

THE DESIGN PROFESSIONAL'S CONCERNS REGARDING PROGRESSIVE COLLAPSE DESIGN

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The Structural Engineering profession has become concerned with the phenomenon of Progressive Collapse in the last 30 years dating back to the collapse in the UK of the precast concrete panel high rise, Ronan Point. The trigger was a gas explosion in a corner flat that precipitated a collapse of a major portion of the building. Following the Ronan Point collapse in 1968, there were several examples caused by various abnormal loading conditions.

Examples of Progressive Collapse include the early shoring removal problem at Bailey's Crossroads in Fairfax County, Virginia in 1973; the partial collapse of the Beirut Embassy in 1983 caused by a bomb blast; the 1993 World Trade Center bombing which caused a progressive type collapse of some of the lower structure; the 1995 bombing of the Murrah Federal Building in Oklahoma City; the bombing of the US Embassies in Nairobi and Dar Es Salaam in 1998; and most recently the flying of airplanes into the World Trade Center Towers in New York and the Pentagon in Washington last September 11.

In general, Progressive Collapse occurs when the loss of load carrying capacity, such as the destruction of one or more columns or load bearing walls, results in a localized failure which leads to a further loss of support and, ultimately, collapse of all or a part of the structure. The causes may vary but the net effect is the same.

DIFFICULTIES FACED BY DESIGNERS

When the issue of designing or modifying a structure to resist Progressive Collapse became prevalent in the structural engineering field, designers began to look for rules to follow. There is no consistent set of goals, guidelines or rules, i.e. no codes or standards relating to Progressive Collapse. Several codes or standards such as ASCE 7 and ACI 318 have references to Structural Integrity but not as a set of criteria for resisting Progressive Collapse.

Within the Federal Government, there are many different interpretations of the same requirements. Many government contracting personnel lack the knowledge to know what they are asking for. Most assume that the potential Progressive Collapse is caused by a blast of some type. "Blast" information is closely held by an "elite" few.

Designers don't really care about the source of the problem. They just want design criteria. Some of these requested criteria might be as follows:

1. What is the design load resulting from the blast pressure?
2. What are the expectations for the behavior of the building (both the structural frame and the enclosure)?
3. What Load Factors (if any) should be applied to the proposed loads?
4. What allowable "stresses" should be attributed to each material?
5. What type of inelastic behavior should be assumed?

The Structural Engineering community needs "blast" information that is understandable to a reasonably intelligent professional. The information should be made useable for application in the design of structures or design criteria should be established based on the "blast" information. These criteria could then be published in either a standard or a guideline.

ARE BETTER TOOLS NEEDED? YES!!!!

Structural Engineers need both design criteria and a recommended procedure for the design of new structures and the analysis of existing structures. Many of us have come up with our own approach for the basis of designing and evaluating structures. The profession needs to have a consistent approach if at all possible.

In addition to a procedure, there should be guidelines for anticipated performance. In most cases, "Life Safety" will suffice but in many cases "Collapse Prevention" and limitation of area of damage is required or at least desirable.

A compilation of the existing design tools would be of great assistance in determining future directions. The statement in ASCE 7 related to structural integrity is not very helpful to the designer but is possibly appropriate for a Load Standard. Designers would do well to understand the prescriptive requirements that already exist in ACI 318 as well as learning from the detailing successes of the past. For instance, in the early 1980's Dr. Mete Sozen developed a "Toughness Criteria" for use by the Department of State on their embassy projects. Our firm had designed a project using these criteria which was under construction when the Beirut Embassy was bombed in 1983. The government decided to upgrade "blast" related requirements on all embassy projects at that time. Even though our 18 story project was already constructed up to the 5th floor, we did not have to make any adjustments to the structure. Admittedly, the exterior skin did have to be changed but the redundancy designed into the structure using the Sozen criteria was sufficient to meet the additional requirements at that time.

A better understanding of the capabilities of existing software would allow the industry to determine if we need other programs or just a better understanding of what we have.

A demystifying of blast resistant design criteria and the development of charts or tables for obtaining design loads for given situations would be extremely helpful.

As has been mentioned previously, a consistent categorization of threats by all agencies would promote a better understanding for both the government and the design professional.

PRESCRIPTIVE VERSUS PERFORMANCE-BASED APPROACHES

Most likely, a combination of prescriptive and performance based approaches will be required. If possible, design loads for a limited (typical) set of circumstances should be prescriptive. Alternatively, under certain conditions, requirements such as the limited damage criteria as specified by GSA could be used, i.e. alternate load paths and limited areas of damage.

Prescriptive requirements such as those in ACI 318 are invaluable to the designer in helping him exercise common sense. Most of the requirements in ACI 318 are based on the philosophy that tying a structure together and providing for potential moment reversals is the right way to go. Some examples of these requirements are as follows:

A. Chapter 7 – Details of Reinforcement

- 7.13 – Requirements for Structural Integrity
- 7.13.1 – Tie things together
- 7.13.2.1 – Joists – one bottom bar continuous
- 7.13.2.2 – Perimeter Beams
 1. Continuous top steel $1/6$ negative required at support ≥ 2 bars
 2. Continuous bottom steel $1/4$ positive required at center ≥ 2 bars
- 7.13.2.3 – Splice locations and enclosure by stirrups with 135° hooks around top bars
- 7.13.2.4 – In other than perimeter beams $1/4$ positive steel required ≥ 2 bars continuous.
- 7.13.2.5 – Two way slabs see 13.3.8.5
- 7.13.3 – Precast provisions – Tension ties in the transverse, longitudinal and vertical directions around the perimeter to tie elements together. See 16.5
- 7.13.4 – Lift slabs – See 13.3.8.6 and 18.12.16

B. Chapter 13 – Two way slab systems

- 13.3.8.5 – All bottom reinforcing in the column strip shall be continuous or spliced with Class A or mechanical splices. At least two bottom bars shall pass through the column core.
- 13.3.8.6 – Deals with shearheads and lift slabs.

C. Chapter 16 – Precast Concrete

- 16.5 – Structural Integrity – This is a large section including many prescriptive requirements for tying precast panel buildings together.

D. Chapter 18 – Prestressed Concrete

- 18.12 – Slab Systems
- 18.12.4 – Tendon spacing requirements plus a minimum of two tendons shall be

provided in each direction through the critical shear section over the columns (typically through the column core).

The purpose of these examples is to show that common sense detailing will be of major assistance in dealing with Progressive Collapse. The above items are not verbatim from the ACI 318 code, but portray the essence of the requirements.

Unusual situations could warrant a performance based approach. Life Safety, no loss of life under likely events, could be considered usual while Collapse Prevention, no collapse under an unlikely event, could be considered unusual and require a performance based approach.

A performance based approach could also be used in lieu of prescriptive criteria if it meets certain performance goals, such as redundancy of structural elements allowing for multiple load paths. Perhaps the assurance of multiple load paths could also be used.

CONCLUSIONS

There are numerous examples of potential causes of Progressive Collapse. Blast or some other abnormal event may be the cause, but the problem remains the same. Structural Engineers must be aware of the potential and must be given the tools to deal with the problem.

The mystique of “blast” engineering must be solved for the practicing engineer. The licensed structural engineers can solve the design and analysis issues related to Progressive Collapse, but they must be informed about the required performance of the structure. If we can develop a standard, code or guideline that will quantify the rules, the problem will more than likely be resolved.