Tri-Service Infrastructure Systems
Conference & Exhibition
August 2 –4, 2005

Design of Buildings to Resist Progressive Collapse UFC 4-023-03

Bernie Deneke, PE
Antiterrorism Force Protection Criteria Program Manager
Structural Engineer
Naval Facilities Engineering Command, Atlantic
Phone: 757.322.4233
Email: bernard.deneke@navy.mil

ARA

WALTER P MOORE

Acknowledgements

Security Engineering Working Group (SEWG)
(Department of Defense)

Tri- Services
(Army, Navy & Marine Corp, Air Force)

Primary Authors:
David Stevens, ARA
Kirk Marchand, Walter P. Moore
Brian Crowder, NAVFAC

"Critiques and Trouble Makers"
Bernie Deneke, NAVFAC
Ed Conrath, USACE PDC
Tim Campbell, USACE PDC

Overview

- Motivated in part by recent terrorist attacks, the Department of Defense now requires explicit consideration of Progressive Collapse (PC) in the design of new buildings and retrofit of existing buildings.
- Previously, there were no US design codes that provided PC design procedures that met DoD's needs.

Overview

- The Security Engineering Working Group, through the Naval Facilities Command (NAVFAC), contracted with ARA to develop Unified Facilities Criteria 4-023-03 “Design of Buildings to Resist Progressive Collapse.”
- The UFC has been approved by the three services (Navy, Army, and Air Force) and will be officially signed in the near future.

Background

- Definition of Progressive Collapse:
  - The commentary in the American Society of Civil Engineers (ASCE) Standard 7-02 “Minimum Design Loads for Buildings and Other Structures” describes progressive collapse as
    - “the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it.”

Background

- In the United States and other Western nations, progressive collapse is a relatively rare event; to occur, it requires:
  - an abnormal loading to initiate the damage

    AND

  - a structure that lacks adequate continuity, ductility, and redundancy.
- However, significant casualties can result when progressive collapse occurs.

Background

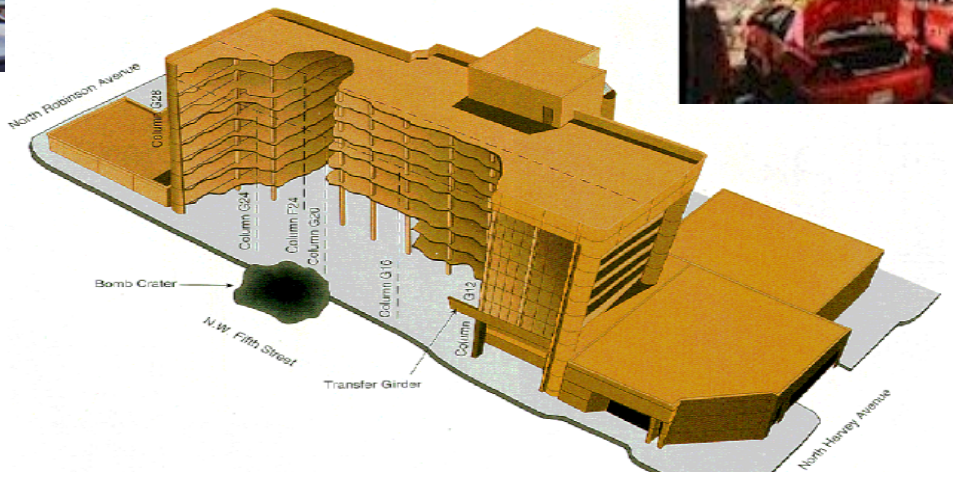
- **Ronan Point Apartment Building – London, England, May 1968**
  - Propane heater exploded on 18th floor of 24 floor building
  - Primary supporting exterior bearing panel blew out
  - Floors above collapsed down
  - Falling debris caused collapse of the lower floors, nearly to the ground
- As a result, the British adopted explicit progressive collapse design measures into their building code.

