



PC UFC Briefing September 21-22, 2004

Overview of PC UFC and Required Level of Design

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Overview of PC UFC



- Purpose and Scope

- ◇ The Unified Facilities Criteria 4-023-03 *Design of Buildings to Resist Progressive Collapse* (PC UFC) provides the design requirements necessary to reduce the potential of progressive collapse for new and existing DoD facilities that experience localized structural damage through normally unforeseeable events.
- ◇ The PC UFC incorporates a prudent, effective, and uniform level of resistance to progressive collapse without expensive or radical changes to typical design practice.

Overview of PC UFC



- Applicability

- ◇ PC UFC applies to new construction, major renovations, and leased buildings and must be utilized in accordance with the applicability requirements of UFC 4-010-01 *Minimum Antiterrorism Standards for Buildings* (UFC 4-010-01) or as directed by Service Guidance.
- ◇ UFC 4-010-01 requires that all new and existing buildings **of three stories or more** be designed to avoid progressive collapse.
- ◇ See Section 1-6 of UFC 4-010-01 for additional detail on the structures that must be considered.

Overview of PC UFC



- Hardening of Structures to Resist Initial Damage
 - ◇ As the initiating event is unknown, the requirements in the PC UFC are not intended to limit or eliminate the initial damage.
 - ◇ When an explosive threat is known, guidelines for blast hardening can be found in:
 - UFC 4-013-01 *Structural Design to Resist Explosives Effects for New Buildings* and
 - UFC 4-013-02 *Structural Design to Resist Explosives Effects for Existing Buildings.*
 - ◇ **Requirements for Specific Local Resistance are only implicitly included in this UFC, through ductility requirements.**

Overview of PC UFC



SUMMARY OF PC UFC PROCEDURE

Summary of PC UFC Procedure



- As suggested by Ellingwood and Leyendecker 1977, the PC UFC employs a “combined approach”.
 - Indirect Design is used for “normal” buildings by specifying minimum levels of strength, ductility, redundancy, and continuity.
 - If the building is “unusual” or the consequences of a progressive collapse event are severe, then explicit consideration of the resistance to progressive collapse must be considered through a Direct Design approach.
 - This combined approach is thought to add minimal expense while significantly improving the ability of structures to resist progressive collapse.

Summary of PC UFC Procedure



- The design requirements were developed such that two structural response modes are available to provide different levels of resistance to progressive collapse.
 - **Catenary resistance**, by specifying Tie Forces,
 - **Flexural resistance**, through the Alternate Path method.
- The overall techniques for both the TF and AP approaches are the same for each construction type, but the details vary with construction type.

Summary of PC UFC Procedure



- *For existing and new construction, the level of progressive collapse design is correlated to the structure's Level of Protection (LOP).*
- Project Planning Team develops and provides the LOP to the designer/engineer.
 - ◇ Note: The engineers/designers don't determine the LOP—that's the Project Planning Team's responsibility.

Summary of PC UFC Procedure



- Procedure for developing LOP is given in UFC 4-011-01
- The LOP is based on the facility's asset value, and is a function of:
 - ◇ mission criticality to the asset's user,
 - ◇ mission criticality to higher level commands,
 - ◇ replaceability,
 - ◇ political sensitivity, and,
 - ◇ relative value.

Summary of PC UFC Procedure



- Very Low Level of Protection (VLLOP)
 - ◇ Only horizontal tie forces are required.
- Low Level of Protection (LLOP)
 - ◇ Horizontal and vertical tie forces are required.
- Medium and High Level of Protection (MLOP, HLOP) are lumped together.
 - ◇ Horizontal and vertical tie forces are required.
 - ◇ Alternate Path is required.
 - ◇ Additional ductility requirements for ground floor, perimeter members are required.

Summary of PC UFC Procedure



- Since a structure's LOP is based on the asset value, 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 LLOP.

Summary of PC UFC Procedure



- **It is expected that the majority of new and existing DoD facilities will be assigned VLLOP or LLOP:**
 - ◇ Design to resist progressive collapse will ONLY require the application of the Tie Force criteria.
 - ◇ For many buildings, these requirements should be met without much difficulty and can usually be satisfied by application of good connection detailing practice.

