Comparison of US Blast Design Procedures and Protection Requirements

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Presentation Outline

- Design Basis Threat
- Performance Objectives
- Blast Analysis and Design Procedures
- Ongoing Protective Construction Design Issues
- Conclusions

Design Basis Threat

Antititerrorism

- Determine on a project specific basis; DoD planners use cost and risk analyses to evaluate antiterrorism and security options.
- Typically external.
- Specific threats (explosives hazards) unknown.
- Distance often used to mitigate potential explosives hazards (e.g., safety bollards maintain minimum vehicle standoff from building).

Conventional Weapon Attack

- Typically external.
- Site-specific threat(s) determined by military experts; explosives hazards from conventional weapons usually known.

Explosives Safety

- Internal and external; separation distances often used to satisfy protection requirements external detonation.
- Explosives type/weight, configuration and location defined by user.

Performance Objectives

Antiterrorism - Reduce collateral damage and the scope and severity of mass casualties in the event of a terrorist attack.

Hardened Structures - Continue to perform primary (military) mission after attack using conventional (non-nuclear) weapons

Explosives Safety - Provide the maximum possible protection to people and property from the potential damaging effects of DoD military munitions, and minimize exposures *consistent with safe and efficient operations (emphasis added).*

Blast Analysis and Design Procedures

UFC 4-010-01, '"DoD Minimum Antiterrorism Standards for Buildings," with Change 2 (2022)

- Glazing requirements seek to limit glass injuries
- Apply UFC 4-023-04, "Design of Building to Resist Progressive Collapse," to buildings of 3 stories or more.

ASCE/SEI Standard 59-22, "Blast Protection of Buildings" (2022)

- Voluntary standard.
- Applies protection levels and response limits in UFC 4-010-01.
- Per scope, ASCE/SEI 59-22 is not applicable to "…potential accidents involving ammunition or explosives during their development, manufacturing, testing, production, transportation, handling, storage, maintenance, modification, inspection, demilitarization or disposal."
- Heavy focus on response of conventional structural elements to blast (shock) load from an external, far range detonation.
- Fragmentation and thermal hazards typically ignored.

Blast Analysis and Design Procedures

UFC 3-340-01, "Design and Analysis of Hardened Structures to Conventional Weapon Effects" (2002)

- Written for engineers with working knowledge of weapons effects, structural dynamics, and the design of hardened, protective structures.
- Structural elements hardened, as needed, to withstand design blast loads and fragmentation hazards.
- Includes detailed data on weapon characteristics and algorithms for predicting weapon fragmentation.
- Due to sensitivity of weapons data, distribution is limited to US Government agencies and their contractors.
- Development of a major update is ongoing.

Blast Analysis and Design Procedures

UFC 3-340-02, "Structures to Resist the Effects for Accidental Explosions," with Change 2 (2014)

- Satisfy DESR 6055.09 explosives safety protection requirements by applying blast design requirements for one of four protection categories.
- Initially published in 1969 as Army TM 5-1300/NAVFAC P-397/AFR 88-22
- Straightforward blast load prediction, analysis and design procedures, illustrated by step by step example problems
- Open distribution has led to widespread use on protective construction designs for a variety of applications.
- Applied in ACI 370R-14's blast design chapter.
- Change 3 in development; planned issuance in CY 24

UFC 3-340-02 Protection Categories

- Protection Category 1 – Protect personnel from higher risk explosives operations
  - Incident blast overpressure ≤ 2.3 psi [15.9 kPa].
  - Fragment energy ≤ 58 ft-lb [79 joules]
  - Thermal flux ≤ 0.3 calorie per cm^2 [12.56 kW per m^2]
- Protection Category 2 – Protect equipment, supplies and stored explosives
- Protection Category 3 – Prevent communication of detonation.
- Protection Category 4 – Prevent mass detonation of explosives.

