Title: **What Does September 11th Mean for Building Structure Design**

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What does September 11th Mean for Building Structure Design?

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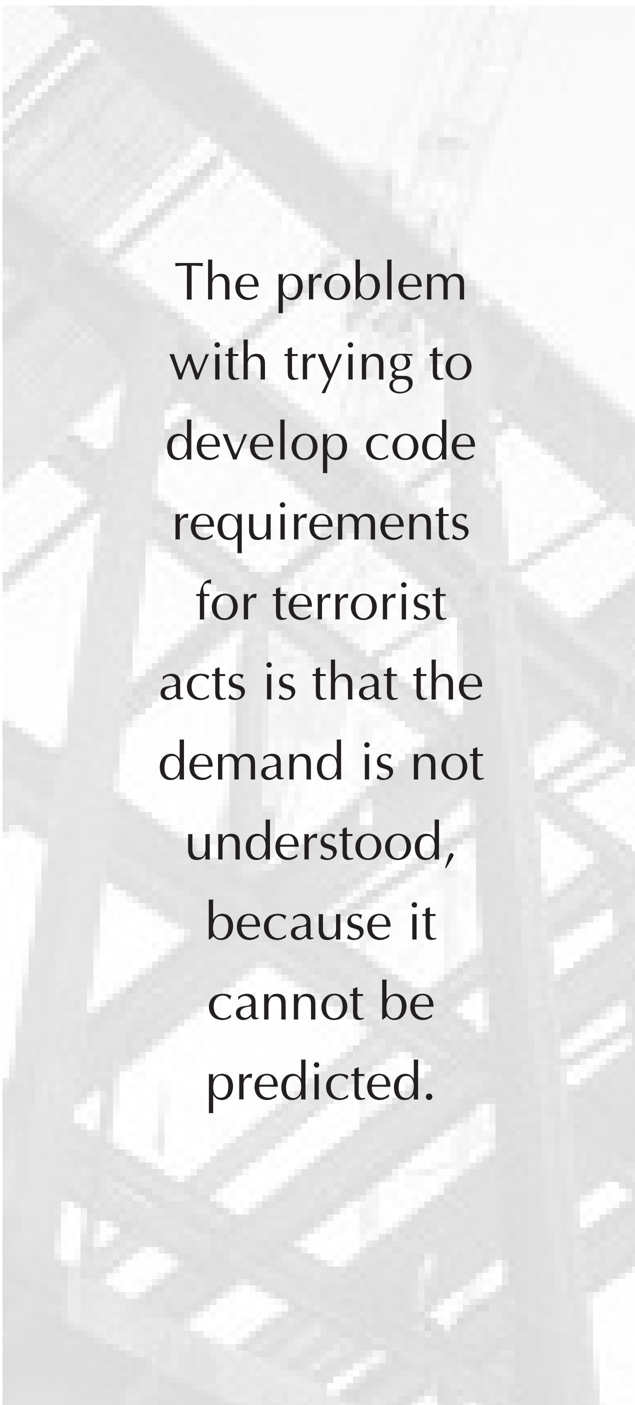

The problem with trying to develop code requirements for terrorist acts is that the demand is not understood, because it cannot be predicted.

The horrible events of September 11th have aroused many emotions and created many questions in the minds of the public, the media, political leaders, and design professionals. For officials charged with developing building codes and designers charged with creating buildings the question is very specific: Is there something wrong with our codes and can we change them so that this doesn't happen again?

However, even though this appears to be a specific question, it is not. What does "this" mean in the question? Does it mean making buildings more resistant to a terrorist attack? Or, does it mean giving buildings the ability to resist a direct airplane hit? These are two very different questions.

Can we make building structures more resistant to terrorist attack?

All building codes develop requirements based on performance objectives for specific hazards. The primary environmental hazards are gravity, wind, and earthquake. When a building is designed, the demand placed on the building by each of these is well understood. The capacity to meet these demands can be supplied.

Another primary hazard is fire. Even though care is taken to minimize the risk of fires, they do occasionally happen. The fire demand placed on a structure is also understood and systems can be supplied to meet life safety objectives.

The problem with trying to develop code requirements for terrorist acts is that the demand is not understood, because it can not be predicted. Any defined attack "load" could be made inadequate by a larger attack. The "design" attack can not be determined in the same technical ways that wind or earthquake loads are determined. Rather, the design approach will need to be determined in the political realm, as it is related to societal values rather than a scientific approach.