Overview of PC UFC



REQUIRED LEVEL OF DESIGN

Required Level of Design



- For both new and existing structures, the Project Planning Team will develop and provide the design criteria, which will include the Level of Protection, as determined by UFC 4-011-01.
- This LOP is used to define the corresponding level of progressive collapse design for new and existing construction as detailed in Section 2-1 in the PC UFC.
- Additional common design requirements for all construction types and all Levels of Protection are given in Section 2-2 in the PC UFC.

Required Level of Design



- Chapter 3 "Design Strategies" provides the general requirements for applying the Tie Forces (TF) and Alternate Path (AP) approaches.
- **The overall techniques for both the TF and AP approaches are the same for each construction type, but the details vary with construction type.**
- Chapters 4 through 8 provide the material specific design requirements.

Required Level of Design



- **Identical requirements are specified for both new and existing construction!**
 - ◇ For new construction, implementation is straightforward.
 - ◇ For existing construction, retrofit designs will be needed if the building violates the criteria.
 - These may not be trivial.
 - This is similar to GSA philosophy.
 - There is no magic bullet or easy dodge—you have to spend the time and money to upgrade.

Required Level of Design

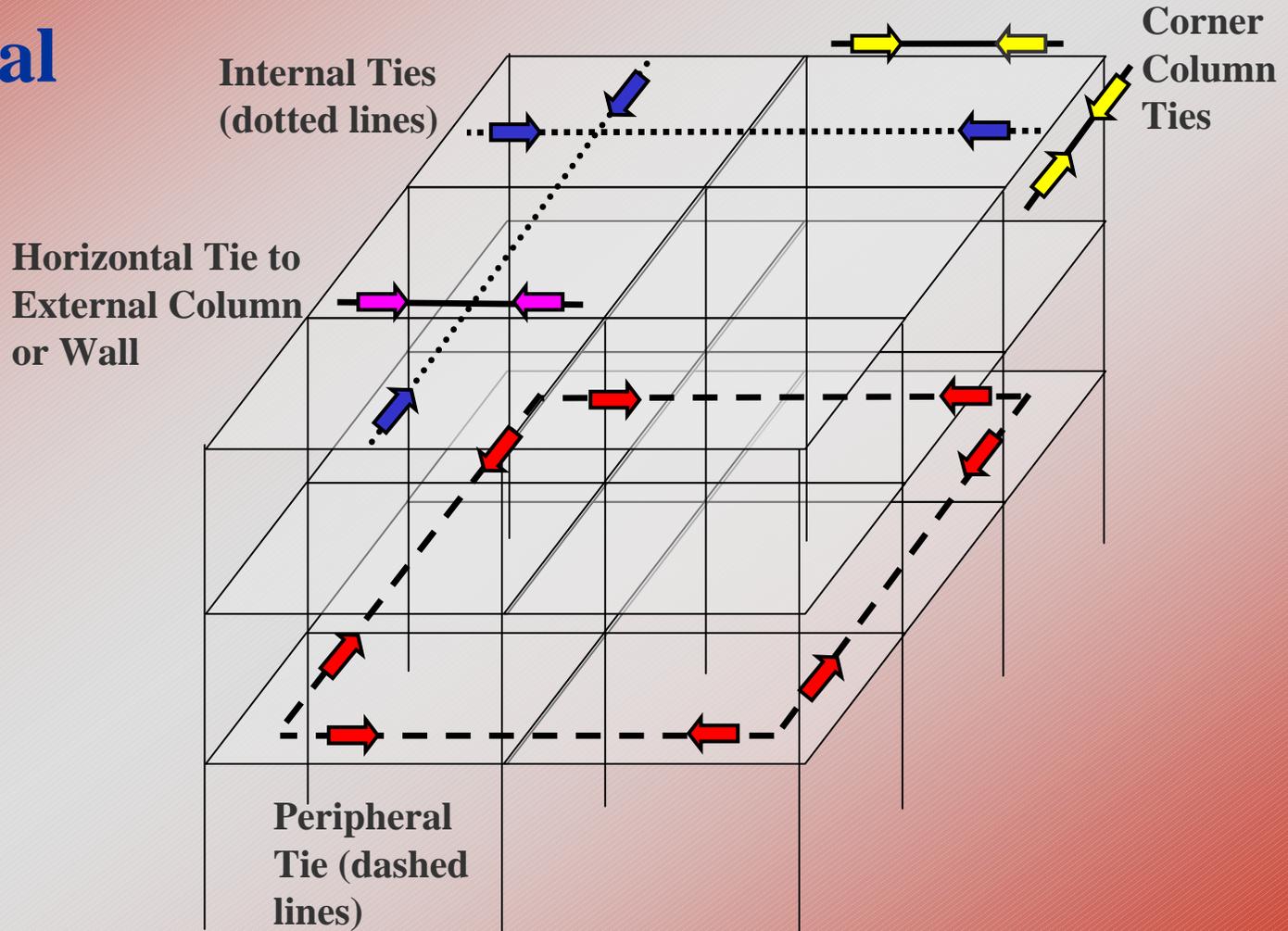


- Very Low Level of Protection Design Requirement
 - ◇ A VLLOP structure must only provide adequate horizontal tie force capacity.
 - ◇ The designer **cannot** use the Alternate Path method to verify that the structure can bridge over an element with inadequate horizontal tie force capacity.
 - ◇ If a structural element does not provide the required horizontal tie force capacity, it must be
 - re-designed in the case of new construction, or
 - retrofitted in the case of existing construction.

