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Guidelines for Design of Protective Structures Subjected To Unconfined Explosions

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ABSTRACT:- In recent times, terrorist attacks are happening at major locations that pose significant threat to human life and infrastructure. The terrorist attack, especially the bomb explosion, causes catastrophic damage on structures, leading to loss of life and damage to assets. Thus, protection of structures against such extreme events or loading conditions is of prime importance. The loss of life and damage of the structure can be minimized by implementing suitable mitigation measures in both structural and non-structural design. The objective of this paper is to discuss on the guidelines for analysis and design of structural components of protective structures against blast pressure for an unconfined explosion. This paper covers in detail about the protection categories, risk assessment, Level of protection and damage, blast phenomenon and methods to predicting blast pressure, dynamic analysis, design and detailing.
Keywords: *Risk assessment, Level of damage, SDOF, Response, Blast phenomena, Dynamic analysis*

I. INTRODUCTION

In the last few decades, terrorist attacks are posing significant threats to the World. On comparing the available data for the past 15 years, numerous terrorist attacks have occurred and resulted in lethal damage to structures, people and reputation of the country. Notable explosion attacks have occurred in countries like Iraq, Pakistan, Sri Lanka, India, Syria etc. resulted in fatalities and damages to assets [1]. Figure 1a shows the number of terrorist attacks that happened all over the world between the year 2000 and 2015 and Figure 1b indicates the number of fatalities happened during the explosions. These attacks highlighted the importance of protection to personnel and equipment to avoid catastrophic damage and fatalities, thus demanding a blast resistant design. The blast loads plays a crucial role in design of structures, especially communication center, data storage center, ammunition storage facility, underground caverns and other defense related structures. In above mentioned structures, the significance of blast loads is predominant, in addition to live, wind and seismic loads. For such critical structures, resistance of blast is the ultimate requirement such that its intended mission is safeguarded. In most cases, designing structures as fully blast resistant is not feasible due to economic and architectural constraints. However, the effects can be minimized by adopting structural and non-structural mitigation measures such as stand-off distance, barriers, landscaping etc., to name a few.

