

Design Roadmap for Explosives Safety Protective Construction

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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**

- **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 ft² (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 2nd 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 ($Z = R/W^{1/3} < 3 \text{ ft/lb}^{1/3}$) blast effects (breach/spall)
- UFC 3-340-02 recommends weight to volume $W/V < 0.15 \text{ lb/ft}^3$

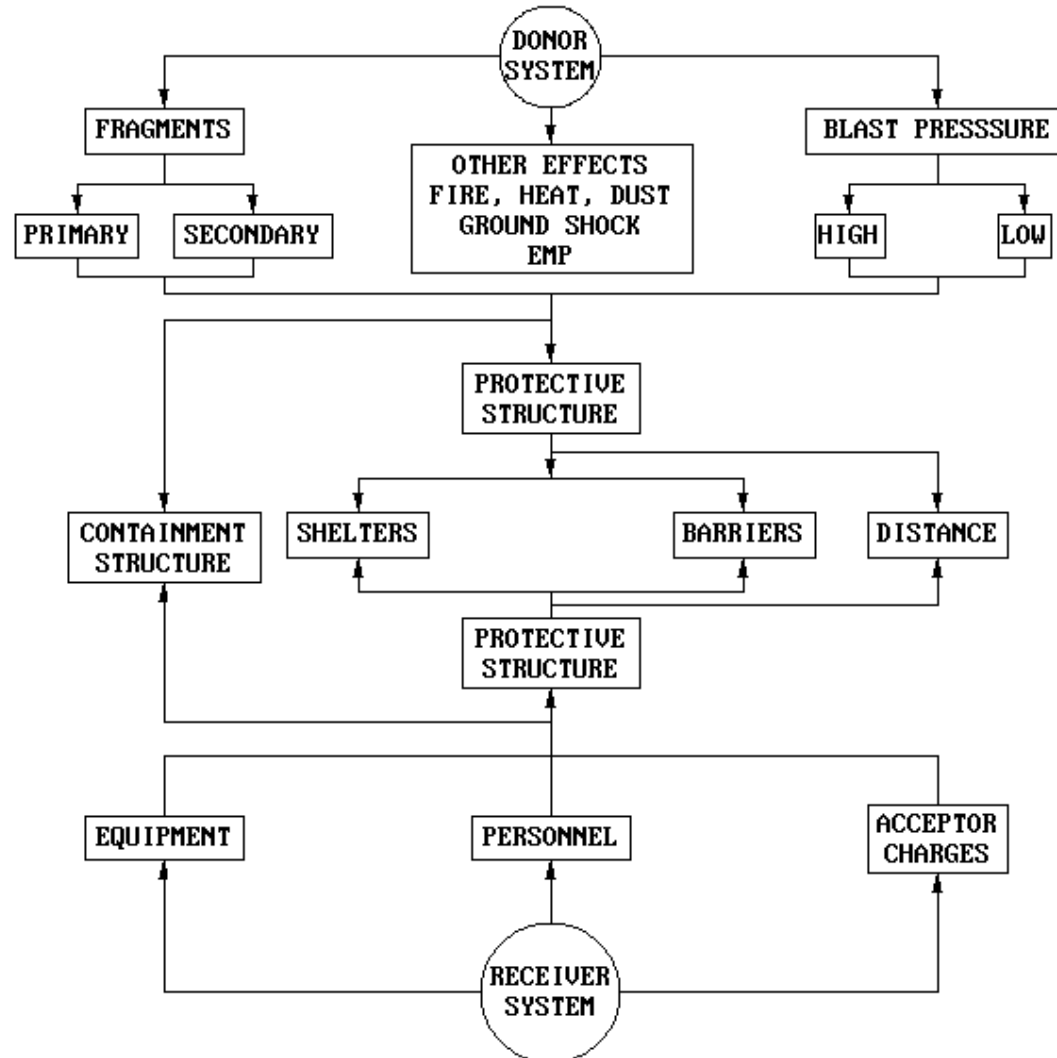
–4 Protection Categories

- 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

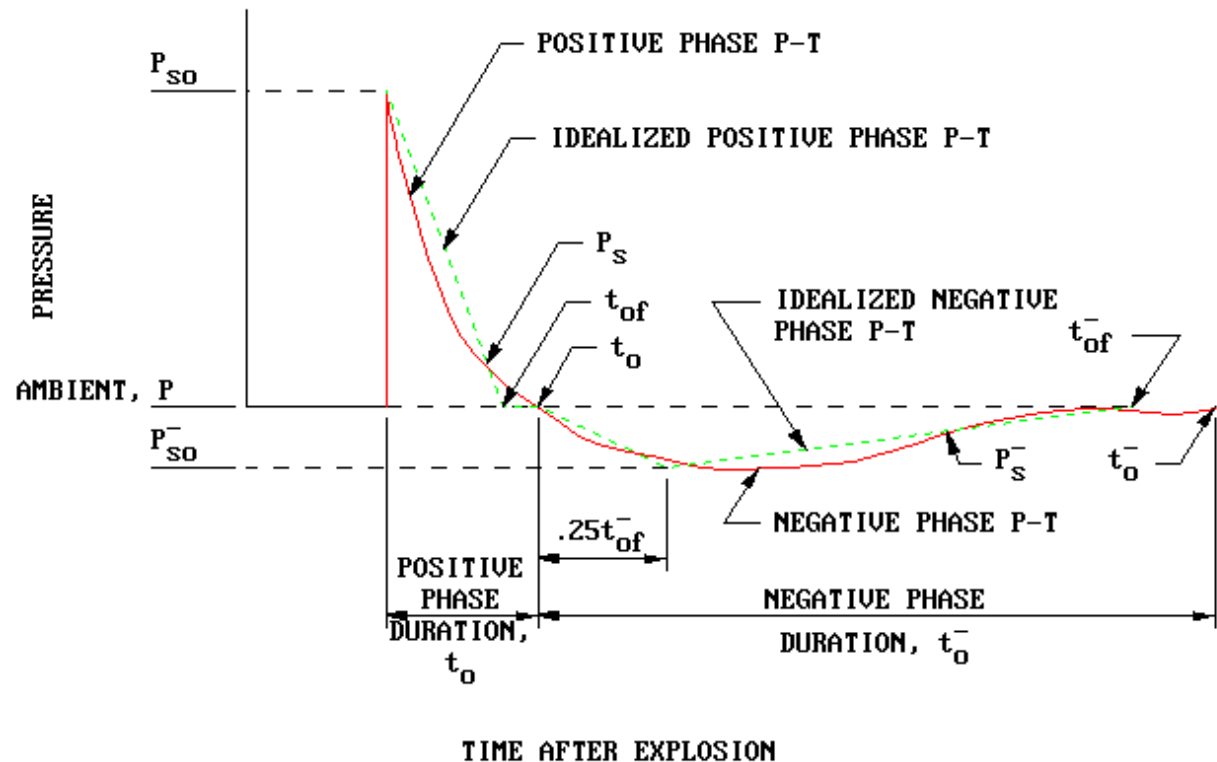
- External blast pressure – negative phase

- 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)

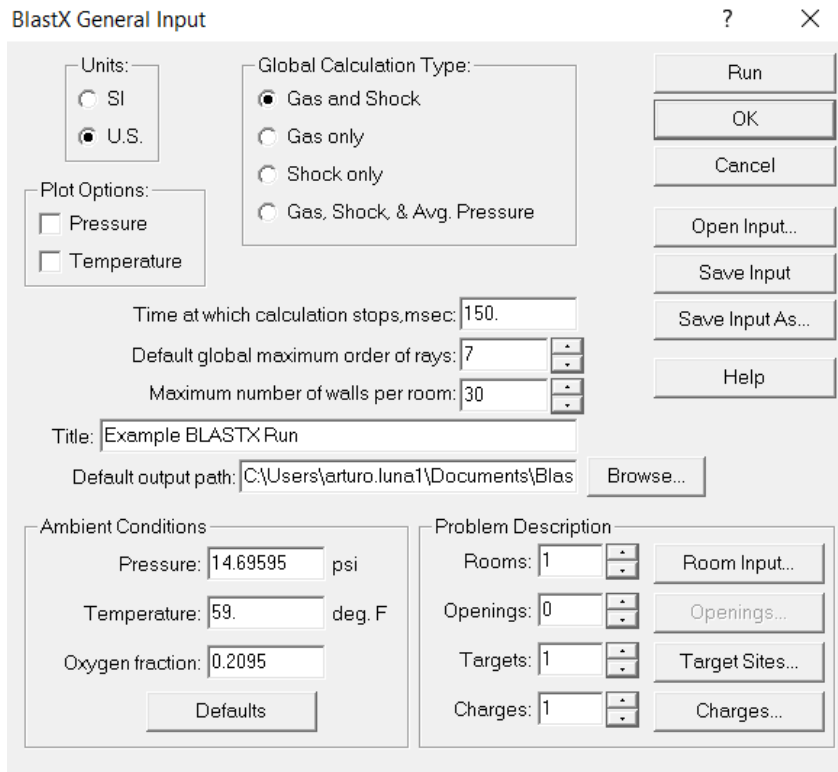
– **Gas pressures**

- 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



BlastX General Input

Units:
 SI
 U.S.