Required Level of Design



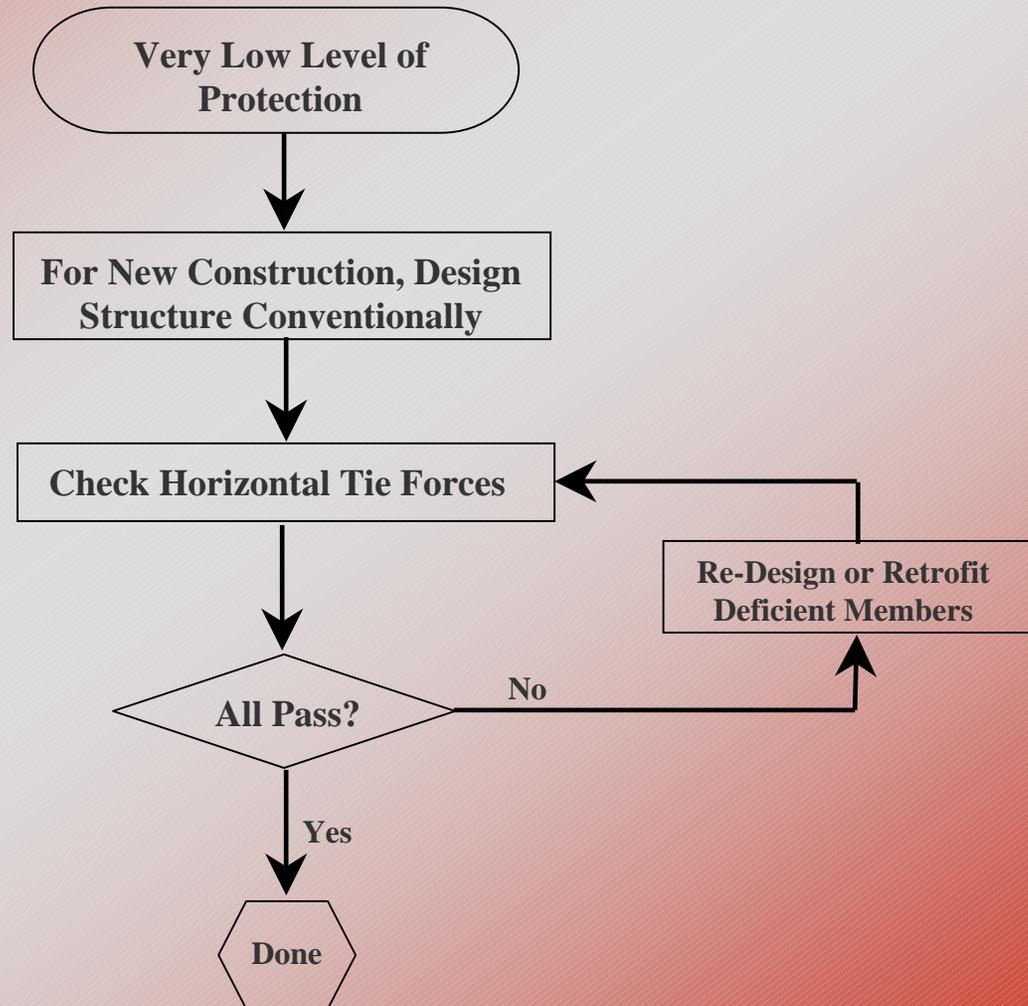
Horizontal Ties



Required Level of Design



Flow Chart for
PC Design of
VLLOP
Structures



Required Level of Design



- Low Level of Protection Design Requirement
 - ◇ LLOP structures must incorporate both horizontal and vertical tie force capacities.
 - ◇ If a structural member or connection cannot provide the required **vertical** tie force capacity, the designer may use the AP method to prove that the structure can bridge over the element when it is removed.