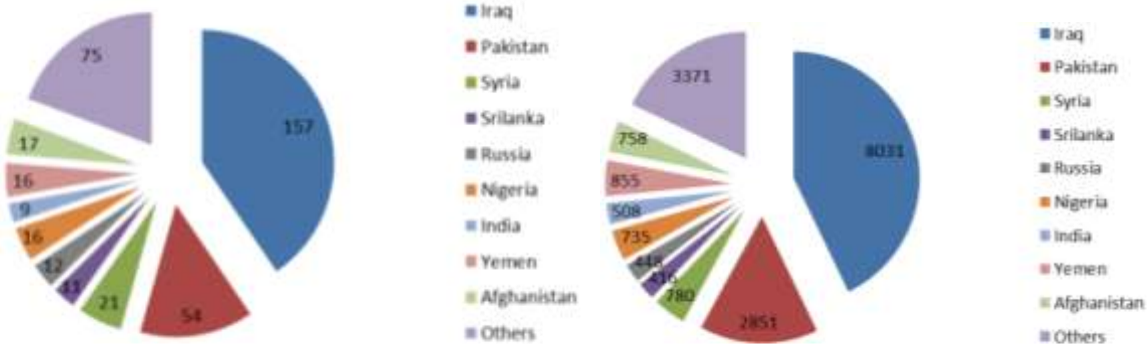


Figure 1 - a) Number of terrorist attacks b) Number of Deaths [1] (2000-2015

Till date, very few literatures are available in the field of blast resistant design of structures. The following are few studies which have been carried out in this special field. T. Ngo and P. Mendis [2] explained the blast phenomenon and its effects on the structures. They have briefly discussed about the method of predicting blast load and dynamic response on structures. The different technical manuals available for the design of blast resistant structures are eloborated. Hrvoje Draganić and Vladimir Sigmund [3] describe the procedure for calculating the blast loading on structures with numerical example. The procedure for calculating blast load on front, side, rear wall and roof is explained in detail. The pressure calculated is applied in building as a pressure-time history to examine the damage on the structural components using SAP 2000. A. V. Kulkarni, Sambireddy [4] has done an analysis of High Rise Structure to examine the dynamic response under blast load. The fundamentals of blast hazards and the interaction of blast waves with structures are examined in their study using SAP2000. The blast pressures are calculated using TM 5-1300 for the charge weight of 800lbs and 1600lbs TNT at stand-of distance of 5m and 10m respectively. Norbert Gebbeken and Torsten Döge [5] studied the effect of shapes and geometry of the structure on blast pressure under explosion. They have also examined the influence of vertical and horizontal shapes in attenuation of blast pressure. The charge weight of 10kg TNT at the stand-off distance of 5m is considered for the horizontal shape and for the vertical shape charge weight of 10kg TNT at the stand-off distance of 3m is considered for the study.

In the references cited above, procedure for calculating the blast pressure on structures and its response has been formulated. Yet, a detailed methodology, which explains the type of structure, the assessment of risk, blast pressure calculation, analysis and design procedure for structural components and the detailing procedure has not been verbalized. In this paper an attempt has been made to provide an outline for the entire process of design for the structure subjected to unconfined explosion.

Analyzing the blast phenomenon and its interaction with structure involves highly nonlinear dynamics and fluid structure interaction aspects that can be solved by using either advanced numerical tools or close-from/analytical approach. This paper discuss about the blast resistant design using the empirical approach. The guideline presented in this paper, for the analysis and design of structures against the blast effects of an unconfined explosion is collated from available literatures and standards like UFC 3-340-02, TM-1300, 'Handbook for blast resistant design' and 'ASCE-Design of blast resistant buildings in petrochemical facilities'. The recommendation from the literature and codes is based on idealization of structure as single degree of freedom (SDOF).