Ongoing Protective Construction Design Issues

Use of UFC 3-340-02 to satisfy protection requirements which are beyond the UFC's scope and supporting detonation tests

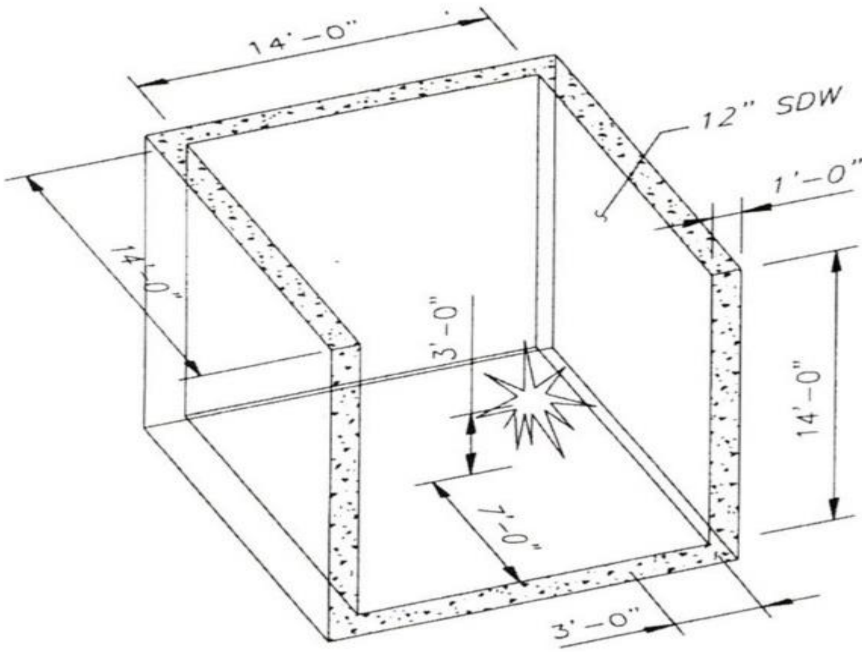
- UFC 3-340-02 was initially developed in 1969 to consolidate knowledge gained from detonation tests sponsored by DDESB's "Work Group to Determine the Effectiveness of Dividing Walls in the Prevention of Propagation of Explosions."

- Since then, the UFC has been updated several times to incorporate knowledge gained through subsequent DDESB/Service detonation tests and related research.

- Nonetheless, UFC 3-340-02's scope is largely limited to the structural elements in typical Services explosives facilities.

- In recent years, designers have increasingly developed protective construction designs which are outside the scope of the detonation test data upon which UFC 3-340-02 is based; in such cases, DDESB staff search for explosives test data to validate the protection afforded by the design against DESR 6055.09/explosives safety requirements.

Typical Service Partial Blast Containment Cell



- Interior cubicle dimensions usually range from 10-feet to 25-feet.
- Exterior wall and roof of legacy cubicles were inset and were constructed of lightweight/frangible materials; access to cubicle was usually provided through a door in the exterior wall.
- Partial blast containment cubicles designed after TM 5-1300/UFC 3-340-02's initial publication in 1969 retained frangible exterior wall but often replaced frangible roof with hardened, reinforced concrete slab.

Ongoing Protective Construction Design Issues

- UFC 3-340-02 focuses on:
  - Calculation of blast loads from an internal detonation.
  - Design of continuously supported reinforced wall/roof slabs to mitigate blast effects from an internal and/or close-in detonation.
  - Design of corrugated metal deck wall/roof systems to facilitate cubicle venting (frangible outward/hardened inward).
- The reinf. concrete walls in partial blast containment cubicle detonation tests did not have openings, so UFC 3-340-02 does <u>not</u> consider:
  - Thermal hazards behind interior doors/penetrations or from a floor trench which passes under an interior wall into a protected area.
  - Protection from accidental HD 1.3 (mass fire) ignition
    - Overpressures gradually increase (no shock load); rate of increase depends on numerous variables (chemical configuration of explosives material, presented surface area, etc.)
    - Temperatures often much higher than conventional fires
    - In poorly vented cubicles, coincident blast overpressures and fire may substantially increase hazards behind interior openings.

Ongoing Protective Construction Design Issues

"Shopping" for blast design requirements - Applying less rigorous blast design requirements developed by another user community which don't satisfy DESR 6055.09 (explosives safety) protection requirements.