INTERNAL EXPLOSION

Background

A.P. Murrah Federal Building – Oklahoma City, Oklahoma

TERRORIST ATTACK



Background

1983

Exterior of US Embassy building in Dar es Salaam after bombing, 7 August.

u.s. embassy at nairobi, kenya

1998

1995

1996

Existing Approaches

- America:
  - ASCE and material specific codes (ACI, AISC, TMS, etc) do not provide explicit and enforceable requirements for progressive collapse.
- UK
  - Explicit requirements in RC, steel, and masonry codes.
  - Overall approach is composed of three methods:
    - Tie Forces (Indirect Design)
    - Alternate Path (Direct Design)
    - Specific Local Resistance (Direct Design)

Existing Approaches

- Proposed British Standards
  - A risk/consequence approach will be used for progressive collapse requirements, to choose structures that require PC design.
- GSA Guidelines
  - Developed by ARA, Vicksburg, for GSA.
  - Alternate Path Method is used exclusively.

Progressive Collapse Design Approach

- UFC 4-023-03, “Design of Buildings to Resist Progressive Collapse”
  - Provides the design guidance necessary to reduce the potential of progressive collapse for new and existing DoD facilities that experience localized structural damage through manmade or natural events.

Progressive Collapse Design Approach

- Applicability
  - Applies to all DoD services and to all DoD inhabited buildings of three or more stories.
  - Applies to new construction, major renovations, and leased buildings and will be utilized in accordance with the applicability requirements of UFC 4-010-01 or as directed by Service Guidance.

Progressive Collapse Design Approach

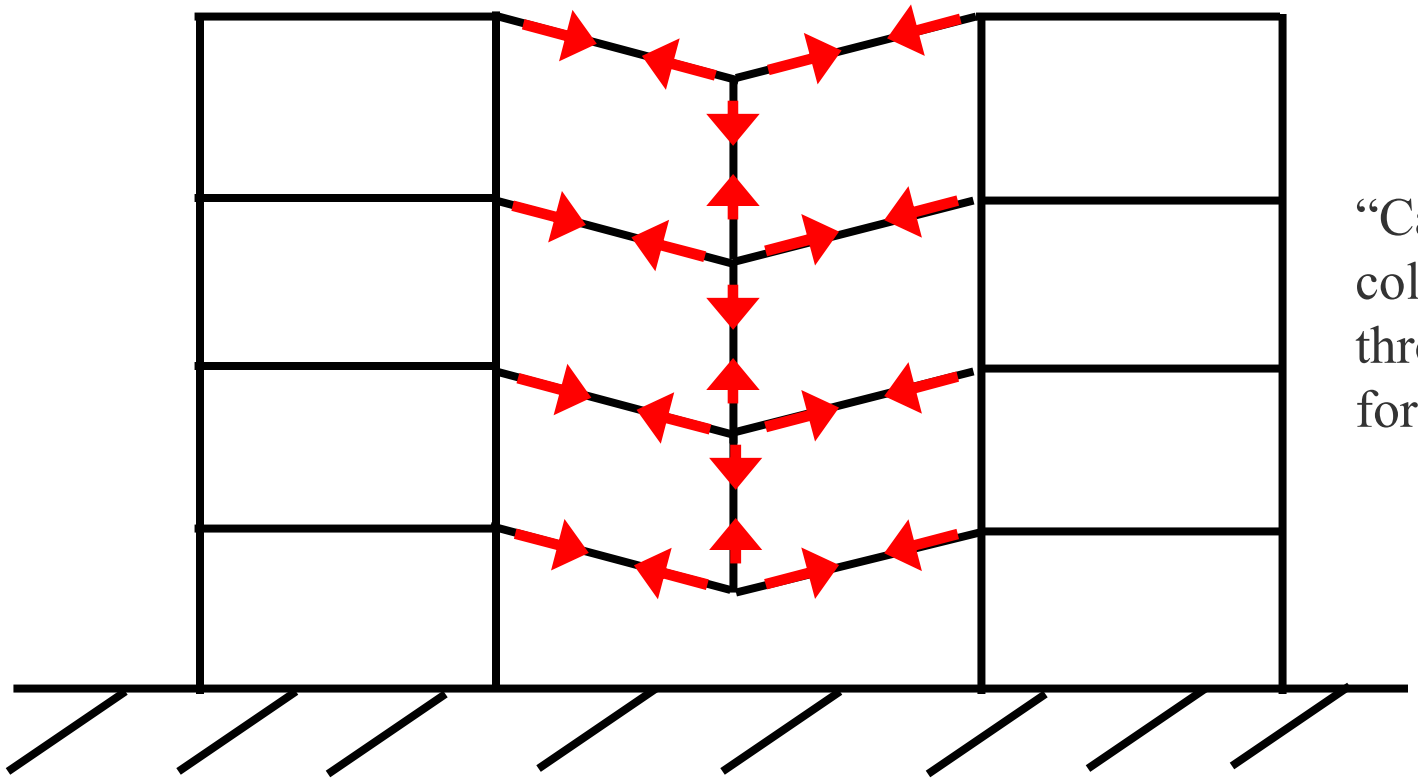
- Five materials are considered:
  1. Reinforced Concrete
  2. Structural Steel
  3. Masonry
  4. Light Frame Wood
  5. Cold-Formed Steel