Global Calculation Type:
 Gas and Shock
 Gas only
 Shock only
 Gas, Shock, & Avg. Pressure

Plot Options:
 Pressure
 Temperature

Time at which calculation stops, msec: 150

Default global maximum order of rays: 7

Maximum number of walls per room: 30

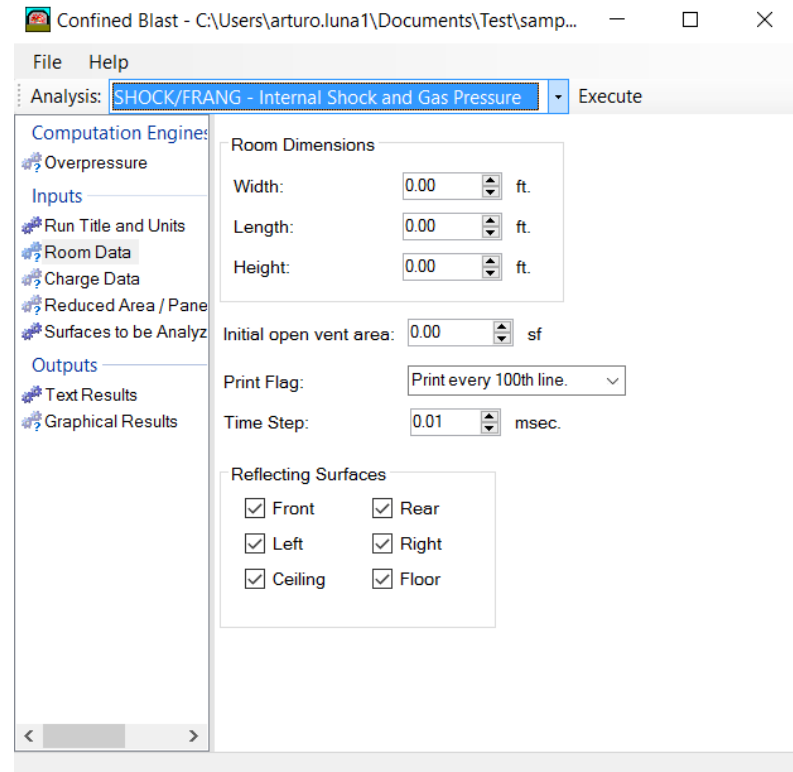
Title: Example BLASTX Run

Default output path: C:\Users\arturo.luna1\Documents\Blas Browse...

Ambient Conditions
Pressure: 14.69595 psi
Temperature: 59 deg. F
Oxygen fraction: 0.2095
Defaults

Problem Description
Rooms: 1 Room Input...
Openings: 0 Openings...
Targets: 1 Target Sites...
Charges: 1 Charges...

Run
OK
Cancel
Open Input...
Save Input
Save Input As...
Help



Confined Blast - C:\Users\arturo.luna1\Documents\Test\samp...

File Help

Analysis: SHOCK/FRANG - Internal Shock and Gas Pressure Execute

Computation Engines:
Overpressure
Inputs
Run Title and Units
Room Data
Charge Data
Reduced Area / Pane
Surfaces to be Analyz

Outputs:
Text Results
Graphical Results

Room Dimensions
Width: 0.00 ft.
Length: 0.00 ft.
Height: 0.00 ft.

Initial open vent area: 0.00 sf

Print Flag: Print every 100th line.

Time Step: 0.01 msec.

Reflecting Surfaces
 Front Rear
 Left Right
 Ceiling Floor

• **Confined Explosions (continued)**

–**BlastX limitations/considerations**

- ‘Maxord’ – number of shockwave reflections, user defined
- Shock diffraction between rooms
 - Explosion should occur $> D = \sqrt{A_{\text{opening}}}$ 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 – $0.2 < Z < 100 \text{ ft/lb}^{1/3}$ for any surface
- FRANG gas pressure model requires non-zero vent area
- TP-13 debris throw calculations valid for NEW < 250 lbs

Protective Construction – Dynamic Analysis

- 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

SBEDS v5.1: General Component Analysis

Click to Input Blast Parameters

Head Load Type
Manual Input

Gravity Displacement
None (vertical component)