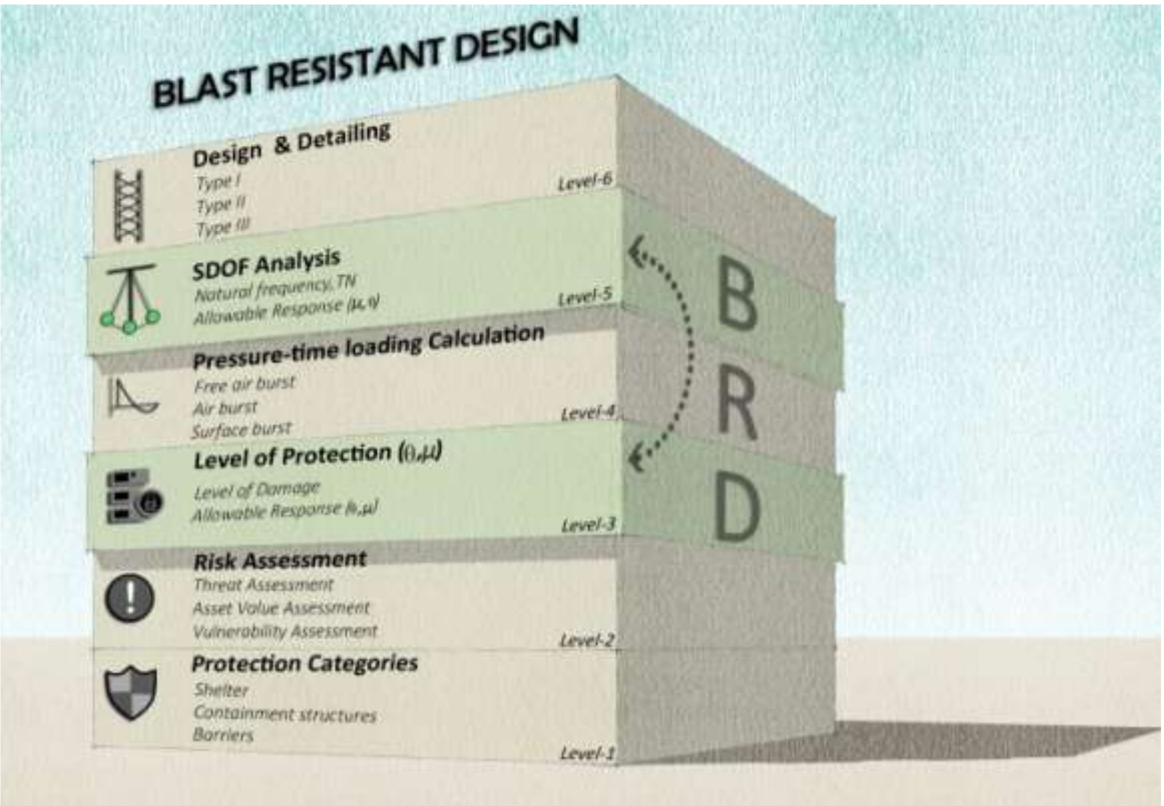


Figure 2 - Blast resistant design process

A Blast resistant design enhances the structural strength of shelter or containment structure against the effects of blast pressure by limiting the structural response in terms of support rotation (θ) and ductility ratio (μ). Figure 2 represents the blast resistant design process that showcases the steps and the design criteria that are involved in a blast resistant design. The first and foremost is the identification of risk and corresponding level of protection. In blast resistant design of structures, it is necessary to categorize the protective structure type like shelter or containment structure in order to adopt an effective design against the explosion effects. After categorizing the structure, the allowable deformations like ductility and support rotations against the blast effects are limited by carrying out the risk assessment process. The deformations in terms of ductility and support rotations are selected based on the level of protection and level of damage for the respective risk level. Study of structural response subjected to the pressure-time loading using SDOF analysis. Subsequent design and detailing based on SDOF analysis.

II. PROTECTION CATEGORIES

Protection category of a structure has to be identified based on the intended mission of the facility. Threat rating and level of protection are crucial in deciding the protection category for a particular structure. The protection category for a structure as per UFC 3-340-02 is presented in
Table 1.

Table 1 - Protection category [6]

Protection category	Design strategy	Type of Protective structure
Protection category 1	Structures protecting personnel	Shelters, Containment structures
Protection category 2	Structures protecting Equipment or explosive storages	Shelters, Containment structures
Protection category 3	Prevention of fragments and blast pressure between the point of detonation and protective structure.	Shelters, Containment structures (In order to protect, Barrier is mandatory)
Protection category 4	Prevent mass detonation of explosives as a result of subsequent detonations produced by communication of detonation between two adjoining areas and/or structures.	Shelters, Containment structures (In order to protect, Barrier is mandatory)

III. RISK ASSESSMENT

Based on the type of protective structure, the structure has to be assessed for the risks to which it may get exposed. This can be carried out using risk assessment process. The risk assessment is a key factor for the design of hardened structures in order to reduce the damage to personnel or equipment or structures, due to chemical, biological and conventional weapon blast. The objective of the assessment is to identify the risk level, minimize the damage and increase the level of protection by selecting suitable mitigation measures [7]. The possible mitigation options should be adopted for the predicted risk level in order to overcome the risk. The risk assessment is computed based on *asset value, threat assessment and vulnerability assessment*. Based on the consequences and impact of the threat, Federal Emergency Management Agency (FEMA 426) has rated the Individual assessments from 1 to 10 as shown in Figure 3.

