Design Roadmap for Explosives Safety Protective Construction

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NAVFAC EXWC

CI7, Explosion Effects and Consequences

Overview

- Role of Protective Construction (PC) within explosives safety
- Understanding QD violations as a design basis for PC
- Some key considerations for PC designers
  - Design loads/load prediction tools
  - Dynamic structural analysis
  - Reinforced concrete/steel design
- PC validation

Explosives Safety Standards

- **Applicable explosives safety standards for storage and operations defined in:**
  - **DoD Manual 6055.09-M, "DoD Ammunition and Explosives Safety Standards"**
- **Explosives safety quantity-distance (ESQD)**
  - **Or QD, defines the required standoff distance necessary to achieve an acceptable level of protection for a given facility/location from a given quantity of ammunition and explosives (A/E)**
- **When QD distances aren't satisfied, protective construction (PC) may be used to provide equivalent protection**

- **To design PC, it is important to understand what aspects of QD were violated**
- **Four predominant exposures within QD**
  - **Inhabited Building Distance (IBD)**
  - **Public Traffic Route Distance (PTRD)**
  - **Intraline Distance (ILD)**
  - **Intermagazine Distance (IMD)**
- **Six Hazard Class/Division (HD) defined for DoD A/E**
  - **Predominant explosion effects of three most prevalent:**
    - HD 1.1: Mass exploding, blast and fragment hazard
    - HD 1.2: Non-mass exploding, fragment and blast hazard
    - HD 1.3: Mass fire (blast and fragmentation negligible)
  - **PC design criteria is written considering effects of HD 1.1 since it is generally the most hazardous**

Basic QD Principles

- For IBD (personnel protection), acceptable hazard levels are as follows:
  - –Overpressure: Peak pressure limited to 1.2 psi for < 100K lbs (0.9 psi for >250K lbs)
  - –Debris/Fragments: Less than one hazardous fragment (KE > 58 ft-lbs) per 600 ft^2 (Equates to approximately a 1% chance of getting hit with a piece of debris that would likely cause injury or fatality)
  - –Thermal: Prevent onset of 2^{nd} degree burns
- QD distances are based on the AE's effects requiring the largest distance

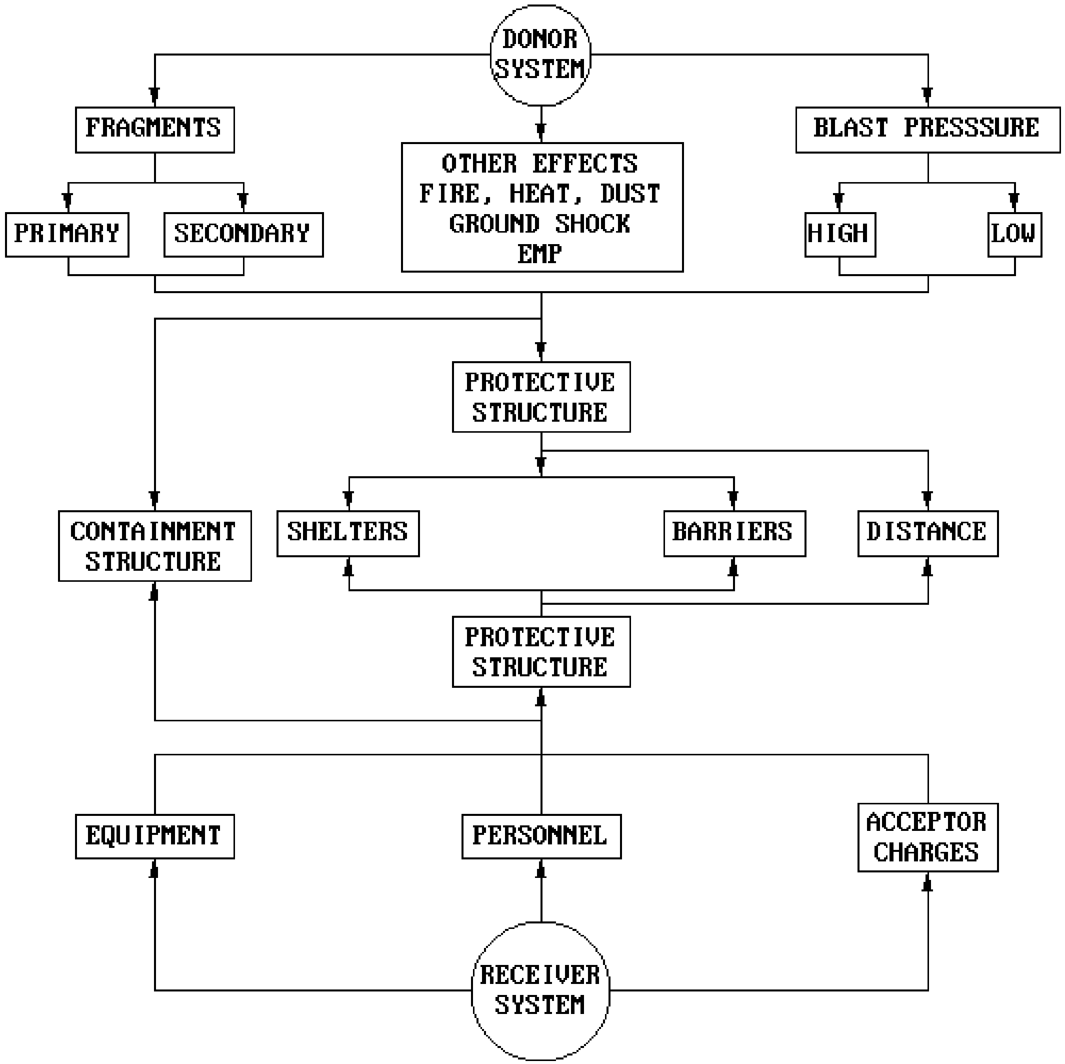
Explosion Effects on Protective Construction (VIDEO)