UFC 3-340-02's reinforced conc. design requirements based on ACI 318.

UFC 3-340-02 expands upon ACI 318 requirements when detonation tests indicate an unacceptable risk of a non-ductile, premature failure or unacceptable exposures to explosives hazards in a MCE (e.g., personnel exposures to concrete spall/building debris).

- UFC 3-340-02's supplementary design requirements are typically applied when protecting from a close-in detonation and/or an internal detonation in which reinforced concrete elements may be placed in tension.
- Other requirements may reflect parametric limits of detonation test data (e.g., rebar/stirrup configurations considered in spall/breach tests).
- Substantial construction delays/cost impacts have occurred when a designer ignores UFC 3-340-02 requirements; Service must either redesign or accept the risk created by each non-conformance.

Ongoing Protective Construction Design Issues

Determination of antiterrorism/physical security requirements without considering explosives safety impacts

Example (partial blast containment cubicle design)

- Replaced lightweight/frangible exterior wall and roof vent surfaces with hardened reinforced concrete elements
- Hardened/increased mass and blast resistance of exterior door(s)
- Minimized vending to exterior
- Increased confinement directs explosives hazards into building rather than away from it; longer duration overpressures will direct thermal hazards through interior door/penetration openings into protected areas.
- Analytical/design procedures to evaluate thermal hazards behind interior doors/penetrations/trenches have not been developed. Critical issue when accidental HD 1.3 (mass fire) ignition is possible.

Ongoing Protective Construction Design Issues

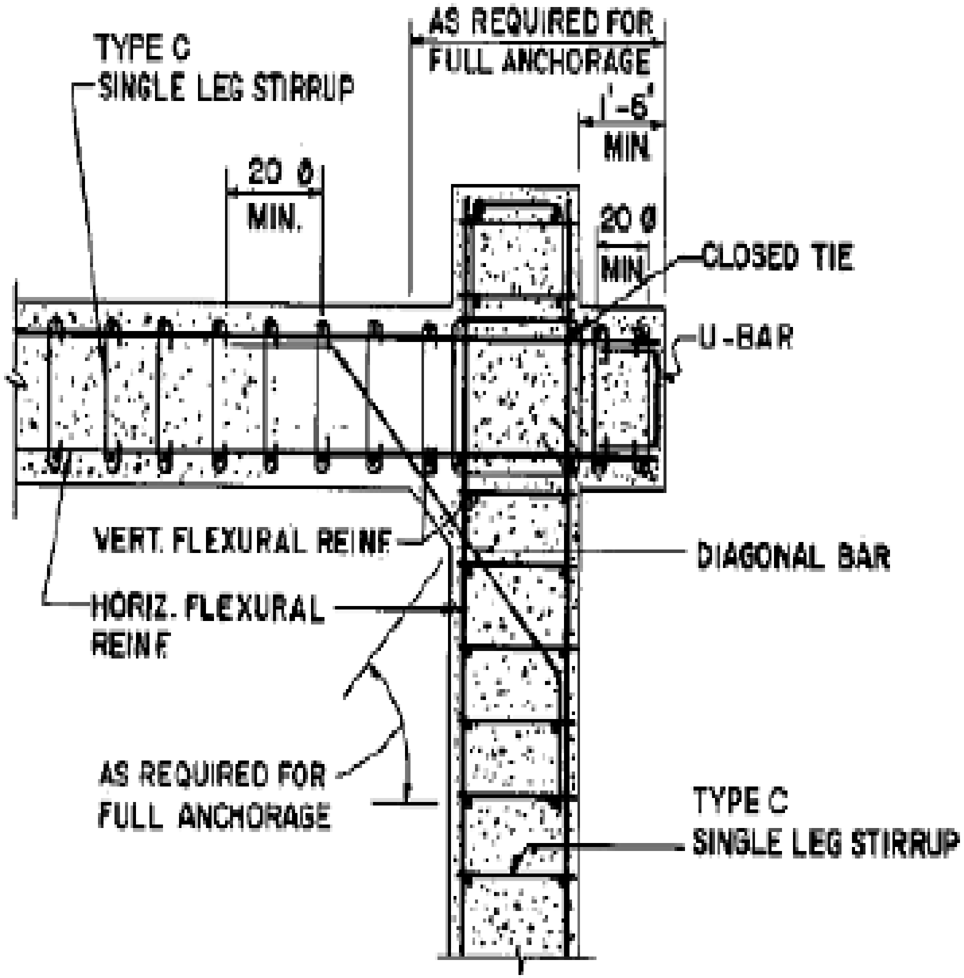
Misuse of blast analysis/design software (often due to inadequate understanding of the software's technical bases and permissible uses)