Required Level of Design

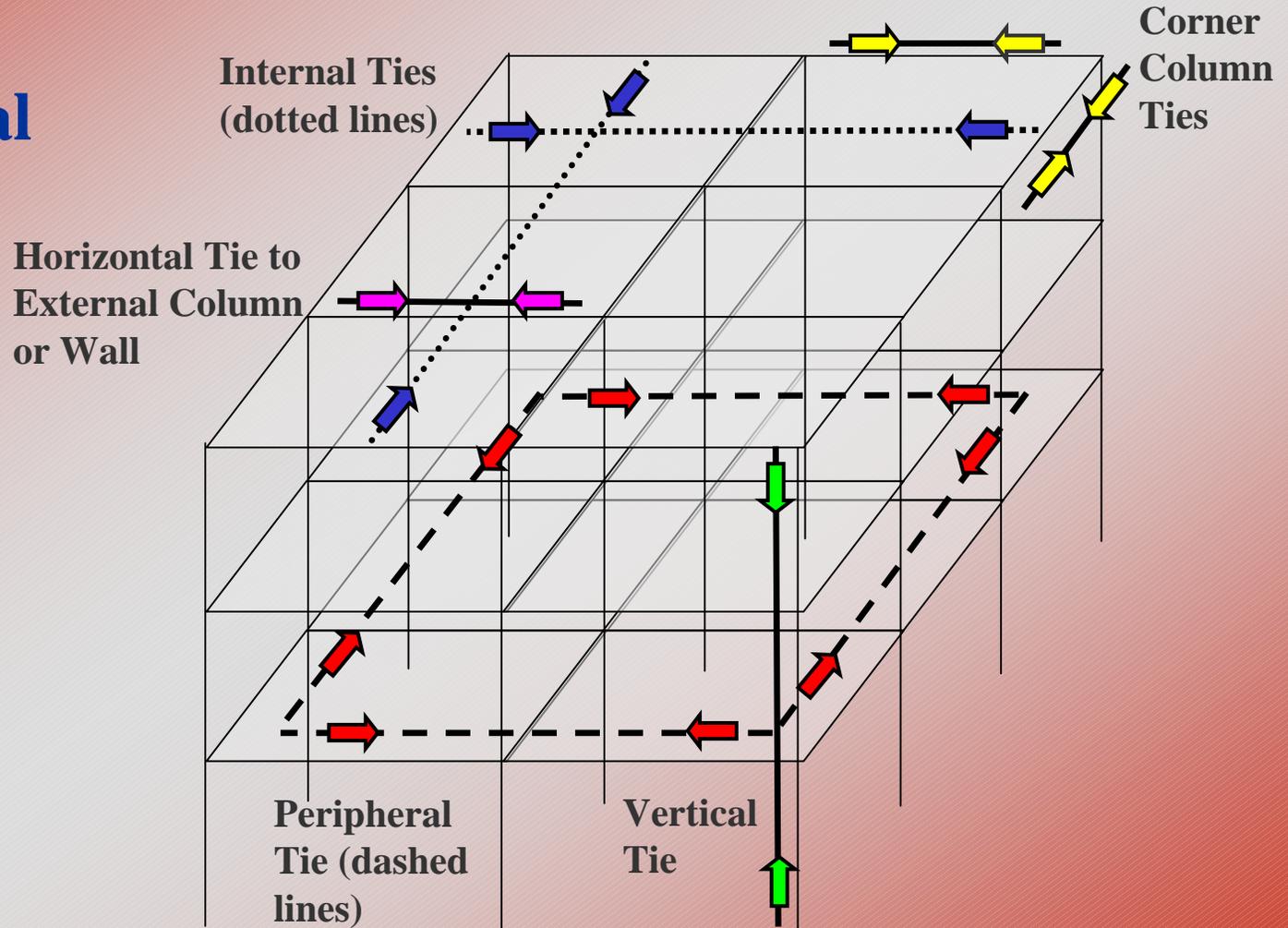


- Low Level of Protection Design Requirement, cont'd
 - ◇ For elements with inadequate horizontal tie force capacity, the Alternate Path method **cannot** be used. The designer must
 - re-design the element in the case of new construction, or,
 - retrofit the element in the case of existing construction.