- **For explosives safety, protective construction requirements are defined in UFC 3-340-02, "Structures to Resist the Effects of Accidental Explosions"**
- **Protective construction is defined as falling into one of three categories:**
  - **Existing, approved protective construction design**
    - Earth-covered magazine (ECM), e.g., Box Type C or Navy MSM
    - Missile Test Cell
  - **Modification of a previously approved protective construction design**
    - Modification of an approved ECM potentially effecting its blast response (e.g., crane installation supported by roof, widening of ECM, etc.)
    - Modifications do not apply to below grade site adaptations
  - **New Protective Construction Design**
    - Can apply to construction of a brand new facility or repurposing of an existing facility for explosives safety operations

- **PC structure types**
  - **Shelters: protect acceptor system (assets and people)**
    - Generally far from donor system, so thermal effects don't control
    - External building envelope (exterior walls, doors/windows, roof) must resist blast effects
  - **Barriers**
  - **Containment structures: limit/prevent release of hazards of donor system**
    - Close-in ($Z = R/W^{1/3} < 3$ ft/lb$^{1/3}$) blast effects (breach/spall)
    - UFC 3-340-02 recommends weight to volume $W/V < 0.15$ lb/ft^3
  - **4 Protection Categories**
    - Protection Category 1 must be selected for personnel protection
    - Other categories protect assets/prevent propagation of explosion
    - Allowable response/deflection varies by category