Pressure-Time Input

Time (ms)	Pressure (psi)
0	15.647
9.33	0
9.33	
9.33	
9.33	
9.33	
9.33	
9.33	

Charge Weight (W) and Standoff (S)

W (lb)	Explosive Type
N/A	N/A
WTNT Equiv (lb)	R (ft)
N/A	N/A

Parameters for Reflected Loads

Wall Height (ft) ¹	N/A
Wall Width (ft) ²	N/A
Incidence Angle ³	N/A

See Notes under Input Design Criteria

Load File-AMM (Filename) (LAST Loaded)
AmLoaded Input File Not Detected

Regional Criteria

θ (deg)	ψ

See All COE Response Criteria for AT/FP

Dynamic Reaction Factors (Optional)

Shear Constant	Elastic	Plastic
F (Support 1) =		
R (Support 1) =		
F (Support 2) =		
R (Support 2) =		

Solution Control

Inbound Natural Period	36.31 ms
Rebound Natural Period	36.31 ms
Max Recommended Time Step	0.10 ms
Time Step	0.01 ms
% of Critical Damping	0 %
Initial Velocity	0 in/ms
Initial Displacement	0 in

SDOF Properties*

Property	Inbound	Rebound**	Units
Mass, M	2696.0	2.696	psi-ms ² /in
Load/Axis/Deflection, F ₁₀₀			
K ₁₀₀	0.75	0.75	
K ₁₀₀	0.76	0.76	
K ₁₀₀	0.57	0.57	
K ₁₀₀	0.57	0.57	
K ₁₀₀	0.57	0.57	
Stiffness, K			
K ₁	60.76	60.76	psi/in
K ₂	55.98	55.98	psi/in
K ₃	0.00	0.00	psi/in
K ₄	0.00	0.00	psi/in
K ₅	0.00	0.00	psi/in
Resistance, R			
R ₁	5.74	-5.74	psi
R ₂	15.79	-15.79	psi
R ₃	15.79	-15.79	psi
R ₄	15.79	-15.79	psi

Half Displacement, x **No Input Required for x Values Below**

x1	x2	x3	x4

Cap Elastic Displacement, X₁₀₀ 0.10 -0.10 in

Shortest Yield Line Distance to Determine S: 72.0 in

Equivalent P-Delta Axial Load Factor, W₁ (Enter W₁ = 0) 1/in²

Equivalent Axial Load, W₁ (Enter W₁ = 0) 0 in/in

Leave Blank for No Axial Load

Strain at First Yield for Strain-Rate

Typically Rebound Play = 1 See Help document for compression membrane brittle ending

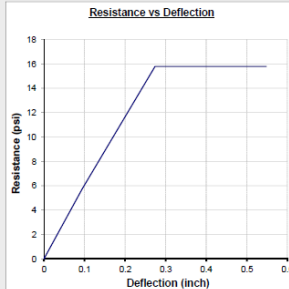
* Use red or orange yellow above cells in Rebound column

Results Summary

S _{max}	μ	deg	No response criteria specified
X _{max} Inbound =	0.21	in	at time = 12.34 msec
X _{max} Rebound =	-0.19	in	at time = 30.67 msec
R _{max}	12.11	psi	at time = 12.34 msec
R _{min}	-11.74	psi	at time = 30.67 msec

Please fill in yellow input cells and any required yield deflections indicated in cell M45. Note that all rebound resistances and deflections should be negative. All load-mass factors should be positive. The ERROR MESSAGES provides some guidance on input if errors are detected, as well as a HELP button. Incorrect or unsuspected input can cause large errors.

Resistance vs Deflection



Notes:

- ¹ Used for clearing of reflected load
- ² Angle in degrees from normal
- ³ Entering data in white cells will OVERWRITE formulas and cause ERRONEOUS results!

* To recover formulas, save your input data and reinitiate Component Type on into worksheet.

* Dynamic axial load per unit width from saved Dynamic Shear History file for supported component.

* Axially loaded width # blast loaded width, modify saved Dynamic Shear file per User's Guide (see General SDOF component)

* Input axial static axial load on component divided by width of blast loaded area.