Progressive Collapse Design Approach

- Design approach employs two main mechanisms:
  - Catenary (Tie Forces, Indirect Design)
  - Flexural (Alternate Path, Direct Design)

Progressive Collapse Design Approach

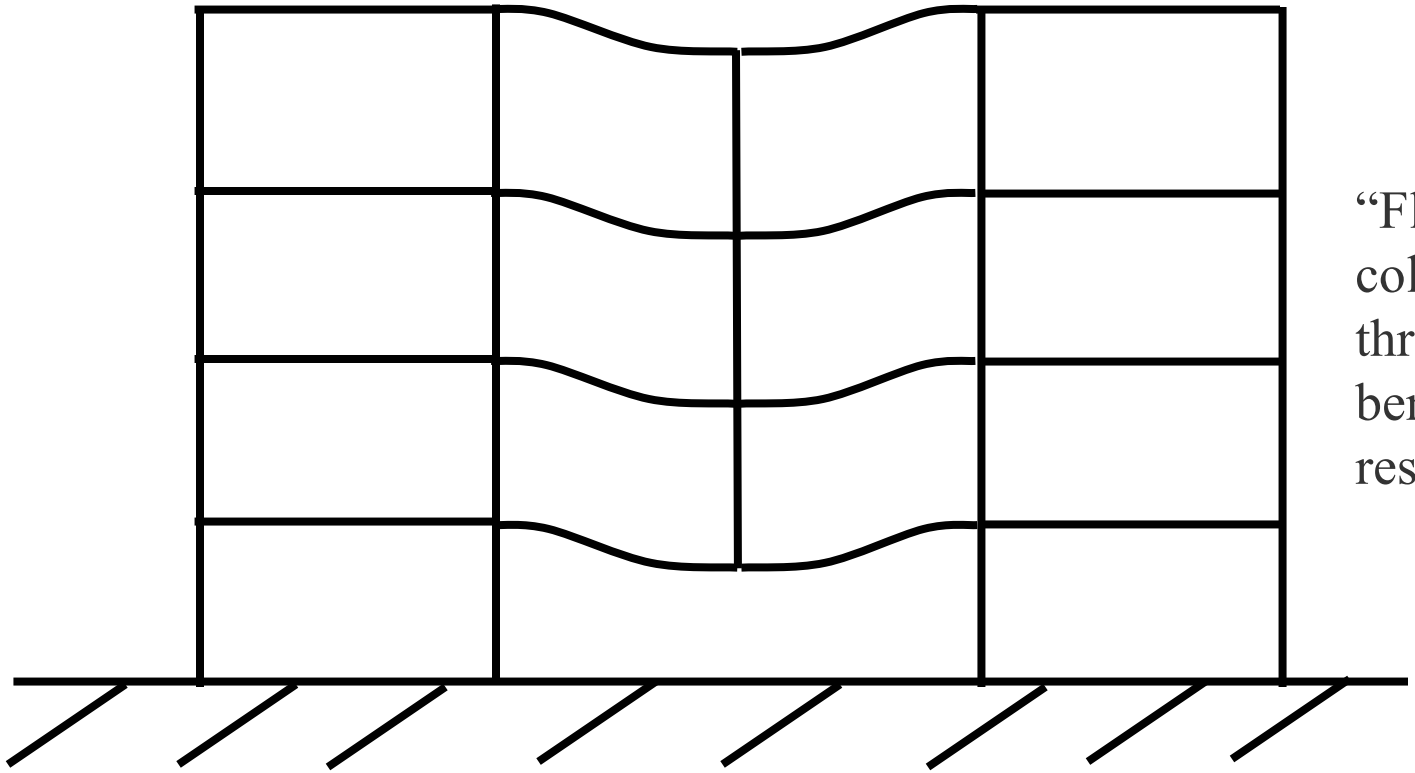
- Indirect Approach, Tie Forces



"Catenary Action"; collapse resisted through tensile forces

Progressive Collapse Design Approach

- Direct Approach, Alternate Path



"Flexural Action"; collapse resisted through bending/membrane response

Progressive Collapse Design Approach

- **The PC UFC is threat-independent and is NOT intended to address the hardening of a building that is exposed to a specific explosive threat.**
- Level of required PC design depends upon required level of protection, which is determined by the Project Planning Team.

Progressive Collapse Design Approach

Level of Protection and PC Design Requirements for New and Existing Construction

Level of Protection	PC Design Requirement
Very Low	Provide horizontal Tie Forces.
Low	Provide horizontal and vertical Tie Forces.
Medium	Satisfy the following three requirements: A) Provide horizontal and vertical Tie Forces. B) Apply the Alternate Path method. C) Meet additional ductility requirements that effectively "harden" the perimeter, ground-floor load-bearing elements
High	

Progressive Collapse Design Approach

- Levels of Protection are based on asset value.
- Thus, we cannot create a list of “typical structures”; however:
  - All inhabited buildings 3 stories and above will require at least VLLOP
  - All primary gathering buildings and billeting will require at least the LLOP
- Most DoD buildings will be VLLOP or LLOP, i.e., Tie Forces are all that’s needed.