Protective Construction – Explosive Protection System

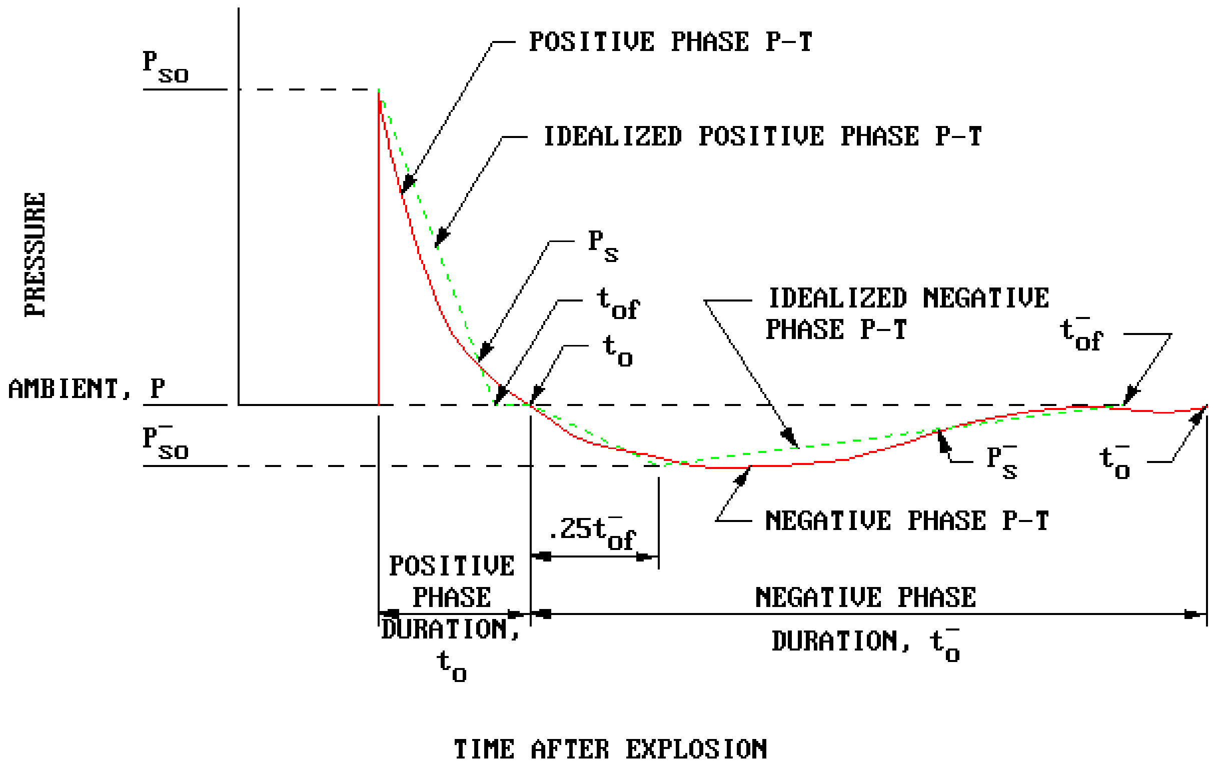
Figure 1-1 Explosive protective system



- Design load basis
  - –MCE = 1.2 (sited net explosives weight)
  - –Can include pressure, frags, & debris
- Unconfined explosions
  - –Create external loads on shelters
  - –Can occur in the air or on the ground
  - –Unconfined hemispherical surface burst is conservative in terms of wave reflection/amplification
  - –Design charts/equations to calculate p(t) on all structure faces
  - –Openings into structure (penetrations/vents) can allow pressure to buildup inside structure

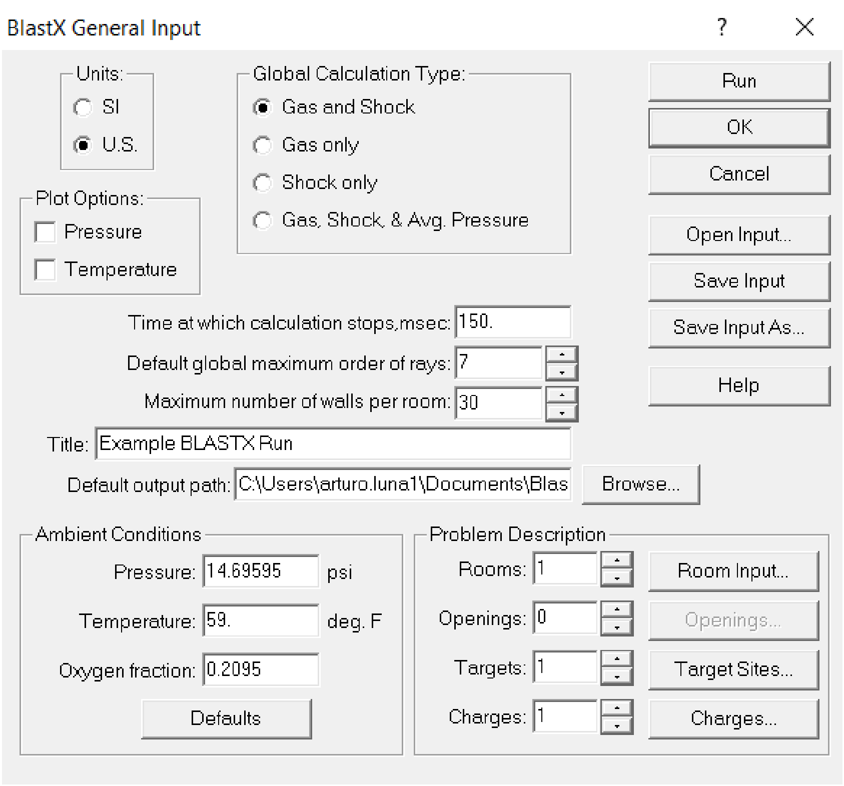
- External blast pressure – negative phase
  - –Low pressure, potentially high impulse
  - –Usually does not affect design
  - –Exceptions: non-rigid construction, rebound sensitive, high NEW's (high impulse)