• 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)

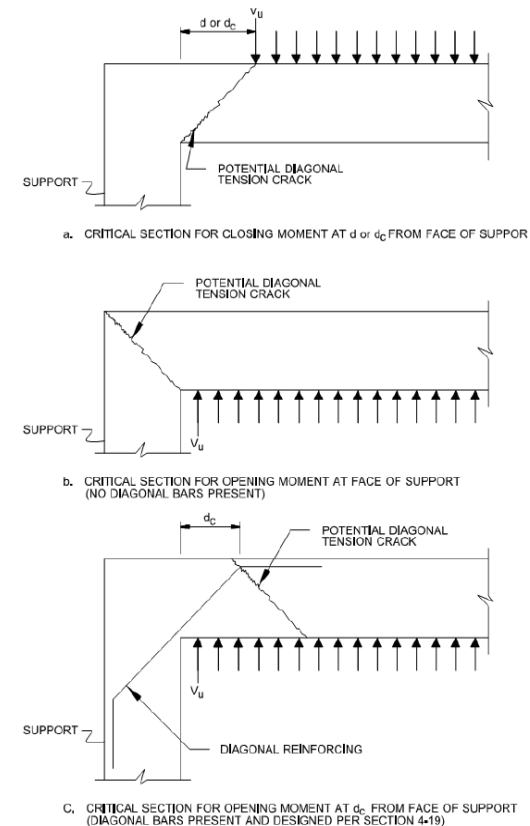
–Direct tension reinforcement required

- Located mid-depth

–Spall and breach

- Minimum thickness

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

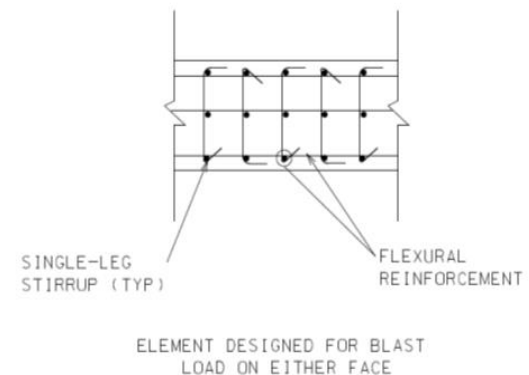
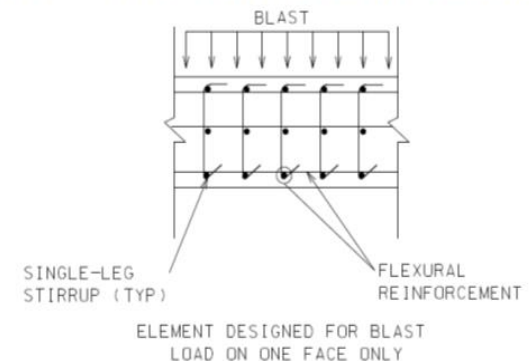
–Stirrup types/orientation

- Depend on response
- Type A - (90° - 135°), up to 2° , $Z > 1 \text{ ft/lb}^{1/3}$
- Type B - (135° - 135°), up to 12° , $Z > 1 \text{ ft/lb}^{1/3}$
- 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

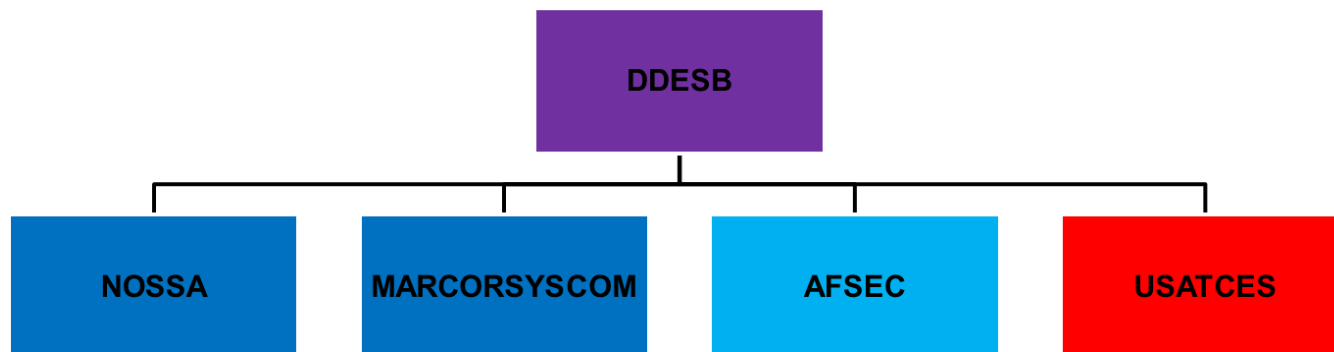
- More critical for steel
- Ex., designer must check combined tension and shear at the connections of containment structures

–Fragments may control over flexure (i.e., plate thickness)

–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

- **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**



- **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**