Can we make building structures more resistant to terrorist attack? Yes. But, the critical decisions of how big of an attack, how much to spend on hardening building structures, and which buildings should be hardened will need to be made by our legislative representatives. Of course, building officials, architects, and engineers will need to assist in this process.

Can buildings structures be given the ability to resist direct airplane hits?

If the "design" terrorist attack is similar to that of September 11th, can buildings be given the capacity to meet this demand? To answer this question, it is important to understand the physics at work when a plane in flight is stopped by a building.

If the performance objective is to "resist" a direct airplane hit then, to protect people inside the building, the plane can not be allowed to penetrate the exterior wall. To stop a Boeing 767 traveling in excess of 500 mile per hour in a distance of a few feet would take a deceleration force in excess of 400,000,000 pounds. The total design wind load on each of the World Trade Center Towers was about 15,000,000 pounds. The total design wind load for a more commonly sized high-rise, say, 40 stories tall, would be about 4,000,000 pounds. To generate resistance in the ratio of demand of 400 to capacity of 15, or even 4, is not practical.

This is looking at the impact load on a "global" basis for the entire lateral load-resisting system of the building. Before the global system can even try to resist the load, the forces would need to be transferred from the impact area at the exterior through the floor diaphragms. No known floor system can take this kind of axial and shear force.

Figure 1.

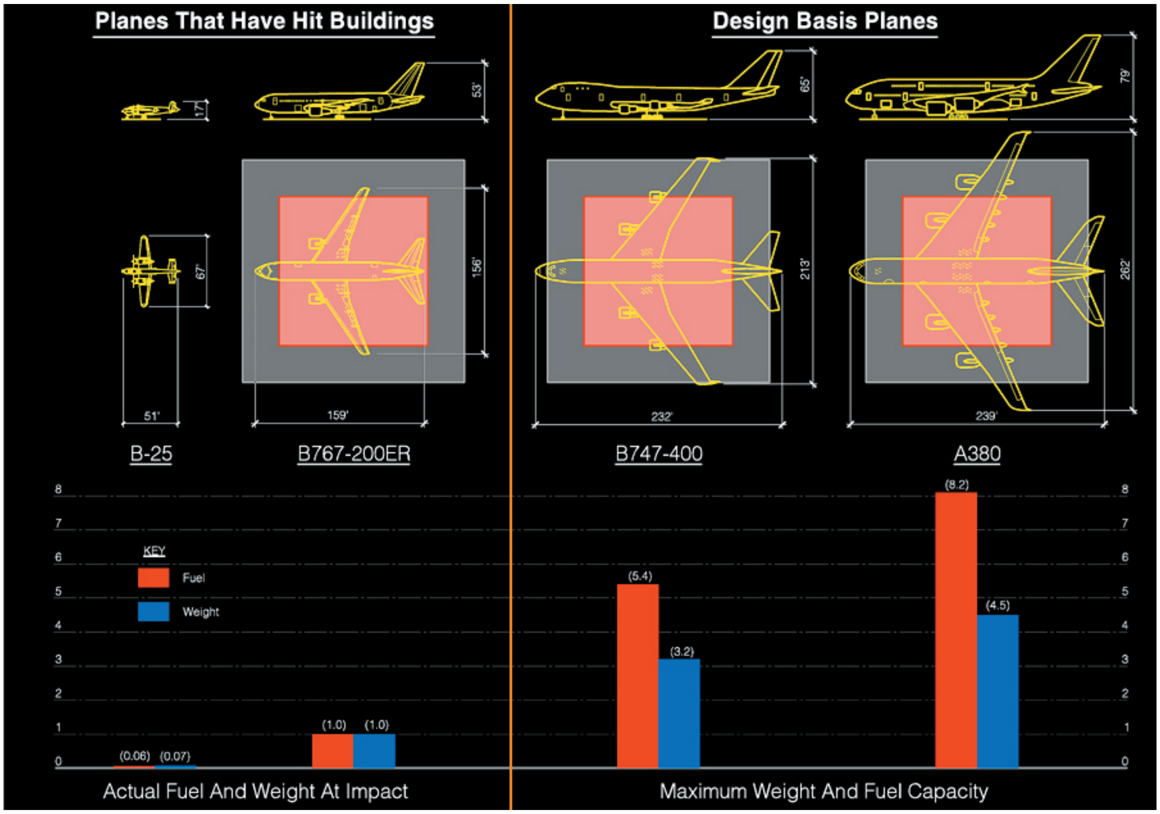

Figure 2.