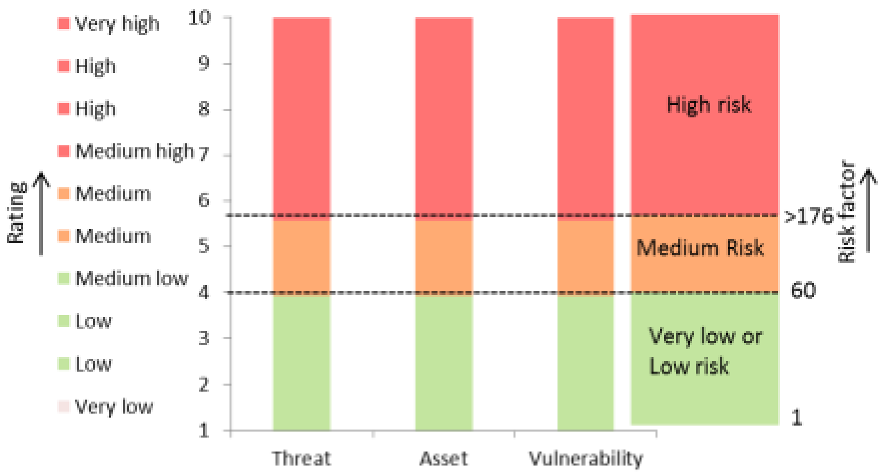


Figure 3 - Risk level

Threat Assessment is a process in predicting the possibility of threat**.** The threat is predicted based on the statistical report of previous attacks occurred at surroundings or it can be selected based on the engineering judgement. *Asset value assessment* process is to identify the impact or consequences of threat on assets like loss of life or damage of assets. *Vulnerability assessment* is to analyze the building functions, building weakness and determining mitigation options to reduce the vulnerabilities. The risk level for a particular structure is determined as follows:

$$Risk\ factor\ =\ Asset\ rating\ X\ Threat\ rating\ X\ Vulnerability\ rating$$

The computed risk factor is used to adopt a suitable type of mitigation measure and level of protection that the structure requires. As per FEMA 426, the values assigned for risk factor (very low or low risk falls between 1 & 60, medium risk for the range of 60 & 176 and high risk beyond 176) is shown in Figure 3.

IV. LEVEL OF PROTECTION AND LEVEL OF DAMAGE

FEMA 430 [8] has classified building's Level of Protection and expected Component Damage according to the risk factor. For a particular structure under construction, level of protection and component damage are evaluated from the risk factor values. The intention of protective design is to ensure the life safety, functionality, and reusability of the entire structure during and after the possible explosion.
The *Level of Protection* for the risk level can be selected from Table 2. In blast resistant design, the structural components are designed individually for the blast pressure.

Table 2- Building Levels of Protection [9]

Level of protection	Building Performance Goals	Overall Building Damage
I (Very low)	Collapse prevention: Surviving occupants will likely be able to evacuate, but the building is not reusable; contents may not remain intact.	Damage is expected, up to the onset of total collapse, but progressive collapse is unlikely.
II (Low)	Life safety: Surviving occupants will likely be able to evacuate and then return only temporarily; contents will likely remain intact for retrieval.	Damage is expected, such that the building is not likely to be economically repairable, but progressive collapse is unlikely.
III (Medium)	Property preservation: Surviving occupants may have to evacuate temporarily, but will likely be able to return after cleanup and repairs to resume operations; contents will likely remain at least partially functional, but may be impaired for a time.	Damage is expected, but building is expected to be economically repairable, and progressive collapse is unlikely.
IV (High)	Continuous occupancy: All occupants will likely be able to stay and maintain operations without interruption; contents will likely remain fully functional.	Only superficial damage is expected.

The risk level implies the damage level that a structure undergoes. The Level of Damage of the structural components for different level of protection is given in Table 3.

Table 3 - Expected Component Damage for Each Level of Protection [9]

	Component Damage Levels		
Level of Protection	**Primary Structural Components**	**Secondary Structural Components**	**Nonstructural Components**
I(Very low)	Heavy	Hazardous	Hazardous
II (Low)	Moderate	Heavy	Heavy
III (Medium)	Superficial	Moderate	Moderate
IV (High)	Superficial	Superficial	Superficial

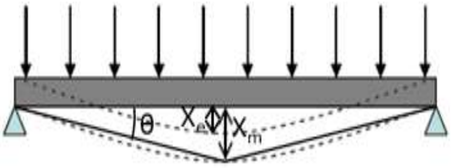
Hazardous	Element is likely to fail and produce debris
Heavy	Element is unlikely to fail, but will have significant permanent deflection such that it is not repairable
Moderate	Element is unlikely to fail, but will probably have some permanent deflection such that it is repairable, although replacement may be preferable for economic or aesthetic reasons.
Superficial	Element is unlikely to exhibit any visible permanent damage

V. PERFORMANCE CRITERIA (μ AND □)

The level of damage of the components subjected to blast is related to its performance criteria. The performance criteria for components are determined using two non- dimensional parameters: the ductility ratio (μ) and support rotation (θ). The ductility ratio and support rotation are as follows:

$$\mu = \frac{X_m}{Xe} \qquad (1)$$

$$\Theta = tan^{-1}\left(\frac{2X_m}{L_{min}}\right) \qquad (2)$$



Where X_e is elastic deflection and X_m is the plastic deflection. The response parameters, μ and θ are determined using SDOF analysis. The deformations in reinforced concrete elements are expressed as support rotation θ whereas ductility ratio μ are used for steel elements [9]. The allowable response of the structure as defined in some of the codes and literatures, for Medium and Heavy level of damage are summarized in

Table 4 [9].