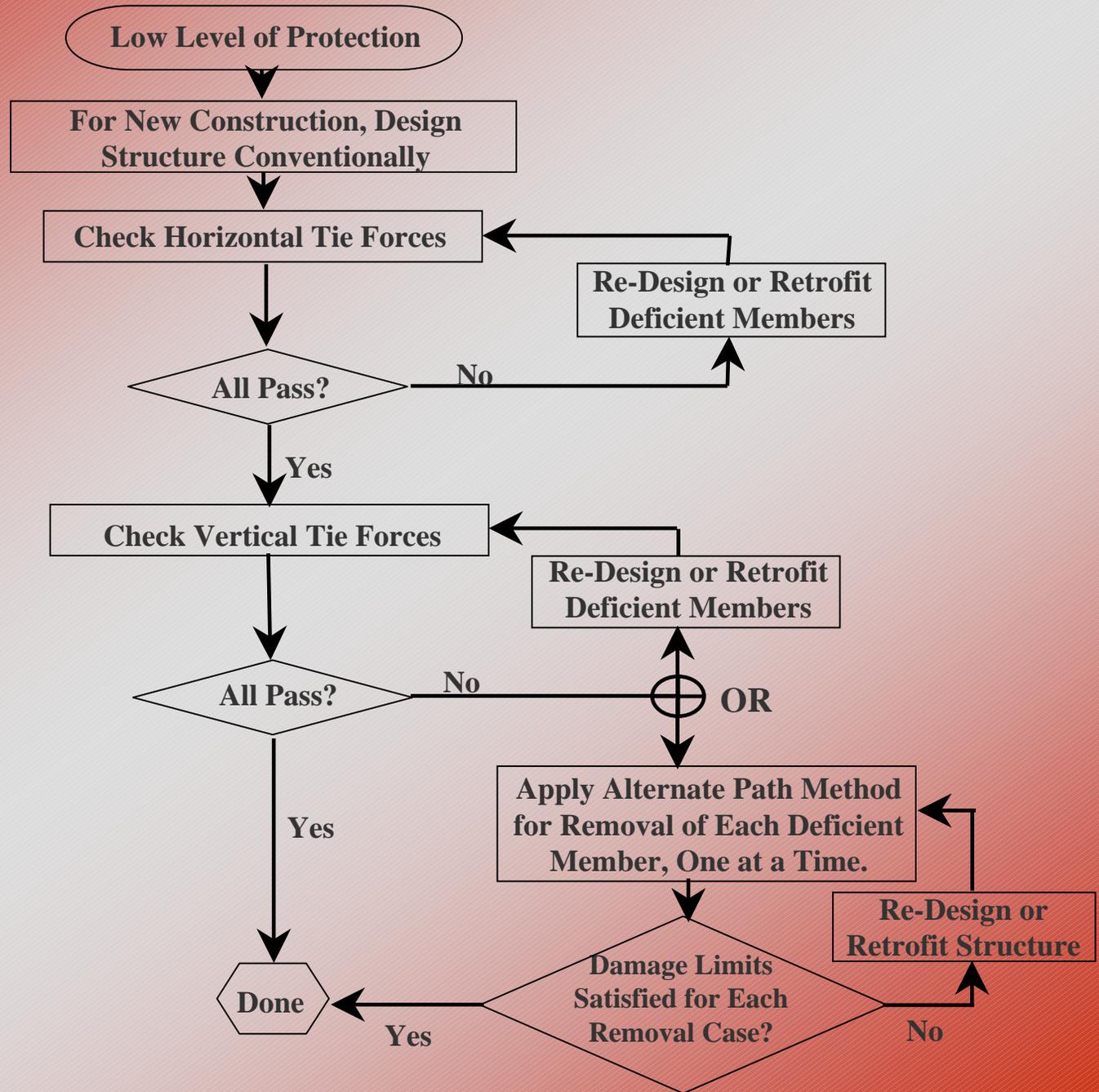
Required Level of Design



Horizontal and Vertical Ties



Flow Chart for PC Design of LLOP Structures



Required Level of Design



- MLOP and HLOP Design Requirement
 - ◇ MLOP and HLOP are treated exactly the same.
 - ◇ Three requirements must be met:
 - 1) Tie Force Requirements for MLOP and HLOP
 - Horizontal and vertical tie force capacities must be provided.
 - If a structural member cannot provide the vertical tie force capacity, the designer may use the AP method to prove that the structure can bridge over the element when it is removed.

Required Level of Design



- MLOP and HLOP Design Requirement, cont'd
 - 1) Tie Force Requirements for MLOP and HLOP, cont'd
 - For elements with inadequate horizontal tie force capacity, the Alternate Path method **cannot** be used. The designer must:
 - re-design the element in the case of new construction, or,
 - retrofit the element for existing construction.

Required Level of Design



- MLOP and HLOP Design Requirement, cont'd
 - 2) Alternate Path Requirements for MLOP and HLOP
 - The structure must be able to bridge over specific vertical load-bearing elements that are notionally removed from the structure.
 - The plan locations of the removed vertical load-bearing elements are described later.
 - For each plan location of a removed element, an Alternate Path analysis must be performed for every floor, one at a time
 - if there are three plan locations and eight stories, twenty four AP analyses must be performed.

Required Level of Design



- MLOP and HLOP Design Requirement, cont'd
 - 2) AP Requirements for MLOP and HLOP, cont'd
 - If bridging (Alternate Path) cannot be demonstrated for one of the removed load-bearing elements, the structure must be re-designed or retrofitted.
 - **Note that the structural re-design or retrofit is not applied to just the deficient element**, i.e., if a structure cannot be shown to bridge over a removed typical column at the center of the long side, the engineer must develop suitable or similar re-designs or retrofits for that column and other similar columns.