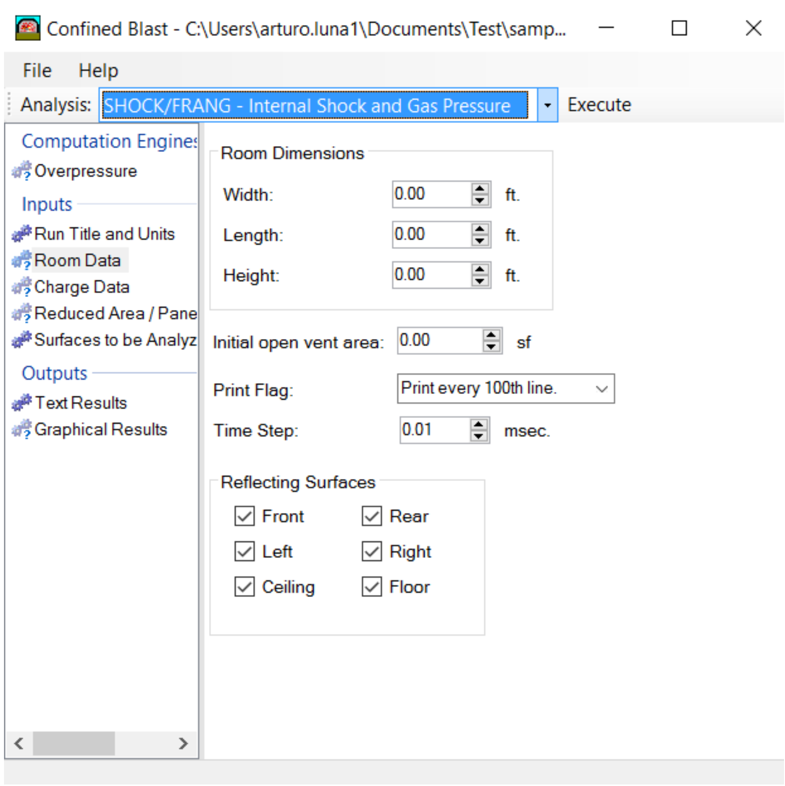
Figure 2-190. Idealized pressure-time variation



- **Confined Explosions**
  - **Result from internal detonations**
  - **Result in shock and gas pressure**
    - Shock pressures are short duration (few ms)
    - Gas pressures long duration (order of magnitude longer)
  - **Gas pressures**
    - Must be vented
    - Impact on structure reduced by venting and frangible panels
    - Frangible panels
      - Glass, metal panel roof, etc.
      - Resistance < 25 psf
      - Lighter frangible panels allow more venting
  - **Design charts/equations to calculate p(t) inside cubicles**

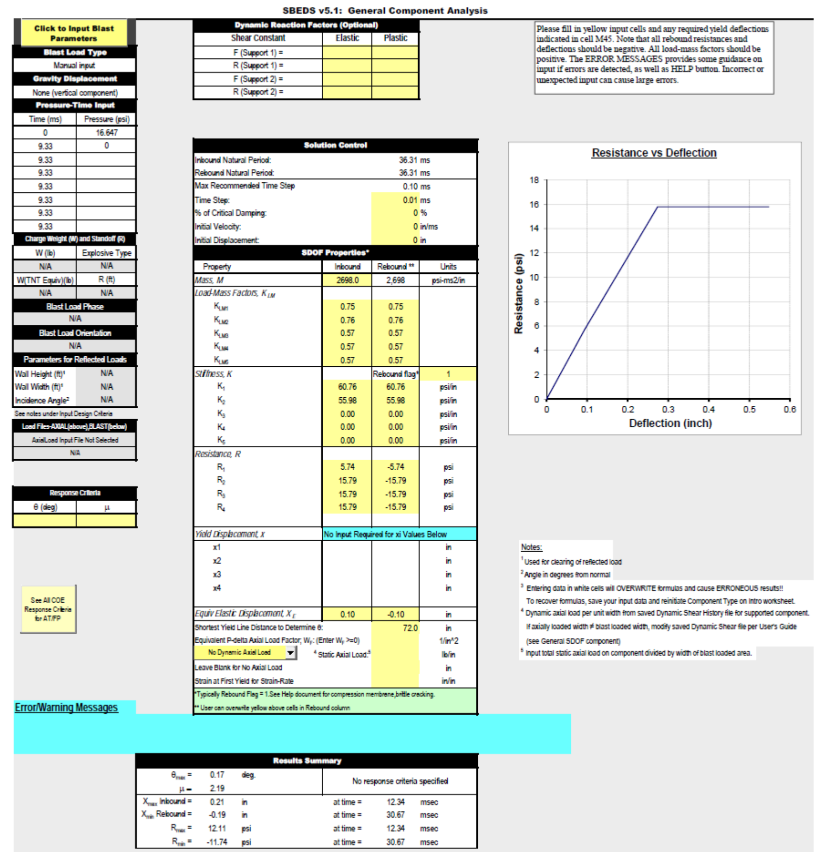
- **Confined Explosions (continued)**
  - –Computer programs available to calculate confined blast
  - –Know limitations of each program