Table 4 - Allowable response [9]

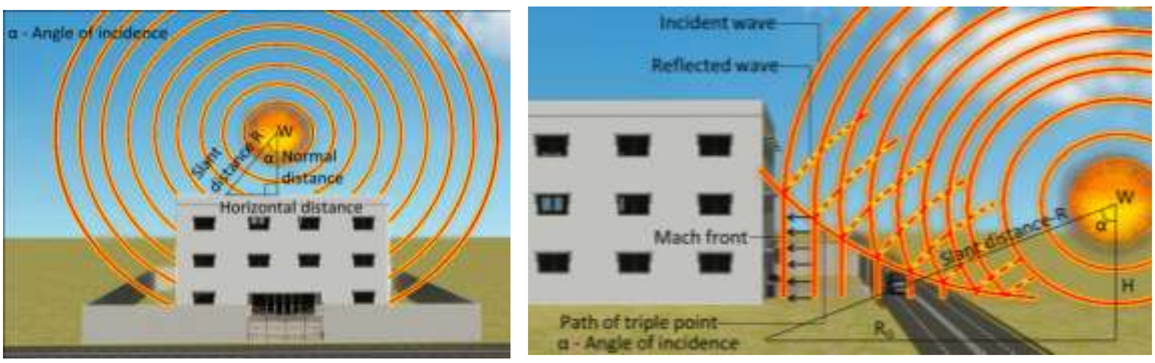
	Medium Damage						High or Heavy Damage					
	DoD criteria		ASCE Blast design		UFC 3-340-02		DoD criteria		ASCE Blast design		UFC 3-340-02	
Element type	μ_{Max}	□Max	μ_{Max}	□Max	μ_{Max}	□Max	μ_{Max}	□Max	μ_{Max}	□Max	μ_{Max}	□Max
RCC beam	-	2	-	2	-	2	-	5	-	5	-	8
RCC slab	-	2	-	2	-	1	-	5	-	5	-	8
Reinforced Masonary walls	-	2	-	2	-	1	-	8	-	5	-	-
Prestressed	-	1	-	1	1	2	-	2	-	2	-	-

VI. BLAST PHENOMENON

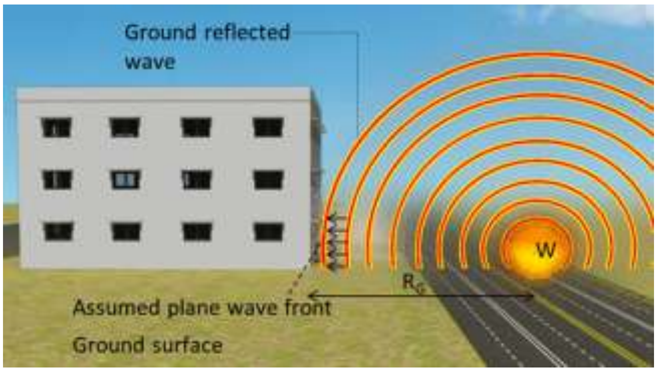
During explosion, the ambient pressure (P) is amplified by the shock wave resulting in peak overpressure (P_{SO}). When the peak overpressure hits the rigid surface, the pressure gets amplified and creates reflected pressure (P_r). P_r and P_{so} shall be obtained from respective figures of UFC 3-340-02 for relevant scaled distance (Z) which is given as,

$$Z = \frac{R}{W^{1/3}} \qquad (3)$$

Where, R = Stand-off distance, W = Charge weight. Normally, explosions are classified into two types as unconfined explosion and confined explosion. An unconfined explosion can occur in free-air or air or on the surface. Understanding the blast wave propagation subjected to different explosion condition is essential prior to a blast resistant design. In *free-air burst*, the detonation occurs above the structure where the spherical blast wave hits the structure without any intermediate amplification as shown in Figure 4 a.



a. Free-air burst **b. Air burst**



c. Surface burst
Figure 4 - Types of burst

'In *air-burst*, the explosion occurs above the ground level where the shock wave impinges on the ground surface before hitting on the structure. The blast wave rather than bouncing back completely, spurts along the ground resulting in *Mach front* as shown in Figure 4 b. The arrival time of ground reflected pressure and overpressure are same for the mach wave front.