Required Level of Design



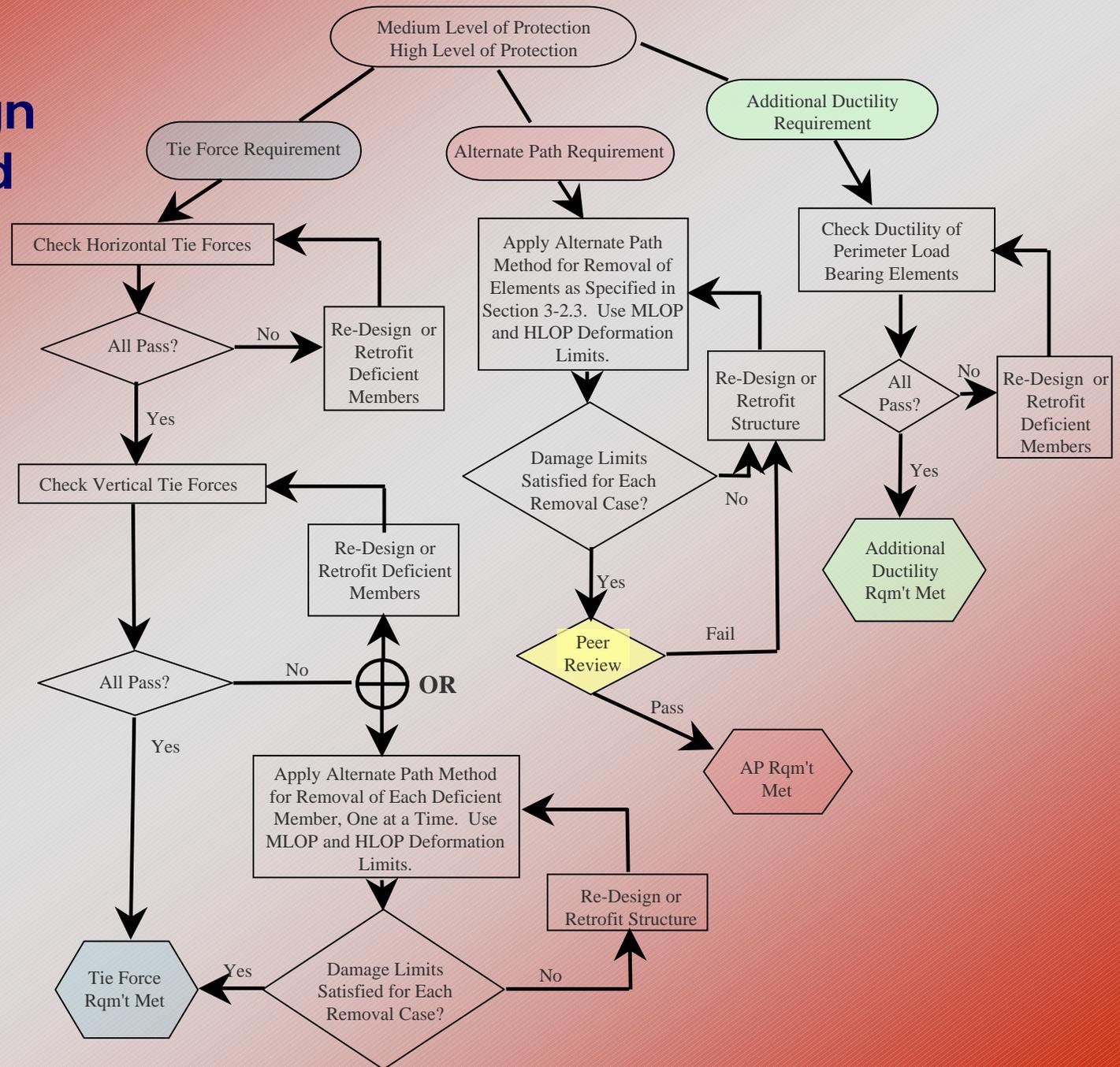
- MLOP and HLOP Design Requirement, cont'd
 - 2) AP Requirements for MLOP and HLOP, cont'd
 - For MLOP and HLOP structures, a peer review must be performed and documented for all Alternate Path analyses.
 - The reviewer must be an independent organization with demonstrated experience performing progressive collapse design.

Required Level of Design



- MLOP and HLOP Design Requirement, cont'd
 - 3) Additional Ductility Requirements for MLOP and HLOP
 - All **perimeter ground floor** columns and load-bearing walls must be designed such that the shear capacity is greater than the flexural capacity, including compression membrane effects where appropriate.