So why did the World Trade Center Towers not collapse immediately due to the impact load on the system? The planes did not stop in a few feet, but had an effective stopping distance of over 100 feet. This would drop the deceleration force down to something close to the capacity of the building. Another part of the answer to this question lies in the way that the exterior of the building was structured. In ***Figure 1***, the exterior wall structure can be clearly seen. The exterior columns were fourteen-inch square welded steel box columns spaced at forty inches on center. This means that there was only 26 inches clear between each column. The columns were integral with the steel spandrels beams and formed essentially a solid wall of steel with perforations for windows. This wall construction was able to form a Vierendeel "bridge" over the hole created in one side of each of the towers.

Both of these facts, that the plane was not stopped at the exterior and that the columns and spandrels were extremely dense, were necessary to prevent the building from collapsing immediately upon impact.

The final point in answering the question of airplane impact loading is that, even if some miracle technology could be invented to take these kinds of loads from a 767, there are larger planes to be considered. The B-25 that hit the Empire State building was a fraction of the size of a 767. The Rockwell Commander that hit the high-rise in Milan earlier this year was about half the size of the B-25. ***Figure 2*** gives a comparison of two planes that have actually hit buildings and two planes that would control the design loads if a building structure needed to resist the impact of planes.

The larger square in each frame was the floor plate size of the World Trade Center (209'x209') and the smaller square is a more common size for a major high-rise (140'x140'). The figure reveals that the design loads for an Airbus A380 would need to be based on about 4.5 times the weight and over 8 times the fuel that was on-board the 767's used in the attack on each of the Trade Center Towers.

Can buildings be designed for direct airplane hits? Yes and no. Yes, for small aircraft. A definite no, for large commercial aircraft.

What should be done about code provisions to minimize the chance of progressive collapse?

This is still one more question that some people are asking. Because the towers ultimately collapsed with one floor crashing down upon the next, it has been called a progressive collapse.

Again, it is important to think carefully about the question. Aren't all collapses progressive? Something breaks, then something else breaks, and so on. Normally, when the term progressive collapse is used, it specifically refers to the loss of one or two columns or bearing walls that cause a collapse to propagate vertically.

In the case of the World Trade Center there were about forty columns lost on one face of each of the towers and there was no propagation of collapse from this loss. So did the World Trade Center have good resistance to progressive collapse? By normal use of the term "progressive collapse" it did. The collapse that did ultimately occur was progressive, like all collapses, but was not "progressive collapse" that some other international codes address.

The difficulty in understanding this concept is illustrated with the following story. A New York Fire Chief wrote that experienced firefighters know that the buildings that are most susceptible to progressive collapse are buildings that are well-tied together. Wait, "well-tied together" is bad. Virtually every structural engineer will tell advise that one of the best way to *prevent* progressive collapse is to tie the building together. How can there be this kind of a contradiction?

The difference is that the engineer is thinking about losing a column or two and the Fire Chief is talking about losing a whole part of a building. As the event that initiates the progressive collapse becomes larger than losing a column the risk becomes that the strong horizontal ties of a building will cause the collapse to propagate *horizontally*.

Any discussion of code provisions with respect to progressive collapse must recognize that both the engineer and the Fire Chief are right depending on the kind of hazard that is defined.

Conclusions

There are structural techniques that can increase the capacity of building structures to resist certain kinds of terrorist attacks. However, there is absolutely no reliable way to design for the impact of a large scale commercial airliner. Any code changes to address these kinds of hazards will depend on decisions within the political realm. However, building officials and designers must assist to help arrive at rational solutions. There will be great difficulty in trying to legislate which new building structures have any risk of terrorist attack. And, finally, every building professional must be careful to think through these new sets of problems in order to get to the *right* questions so that the *right* solutions can be found for society and *real* increases in safety can be achieved.

About the Author

Jon Magnusson is Chairman/CEO of Magnusson Klemencic Associates in Seattle, Washington.