In *surface-burst*, the explosion occurs on the ground surface where an immediate reflection of blast waves produces the hemispherical shock wave front as shown in Figure 4 c. The typical pressure-time relationship for an unconfined explosion is shown in Figure 5.

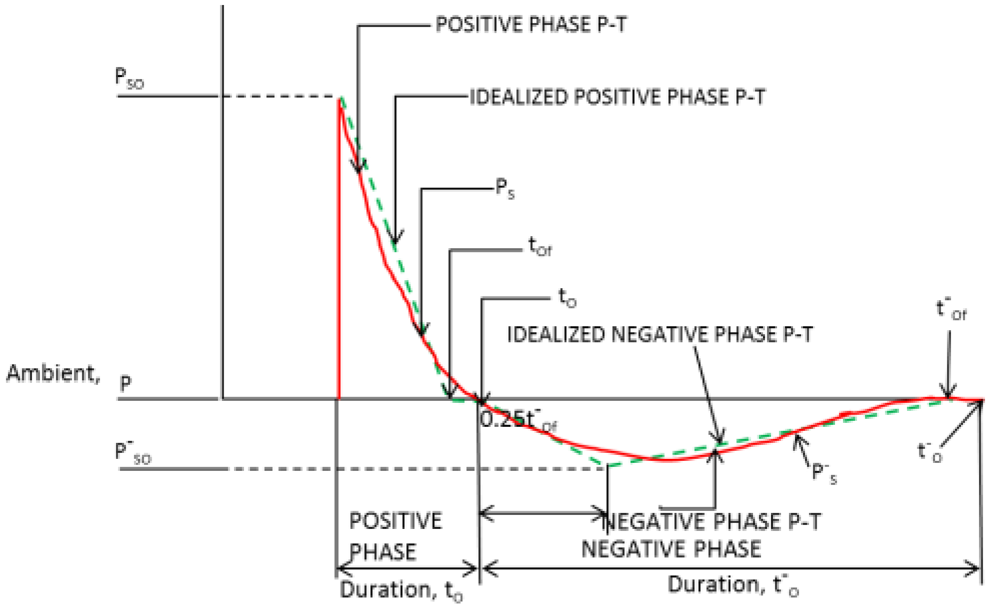


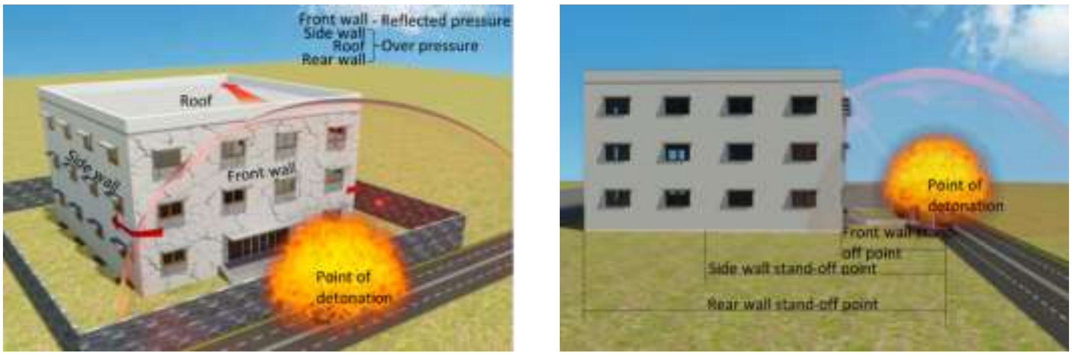
Figure 5 - Typical Pressure-time relationships for blast load

Depending on the angle of impact of the blast pressure, profile of the structure and exposure of blast pressure, the scenario to calculate the blast pressure will change. In general, computation of blast pressure for a structure subjected to an external blast (unconfined) is explained below.

