reach maximum strength. I found that the high early strength concrete peaks within weeks. However, this type of concrete has a nasty characteristic — it is prone to unpredictably losing strength rapidly, resulting in a history of catastrophic collapses. The ancient Romans were aware of this failure mode and stopped using it thousands of years ago. Unfortunately, my cursory online search over the last weekend has failed to identify this particular material or its poor history and I can't recall what it is called. So that line of reasoning is not likely to serve me well in my considerations about system safety. However, if they happened to have used this material, and if my recollections of its structural properties over time are correct, it certainly could fit into something that perhaps would have been found and avoided by a system safety effort. For now, I will leave that trail hanging out as pure speculation.

The *Times* article brought up a number of other possibilities that are perhaps more germane to the subject. They reported on a number of problems, speculating that perhaps they either caused the collapse, or contributed to the magnitude of the problem. It appears that this event was most likely a chain of events that started with the failure of one structural element, transferring the load it was supporting to other elements, thereby overstressing them and resulting in failure, which then transferred that load to other elements resulting in a kind of domino effect. The question of "cause" gets down to which element triggered the event and why, as well as why such an overload of one element could overload other elements to the point of failure of the entire structure. It is sometimes thought that having many parallel structural elements provides safety through redundancy; perhaps they decrease safety by adding many additional failure opportunities.

The building has five main structural features in its design: a foundation (consisting of a grid of driven piles), a below-surface parking garage, a grid of pillars that supports the next level, a multistory building and a large ground-level deck that features a large swimming pool.

The *Times* article listed a number of "findings" that have turned up so far. I have no way to be sure of the veracity of the information, nor can I judge whether or not they even include the "cause" of the collapse. I offer them here by way of discussion of a much more general problem concerning the appropriate scope and depth of system safety efforts when applied to a building of this type. A partial list of problems the article discussed includes:

- During a 2018 inspection, it was noted that the piles had problems with water intrusion.
- During the same 2018 inspection, abundant cracking and crumbling of the support columns, beams

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(Photo: NIST)

and walls were noted in the underground parking garage.

- Large planters (weighing tens of thousands of pounds) installed on the deck were not specified in the design drawings. The article speculated that these may have overstressed the design because they were not included in the designs.
- Several beams supporting the deck in the vicinity of the planters (shown in the original designs) were not included in the building.
- The deck was designed to be flat, without a slope that would ensure drainage.
- The waterproofing material on the surface of the deck had deteriorated and been replaced in a manner that trapped moisture rather than repelling it.
- One corner of the deck appeared to have little-to-no reinforcing steel.
- Columns in the immediate vicinity of a cave-in may have punched through the deck at the locations with little reinforcing steel.
- The design of the columns called for splices being made at a particular height, creating regions within the columns that had too much steel for the amount of concrete. This resulted in sections of the columns that were weaker than the design calculations indicated.
- The rebar in the slab was located very close to the surface of the slab (3/4”), perhaps resulting in less-than-optimal performance (some engineers contend, however, that the second layer of concrete rectified this deficiency.
- It appears that the number of horizontal reinforcing rods that connected the deck to the columns was less than shown in the design.
- There was an extra penthouse added to the top of the building that was not in the original design.
- The 2018 inspection identified numerous locations on balconies with exposed reinforcing rods and crumbling concrete.
- Water was leaking through the roof. Repairs on the roof were underway the day before the collapse.
- Large amounts of water were observed pouring into the underground garage, along with chunks of debris, the day before the event.
- Video footage indicated that the collapse appears to have started with a hole caving in on the deck, then the rest of the deck collapsing, rapidly progressing to the middle section of the building, followed by the other wings. The sections that remained standing appear to have been supported by the elevator shafts.
- There was speculation that perhaps a vehicle ran into, and damaged, one of the support columns.

I have no idea which, if any, of these issues caused, or triggered, the collapse. However, this rather extensive list got me wondering which of these fall under the purview of “system safety,” and therefore which might have been avoided given a strong “design for safety” (system safety) effort.

My experience has been that “design for safety” in the construction industry tends to be limited to designing for safety during construction, perhaps extending to operating and maintenance personnel during normal operational phases of the project. I have heard little about the safety of the design to meet its performance expectations (or safety requirements) especially under conditions of foreseeable change (such as installing landscaping features on a deck with a swimming pool). The assumption seems to be that the design engineers/architects and building contractors take care of safety as a functioning system through following sound engineering practices, and using dedicated high-quality contractors and expert building inspection services. Unfortunately, it seems that many problems during the "operational phase" of large structures, such as the collapse of the Champlain Towers South Condo, can be tied directly back to problems in the design, construction and/or inspection.

I leave it up to you to make a judgment about which of the listed shortcomings, if any, could have contributed to the collapse, and which could likely have been avoided with a strong system safety effort. It appears that many of the issues had to do with incorrectly following the design, and then not catching the deviations during inspections. Perhaps these are outside of the scope of system safety — or maybe they *are* within scope. There are other issues, such as the addition of a large planter that changed loading above and beyond what was specified in the design documentation. Perhaps this is the kind of "change" that should result in calling the design team — including system safety — back in a "change review" process. There was probably a discussion about this change before it was made; I wonder if the people with knowledge ofthe design were included in the decision.

I found this disaster to be fertile ground for considering when, or how, system safety expertise should be included in the process, and what sort of issues that effort is likely to uncover or identify. It is interesting to speculate which of these problems could have been identified and mitigated during the design process, and later during reviews of proposed changes. I think this is an important consideration if we are to positively impact the direction of current attempts to introduce "safety through design" concepts into construction projects — safety through design has to reach much further than construction activities. It needs to include the users, public, long-term structural integrity (including the effects of foreseeable modifications) and the environment. It is my opinion that achieving safety throughout the life of a design requires an effective system safety effort. ⬣