- Varying (elastic) damping ratio until blast design satisfies (highly inelastic) response/deflection limit.
- Adding area of a steel fragmentation plate (attached to a concrete wall) to rebar area when calculating a wall's ultimate resistance.
- Heavy reliance on software increases risk of missed blast design requirements.

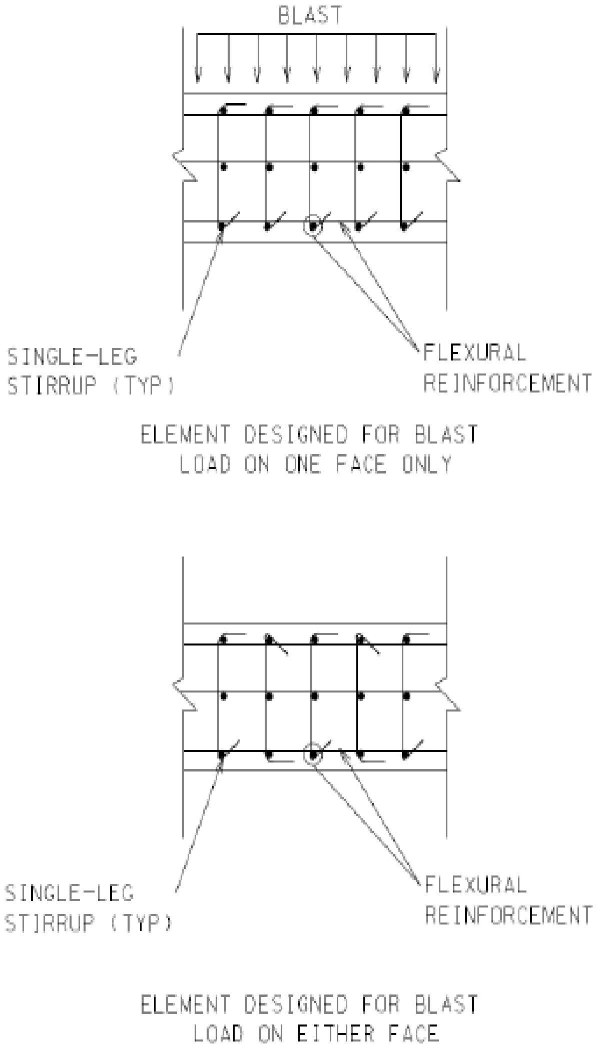
Overdesign

- In UFC 3-340-02, structural elements are first designed in flexure to satisfy applicable response limits.
- An element's ultimate resistance then is used to determine design requirements in diagonal tension, direct shear, and direct tension.
- An overdesign increases rebar congestion, complicating rebar installation and concrete placement and negatively impacting cost and schedule.

Typical Blast Wall/Slab Rebars (Explosives Safety)



External blast at scaled charge standoff ≤ 1.0 (Type C stirrups)



Prot. Cat. 1– Internal blast at scaled charge standoff > 1.0

Avoid Overdesign

Conclusions

- Identify all uses of protective construction before initiate design; recognize that in some buildings, blast design performance requirements from multiple users may apply.
- Do not mix levels of protection and blast design requirements applied by different user communities.
- Use design charrettes to eliminate proposed building configurations which present unacceptable/unduly severe explosives hazards to (protected) personnel/property.
  - Consider feasibility of confinement and shelter concepts.
  - On confinement type designs, consider locating partial blast containment cubicles along one side of a building and vent hazards away from the building.
- **Research/testing needed to investigate knowledge/data gaps and to develop analytical/design procedures to mitigate new/evolving hazards.**