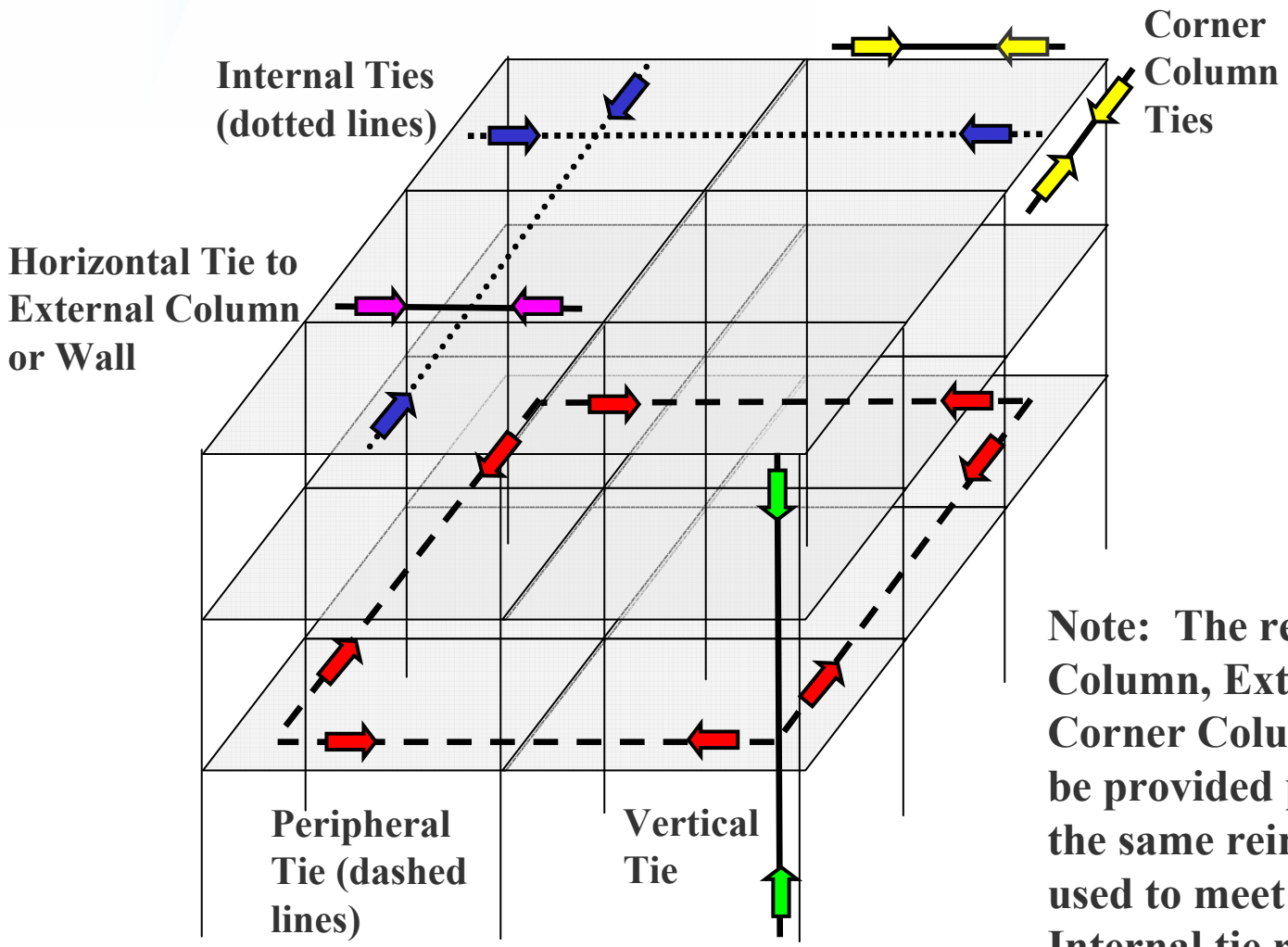
Progressive Collapse Design Approach

- LRFD approach is used for both Tie Forces and Alternate Path requirements
  - Consistent with existing material design codes.
  - May allow easier transition to the civilian world.
  - Makes use of the ASCE 7-02, Section C2.5, Load Combinations for Extraordinary Events:

$$(0.9 \text{ or } 1.2)\ D + (0.5\ L \text{ or } 0.2\ S) + 0.2\ W$$

ARA WALTER P MOORE

Progressive Collapse Design Approach



Note: The required External Column, External Wall, and Corner Column tie forces may be provided partly or wholly by the same reinforcement that is used to meet the Peripheral or Internal tie requirement.

Progressive Collapse Design Approach

- Tie Forces
  - For example, for steel

    In each direction, internal ties must have a required tensile strength (in kN) equal to the greater of:

$$0.5\ (1.2D + 1.6L)\ s_t\ L_l \qquad \text{but not less than 75 kN}$$

where: D = Dead Load (kN/m^2)

L = Live Load (kN/m^2)

L_l = Span (m)

s_t = Mean transverse spacing of the tie adjacent to the ties being checked (m)