Flow Chart for PC Design of MLOP and HLOP Structures



Required Level of Design



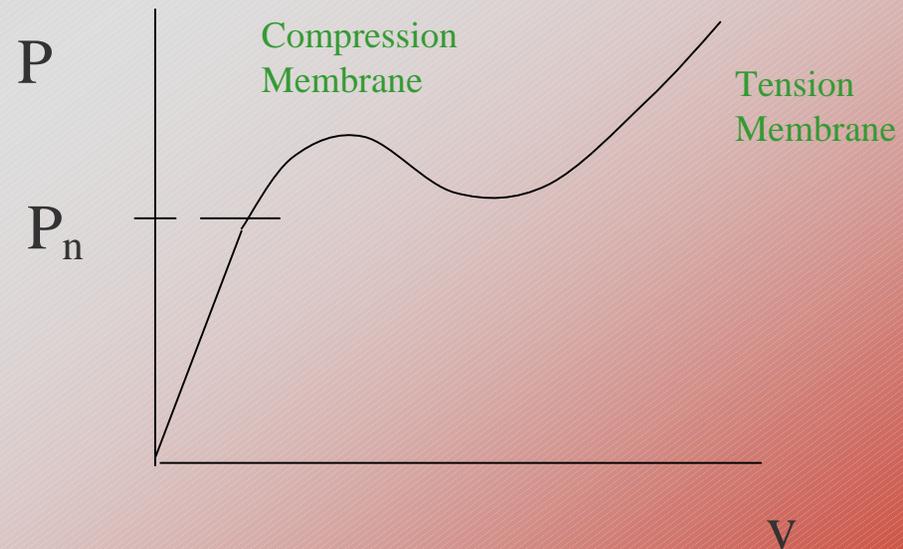
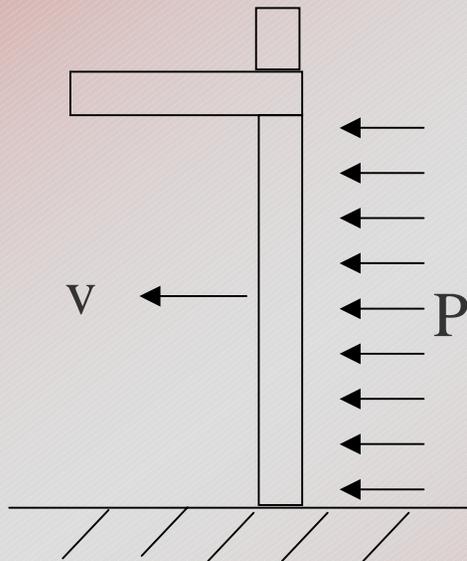
- Additional Ductility Requirements
 - Additional ductility requirements are specified for all construction types, for structures with MLOP or HLOP.
 - The main goal is to insure that the failure mode for all external columns and walls is flexural and ductile, rather than shear and brittle, by requiring that the shear strength exceed the flexural strength.

Required Level of Design



- Additional Ductility Requirements

- As the flexural strength can often be increased by compression membrane effects under dynamic load, the engineer must consider this in determining the capacity of the columns and walls.



Required Level of Design



- Additional Ductility Requirements, cont'd
 - Park and Gamble 1999 and UFC 3-340-01 provide guidance on compression and tension membrane effects.
 - For reinforced concrete columns, the shear capacity can be increased by simply increasing the number of column stirrups or by providing spiral reinforcement.

Required Level of Design



- Additional Ductility Requirements, cont'd
 - Shear capacity can also be increased by adding external hoop reinforcement in the form of circular or square steel or composite jackets, which can be used as stay-in-place forms.
 - For structural steel columns, the shear capacity can be enhanced by filling the section core with concrete and enclosing with steel plates.
 - For masonry walls, fiber-impregnated polymer coatings can be applied to one or both surfaces.

Required Level of Design



- Additional Ductility Requirements, cont'd
 - Due to the numerous ways that ductility and shear strength can be enhanced, no specific guidance is given herein.
 - However, **the analysis and design approaches must be based on methods or data that are approved by the authority having jurisdiction.**

Required Level of Design



- UFC specifies **common design requirements** for all levels of protection (VLLOP through HLOP), for all new and existing construction.
 - ◇ Effective Column and Wall Height
 - In an extreme event, it is possible that a floor system will be destroyed and a column will lose lateral support.
 - Thus, all multistory vertical load carrying elements must be capable of supporting the vertical load after the loss of lateral support at any floor level (i.e., a laterally unsupported length equal to two stories must be used in the design or analysis).

Required Level of Design



- Common Design Requirements, cont'd
 - ◇ Effective Column and Wall Height, cont'd
 - Use the load combination in Section 3-2.4.1 for Nonlinear Dynamic AP analysis.
 - Use the appropriate strength reduction factors and over-strength factors as specified in Chapters 4 to 8.

Required Level of Design



- Common Design Requirements, cont'd

- ◇ Upward Loads on Floors and Slabs

- For DoD facilities, significant upward loads may be created by direct fire weapons.
- In each bay and at all floors and the roof, the slab/floor system must be able to withstand a net upward load of the following magnitude:

$$1.0 D + 0.5 L$$

where $D =$ Dead load (kN/m² or lb/ft²)

$L =$ Live load (kN/m² or lb/ft²)

Required Level of Design



- Common Design Requirements, cont'd
 - ◇ Upward Loads on Floors and Slabs, cont'd
 - This load is applied to each bay, one at a time, i.e., the uplift loads are not applied concurrently to all bays.
 - The floor system in each bay and its connections to the beams, girders, columns, capitals, etc, must be designed to carry this load.
 - A load path from the slab to the foundation for this upward load does not need to be defined.