Detailing to Prevent Progressive Collapse…

Without Breaking the Bank

By Jim DeStefano, P.E.

Progressive collapse is a topic that structural engineers have discussed and debated since the Ronan Point Collapse nearly 40 years ago. The discussions have always been somewhat academic and philosophical, but never had much bearing on how we actually designed building structures. That is, up until the tragic events of September 11, 2001. With the threat of terrorism now at our doorstep, discussions on designing for progressive collapse have become very real.

Some Federal agencies are now requiring certain public buildings to be designed to resist progressive collapse. NIST has recommended that the *International Building Code* include provisions for buildings to be engineered to resist progressive collapse. SEI has formed a committee to study progressive collapse. Suddenly it has become very serious and is no longer an academic issue.

The problem is, we as a profession don't really know how to design buildings to resist progressive collapse. We can't even agree on what progressive collapse is, or what we should call it.

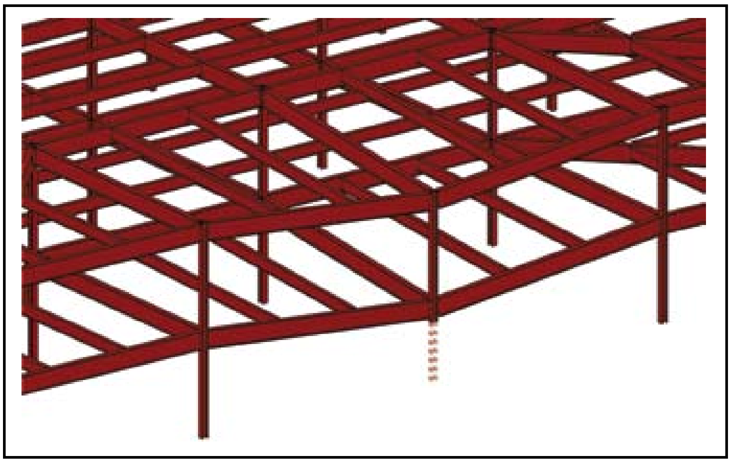

Figure 1: Deflected shape of structure with an exterior column removed

The most likely perceived terrorist event is a car bomb removing an exterior column. Consequently, a common design criteria for progressive collapse resistance has been that the structure should continue to stand if any one column is removed. Some engineers have come up with very exotic and expensive methods of achieving this goal. In most cases, however, if two adjacent columns are removed, all bets are off.

Hopefully, these types of terrorist events will be rare. The goal should be prevention of a global building collapse. There is really no need to be overly concerned with stress levels or deflections. If we can accept large deflections in our buildings when these events occur, we can take advantage of catenary behavior. In structural steel framed buildings, it is possible to detail the structure to allow for catenary action without adding much cost to the structure.

