TALL BUILDINGS AND STRUCTURAL COLLAPSE

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Multi-storey buildings are usually well-designed and carefully built. When subjected to normal loads, such as wind and earthquake and when such loads are within expected bounds, the chance of collapse is practically nil. The concern about such an event come from unexpected loads, such as certain impacts or the action of explosives, whether accidental or malevolently imposed.

Protection Strategy

It is not possible to protect a tall structure against any unknown loads. For example, an explosion can be made powerful enough and/or happen so close to the building that it can overcome any resistance. The only sensible way to mitigate such a scenario is to increase the chance of survival by avoiding conditions that may bring about a total collapse. This can be achieved by at least two ways:

1. Eliminating any known weak spots, as they may become the local sources of failure.
2. Shaping the structure so that a local failure does not lead to a chain reaction in the form of a progressive collapse.

The problem with weak spots is that they are not readily recognizable and their response under strongly dynamic conditions is not always appreciated, unless the analyst has considerable relevant experience. It may be argued that such weak details were present, for example, in the World Trade Center towers, and contributed to their failure. The reason for their presence was either the lack of attention to detail or the lack of knowledge how those details worked, or both. What seems safe under normal design loads often becomes critical under intensely dynamic conditions.

To be more specific with respect to the case of WTC, this writer believes that one such weak link was the connection of the floor-supporting angles to the columns at both ends. The calculation supporting that connection did not appear convincing and the responsible engineer has overstated its strength. This type of connection also happens to be quite sensitive to dynamic loading. Of course, it would be unreasonable to blame the engineer for the additional developments he could not predict; sagging of floors under fire and the associated catenary tension on the critical connections.

One simple description of a progressive collapse goes as follows. Imagine a building, made up of identical-looking stories. At the ground level, the corner is supported by a column, then there is a concrete slab above it and a similar column continues, supporting the slab of the next story, etc. If, for some reason, the ground-level column is destroyed, the first slab may not be able to support the column above and it will break off. This, in turn, is likely to cause a successive failure of the slabs above it, all the way to the top of building, until the entire vertical segment of the building changes into a heap of rubble. Under unfortunate circumstances, this may also lead to a collapse of the entire structure.

One should keep in mind that the simultaneous requirements of structural safety on one hand and economy with functionality on the other are often contradictory. To get a safer building, from a collapse viewpoint, the owner must pay more for design of details, as in

Item 1 above. Also, satisfying Item 2 means a higher cost of additional members to increase redundancy and therefore safety.

Modern buildings tend to have much fewer columns than in the past. While they are sufficiently strong under normal loads, they may be more susceptible to collapse when partially damaged. It does not take great insight to recognize the following: If there are only 40 rather than 80 columns in a building, each of them carries twice as large percentage of the building weight, so the relative consequences of removing or damaging one such column will be greater.

Roles and responsibilities.

The job of a (conventional) structural engineer is to shape and design a safe structure, when normal loads are involved. The additional part of the process, namely assuring maximum safety under unexpected loads belongs to a structural analyst, who is also a structural engineer, but of a different profile. This individual is well versed in advanced structural dynamics so that he or she can create and examine various postulated disaster scenarios.

These two types of engineers would typically work in separate teams. The second team, usually an external consultant, has a leader who should understand well how the structure works and what may cause its collapse under unexpected loading conditions. The team members must be not only experienced in structural dynamics, but also in detailed stress analysis, as it will be the details that make the structure fail or survive. The leader must be capable of anticipating and verifying his analysts' results by performing simplified estimates. Other members of this team would have a much narrower knowledge and would work to create FEA models, execute computer programs, try to make sense of the results and create graphical representations.

In searching for potentially weak spots the traditional computer modeling software is of somewhat limited value. Unless such locations can be anticipated ahead of time, the model of the structure may be constructed in such a way that they are missed and subsequent simulation will not necessarily point to their existence – especially since there are many more weak spots under extreme loads than under the normal conditions. In this sense, one can state that the collapse safety of a building hangs, to a large extent, on the insight of the lead analyst. If this person was advanced to the lead position merely on an administrative basis, rather than by virtue of possessing outstanding knowledge, then his or her report will be meaningless.

Critical Expertise

The behavior of structures under strongly dynamic loads, such as explosions is a difficult subject. Even among the specialists in the field, the knowledge is not uniformly distributed in the sense that their know-how overlaps. This means that given the same structure, not every such specialist will recognize the same weak spots and consequences of local failures.

The results of accidental loading analysis are almost always confidential. This means that if the work is faulty, it will never be known, except perhaps in a *post mortem* analysis, after a collapse. What does 'faulty' or 'incorrect' mean?... One of the ways to define it is to say that predictions resulting from such analyses would not agree with physical test results. Unfortunately, most errors are such that they result in unsafe predictions, meaning that the structure is presented as more resilient than it really is. In a minority of cases, where the analysis under-predicts the structural strength the penalty is relatively small: The requested size of elements to meet a specified threat is larger than necessary.

While the reports dealing with postulated explosive attacks and eventual collapses are confidential, their authors publish papers, which often reflect on their methodology. It is apparent that misconceptions resulting from inadequate knowledge of either structures or dynamics may sometimes be involved.

To get the best of results possible, the architect or the building owner should carefully investigate the technical capability of the team leader of the analysts, be it an independent consultant or an employee of a large firm. There are several ways to get a better appreciation of the leader's competence. One is the length of his or her experience; this should include at least 20 years of related engineering work to accumulate enough knowledge helpful in this complex field.

There also is a simple test, which can be conducted in a face-to-face encounter. After the candidate delivers an impressive presentation of computer-aided work, a question can be asked: "How much of this could you do if I took your computer away?" The proper answer should be something like this:

> *Quite a lot can be done by hand calculations but it would not be nearly as accurate. Still, it may be sufficient for preliminary estimates and employing such calculations early could result in substantial cost savings.*

If, on the other hand, the reaction is a lasting puzzlement, then the expertise is much in doubt. One should be aware that the safety and survivability of a structure under extreme conditions hangs largely on the expertise of that one person. To improve the odds, the architect or owner should request that the collapse analysis to be at least independently reviewed, if not independently conducted again.

Conclusion

Like in other cases of engineering endeavor, much depends on the attitude of the project owner. Yet, such attitudes can change remarkably fast, as the writer has once witnessed. The owners of a certain industrial project were unhappy about a postulated aircraft impact condition that could affect a sensitive part of the facility. Although forced to engage a specialist to help their engineers address the problem, they thought that such fairy tales should not be imposed on them. Their frustration showed itself in the amount of time it took them to compensate the specialist for his work. Then came September 11, 2001; the payment was mailed two days later.

The structural design team has a role to play, too. Are they really serious about dealing with extreme conditions, or do they just want to demonstrate some attention to the matter? What will their actions be, if they know that two different specialists are likely to give them overlapping, but different opinions? Will they accept less than credible opinions only because the "computer says so"?

The attitude of every influential person in a project can contribute to safe and economical design and construction for multi-story buildings.