6.1 External blast load on structures

External blast happens in an open atmosphere, where there is a space for the blast waves to escape is said to be unconfined explosion. Many cases of blast fall under the category of external blast. A step-by-step procedure for calculating the pressures acting on the four sides and roof of the structure due to unconfined explosion is explained. This procedure can be adopted for different types of burst to find the pressure on elements. Figure 6a and 6b depicts the blast loading on structure and varying stand-off points for a rectangular structure respectively.

For determining the blast pressure, the general arrangement detail of a structure is considered as shown in Figure 7 , where columns C1 and C2 are connected with walls and slabs. The wall and slab which is exposed to blast waves are classified into front wall, rear wall, side wall and roof depending on the point of detonation. Depending on the geometry and angle of incident of the blast wave, drag coefficient will vary. The below procedure can be used for other shapes by adopting suitable drag coefficient.



a. Blast loading on structure **b. Varying Stand-off point for Walls**

Figure 6 - External blast loads on structure

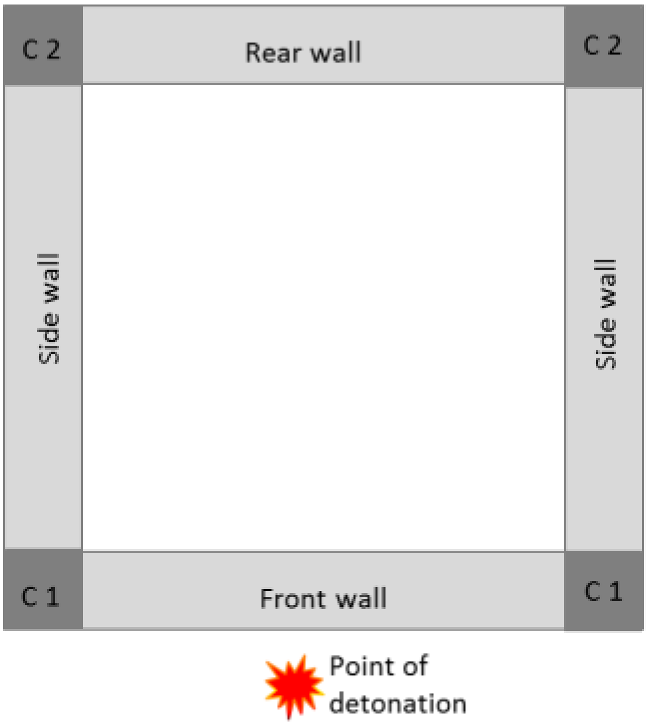


Figure 7 - General arrangement of a structure

6.2 Pressure on front wall

The blast wave expands outward from the point of detonation and hits the front wall at time t_A and the pressure will get amplified immediately to peak reflected pressure P_r as shown in Figure 8. The time required to relieve the reflected pressure is denoted by t_C. In addition to the reflected pressure, the dynamic effects creates additional force due to the drag effect of blast pressure C_Dq where C_D is the drag coefficient and q is the dynamic pressure which relates the geometry. For pressure calculation on front wall the drag coefficient CD can be taken as 1. The reflected pressure P_r and overpressure P_{SO} are taken from figure 2-3 to figure 2-16 of UFC 3-340-02 for the defined type of blast. The actual duration of the blast pressure t_O is replaced by fictitious duration of incident pressure t_{of} and fictitious duration of reflected pressure t_{rf} as explained above. The region which gives the smallest impulse, shall be taken as design load for front wall.