- **Confined Explosions (continued)**
  - **BlastX limitations/considerations**
    - 'Maxord' – number of shockwave reflections, user defined
    - Shock diffraction between rooms
      - Explosion should occur > D = sqrt($A_{opening}$) from opening, valid for incident pressure at opening < 900 psi
    - Shockwave diffraction around corner intended for non-line-of-sight
  - **ConBlast limitations/considerations**
    - Shock model – $0.2 < Z < 100$ ft/lb$^{1/3}$ for any surface
    - FRANG gas pressure model requires non-zero vent area
    - TP-13 debris throw calculations valid for NEW < 250 lbs

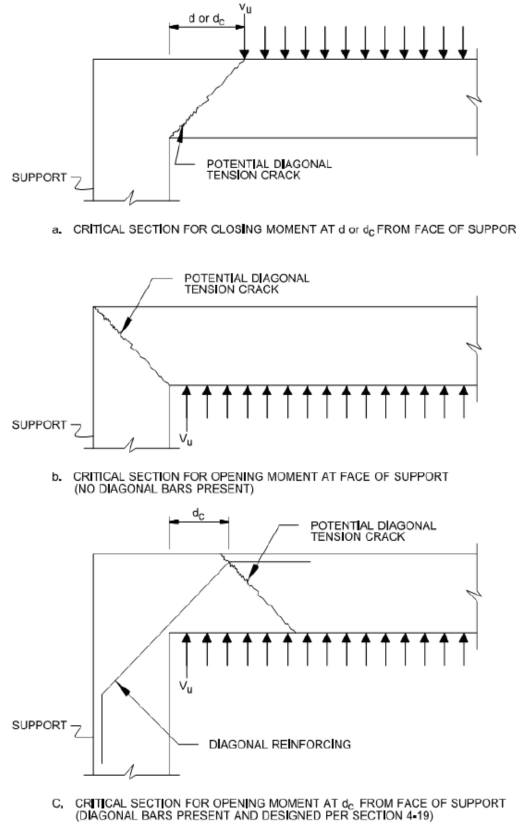
- Blast resistant construction must typically respond inelastically to be economical – dynamic analysis required
- Mass more effective than damping at reducing response
- Dynamic analysis via response charts
- SBEDS ‘General SDOF’ can do numerical integration
- SBEDS component resistance functions not suitable



- **Reinforced concrete partial/containment cells**
  - **Flexure: don't overdesign!**
  - **Diagonal tension reinforcement**
    - Required for close-in range
    - Design stress reduced if wall/slab is in tension
    - Critical section
  - **Direct shear**
    - Concrete has zero capacity under tension (diagonal bars required)
  - **Direct tension reinforcement required**
    - Located mid-depth
  - **Spall and breach**
    - Minimum thickness