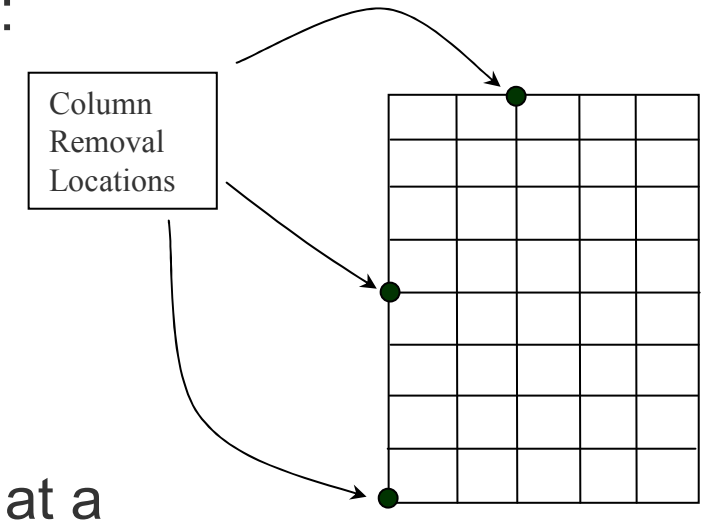
ARA WALTER P MOORE

Progressive Collapse Design Approach

- Alternate Path
  - Structure must be able to bridge over a removed element.
  - Not intended to replicate an event, but to ensure a consistent level of resistance.
  - Applied in 2 situations:
    1. An element cannot provide adequate vertical tie force—bridging must be shown.
    2. For MLOP and HLOP.

Progressive Collapse Design Approach

- Alternate Path, cont'd
  - For Alternate Path in MLOP and HLOP structures, these locations of column/wall removal are required:
    - Center of short side
    - Center of long side
    - Corner
    - Significant changes in structural system
  - Columns/walls are removed, one at a time, from EACH floor (i.e., with 8 floors, at least 24 Alternate Path analyses are required).



Progressive Collapse Design Approach

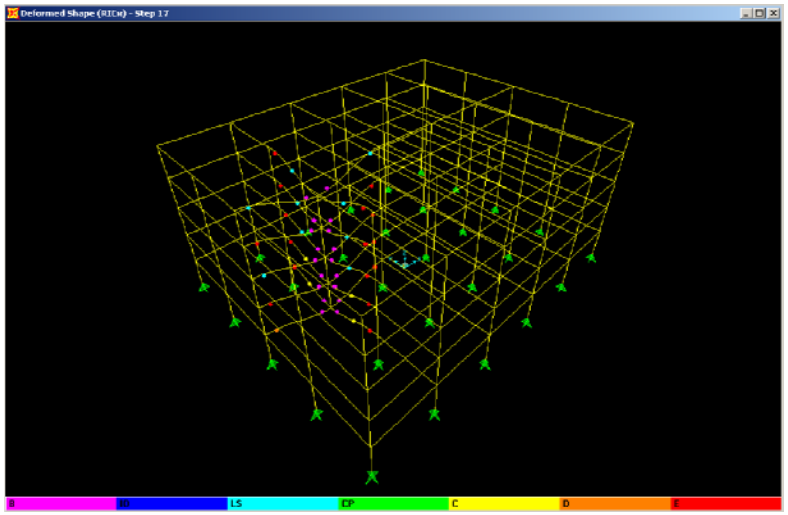
- Alternate Path, cont'd
  - Damage Limits
    - Exterior column or wall removal:
      - Local damaged area of the floor area directly above and directly below the removed element must be less than 70 m^2 (750 ft^2) or 15% of the floor area, whichever is smaller. The damage must not extend beyond the bays associated with the removed wall or column.
    - Interior column or wall removal:
      - Similar, but 140 m^2 (1500 ft^2) or 15% of the floor area, whichever is smaller.

Progressive Collapse Design Approach

- Common Design Requirements For All Construction Types
  - Increased Effective Column and Wall Height
  - Upward Loads on Floors and Slabs

Progressive Collapse Design Approach

- PC UFC contains appendices with worked examples of:
  - 5-story reinforced concrete structure.
  - 5-story steel structure
  - 3-story wood barracks



ARA WALTER P. MOORE

Summary

- The DOD UFC 4-023-03 bases the level of required progressive collapse design on the facility's required level of protection.
- Overall approach is similar to British requirements.
- Most DOD structures will be rated at Very Low or Low Level of Protection and only Tie Forces will be required; this should not be an odious demand.
- The UFC is a living document and can/will be modified in the future as engineers, designers, and facility owners provide feedback on the cost and impact on their structures.

Questions

Bernie Deneke, PE
Antiterrorism Force Protection Criteria Program Manager
Structural Engineer
Naval Facilities Engineering Command, Atlantic
Phone: 757.322.4233
Email: bernard.deneke@navy.mil