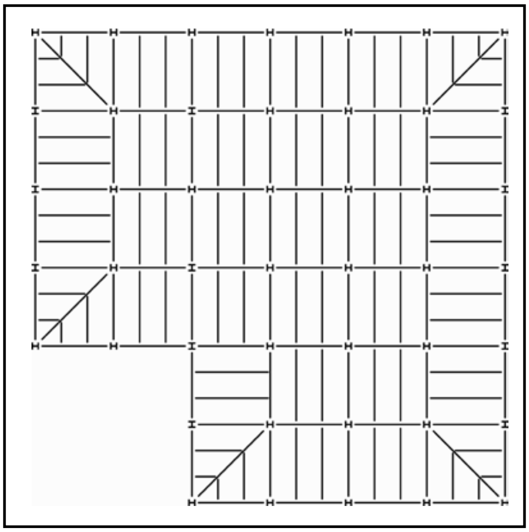

Figure 2: Framing layout for a progressive collapse resistant building

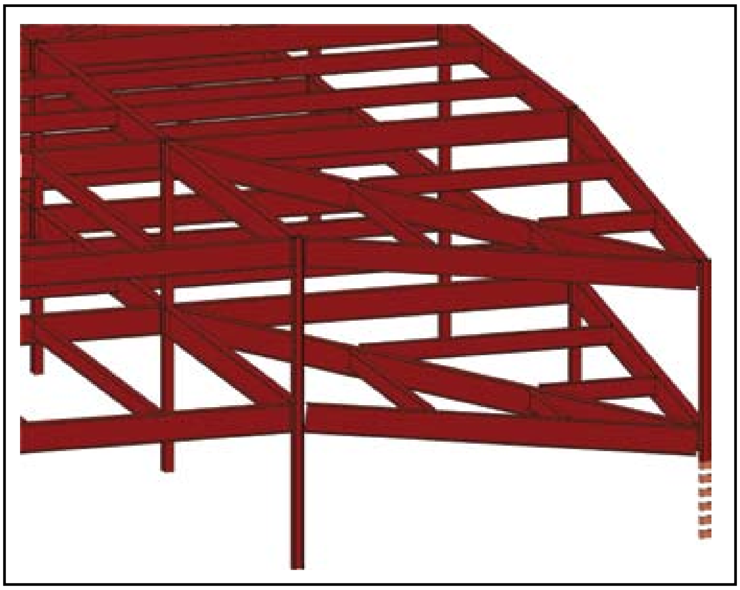

Figure 3: Deflected shape of structure with a corner column removed

The fundamental principal of catenary behavior is that when members that were originally intended to resist load in flexure are subjected to large deflections, an alternative load path develops as they begin to resist load with axial stresses prior to collapsing. An example can be seen in *Figure 1*. When an exterior column was removed from the lower floor of the structure, the spandrel girders became tension members, averting a global collapse.

The Achilles heel of catenary behavior has always been the corner columns. Not to worry though, a simple solution is at hand. If a diagonal girder is introduced into each corner bay as indicated on the framing plan in *Figure 2*, a stable axial load mechanism can develop if the corner column is removed. The deflected shape is illustrated in *Figure 3*. The exterior spandrel girders are in tension and the diagonal girder is in compression.

Catenary behavior is equally effective at preventing a global collapse in a high-rise building or a low-rise building. Since the axial loads are carried by girders at every level, there is no excess accumulation of load at one floor of a high-rise building. On the average, the girders at any one floor only carry the load of one floor.

Here are a few tips on how to configure the structure to allow for catenary behavior:

1. Orient the framing so that the girders are on the exterior wall and the filler beams are perpendicular to the exterior (avoid bar joists). You want your heaviest members on the perimeter.
2. Introduce diagonal girders in the corner bays, as previously mentioned.
3. Orient wide-flange perimeter columns with their strong axis parallel to the exterior wall. This allows the girders to connect directly to the column flange.

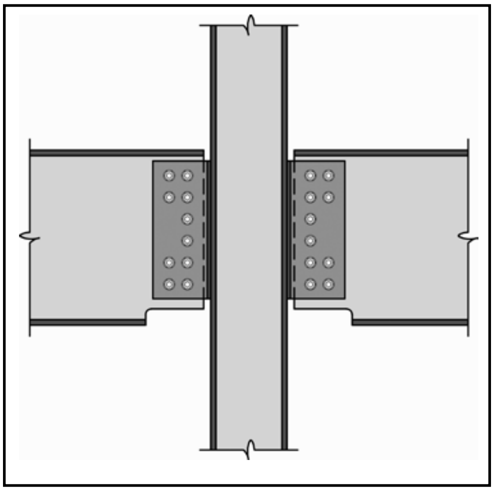

Figure 4: Connection detail of spandrel girder to column

4. Use ductile girder connections to the columns that have the ability to rotate and resist high axial loads. A suggested connection type is shown in *Figure 4* with double rows of bolts in double shear. Avoid seat connections and one sided connections.

Unless you have a specialty structural analysis program for analyzing structures under extreme loading, you will need to trick your computer. Most commonly used frame analysis programs are based on small deflection theory, and are not capable of performing a second order analysis. To analyze a structure for catenary behavior, simply remove a column from your frame model and introduce a large displacement (I would suggest 2 feet) into the nodes above the removed column. The results are not exact, but they will tell you if the structure is globally stable and it will provide axial forces that are sufficient for design purposes.

For enhanced performance, the seismic moment frames can be located on the building perimeter. This allows the catenary behavior to be supplemented by Vierendal truss action. This is what allowed the World Trade Center towers to redistribute load when ⅔ of the perimeter columns were severed. Naturally, it is helpful if the moment connections are detailed to develop the full strength of the girders.

So, by following these few simple guidelines, you too can engineer buildings to resist progressive collapse. And, you can do it without bankrupting your client.▪

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