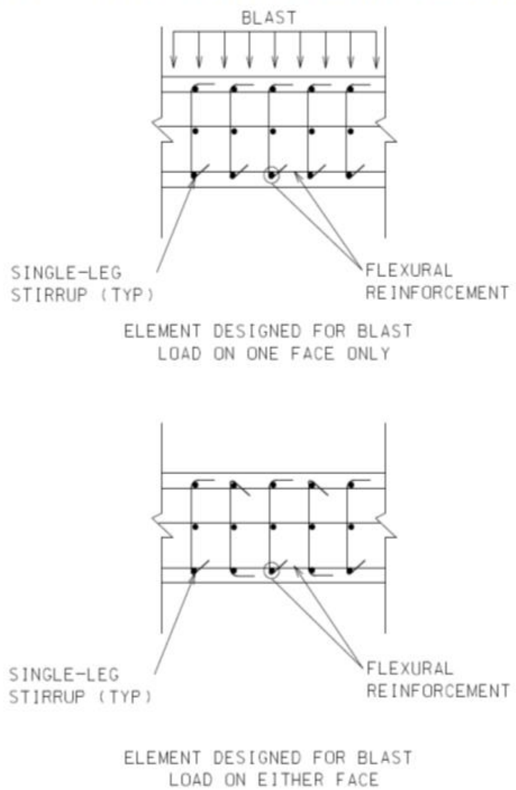
UFC 3-340-02
5 December 2008
Change 2, 1 September 2014

Figure 4-14 Location of Critical Sections for Diagonal Tension



- Reinforced concrete detailing
  - –Minimum diagonal tension reinforcement not applicable for Type 1 walls in far design range
  - –Stirrup types/orientation
    - Depend on response
    - Type A - (90°-135°), up to 2°, Z > 1 ft/lb$^{1/3}$
    - Type B - (135°-135°), up to 12°, Z > 1 ft/lb$^{1/3}$
    - Type C - (180°-180°), up to 12°
  - –Splices
    - Lapped, low stress, stagger
    - Mechanical splices must be tested
    - Welded generally not permitted

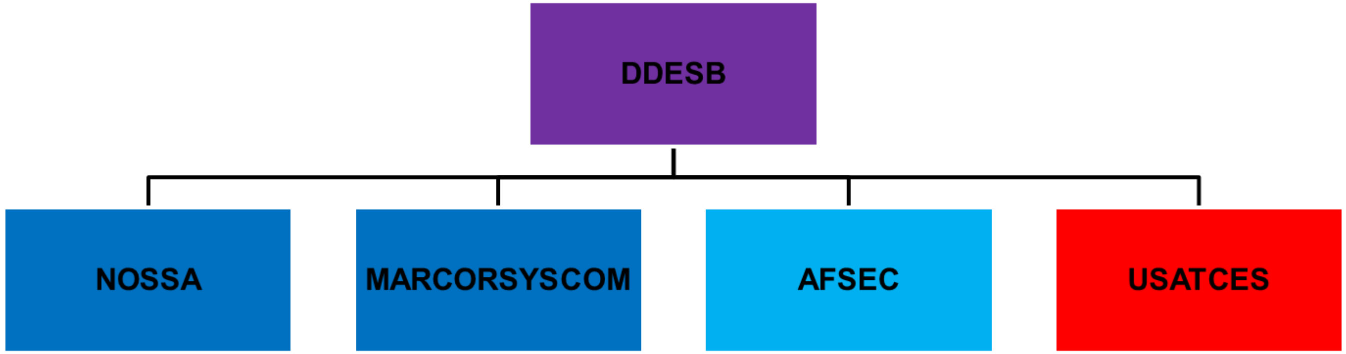
Figure 4-101 Placement Requirements for Type A Single-Leg Stirrups



- **Steel design considerations**
  - **Close-in design**
    - Concrete generally performs better
    - If steel is used, avoid brittle modes of failure (weld/connection fracture, fragment penetration by keeping charge low)
  - **Rebound response**
    - Can be significant, up to 100% of inbound, in steel due to lack of damping
  - **Stress interactions**
    - More critical for steel
    - Ex., designer must check combined tension and shear at the connections of containment structures
  - **Fragments may control over flexure (i.e., plate thicknesss)**
  - **Dynamic connection design**
    - Dynamic capacity of connections can be used
    - Account for dynamic strength by dividing load by 1.7(DIF) then use AISC allowable static strength capacity tables

Protective Construction – Validation

- **DDESB Memo 21 October 2008/TP-26 define minimum requirements to validate protective construction**
- **Requires review by a competent DoD blast agency**
  - **Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC)**
  - **US Army Engineering and Support Center, Huntsville (USAESCH)**
- **DoD blast agency is not approval authority**
- **Stakeholder coordination is key – communicate early and often, especially at concept stage**



Conclusions

- Understand QD violations to form PC basis of design
- Design procedures vary for shelters vs containment structures
- Maintain awareness of limitations on software engineering tools
- Detailing and response of containment structures is more complex
- Concrete vs Steel design considerations
- Identify and talk to your DoD approval authority & blast design review agency