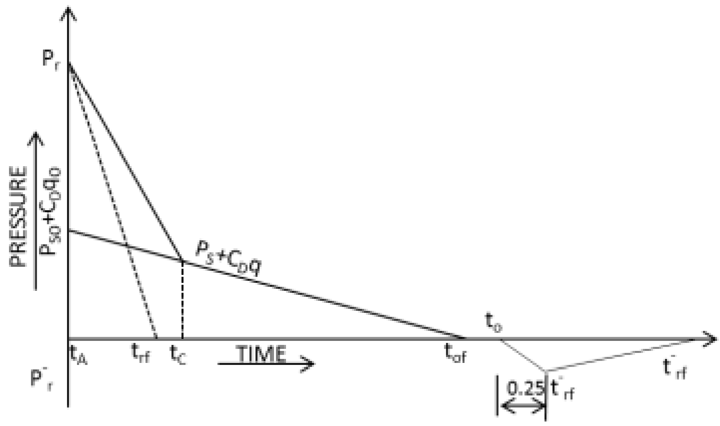


Figure 8 - Pressure-time relationships Front wall

6.3 Pressure on Roof and Side wall

When the shock front strikes the structure, pressure transferred to the roof slab and side walls are equal to the incident pressure at a given time. The loading on portion of roof slab or wall depends upon the magnitude of the shock front, location of the shock front and wavelength L_w of positive and negative pressure. The actual load on the surface is determined by step-by-step analysis of wave propagation through surface. This should be done at various points on the surface along the length.

The shock front at the face of the structure linearly increases from zero at time t_f to maximum at time t_d and then it decreases to zero at time t_b. The pressure acting on the roof and side wall is determined by using the below relation. The incident pressure on side wall and roof is determined from figure 2-3 to figure 2-16 of UFC 3-340-02 for the defined type of burst. The standoff distance for calculating incident pressure on roof and sidewall can be considered as shown in Figure 6 b. The equivalent load factor C_E, the rise time and duration of the equivalent pressure are obtained from figure 2-196 to 198 of UFC 3-340-02 for the respective wave length-span ratio L_w/L. The drag coefficient for roof and side wall is taken from Table 5 as the function of peak dynamic pressure.

$$P_R = C_E P_{sof} + C_D q_{of} \quad (4)$$

Table 5 - Drag coefficient for rectangular shaped structure

S.no	Peak dynamic pressure (psi)	Drag coefficient
1.	0-25	-0.4
2.	25-150	-0.3
3.	50-130	-0.2

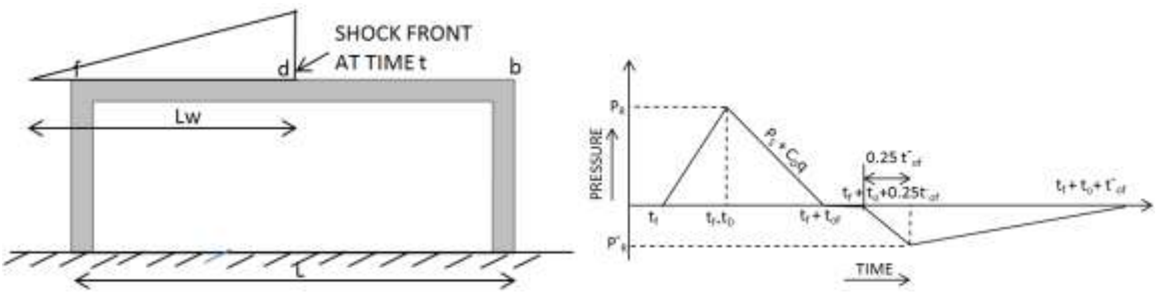


Figure 9 - Pressure-time relationships Roof and Side wall

6.4 Pressure on Rear wall

When the shock front passes over the rear edges of the roof and side walls, the pressure front expands and forms secondary waves which act on the rear wall. The secondary waves formed are reinforced with reflecting waves from the roof and side wall. Reduction in blast pressure happens due to the drag effects as it passes on front and side walls. The peak pressure on the rear wall is calculated using the peak pressure, P_{sob} that accumulated at the back edge of the roof slab as shown in Figure 10.

$$P_R = C_E P_{sob} + C_D q_{of} \quad (5)$$

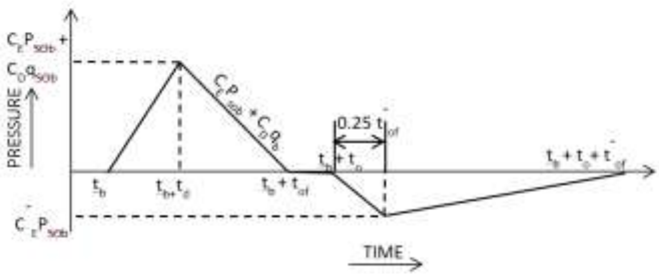


Figure 10 - Pressure-time relationships Rear wall

The equivalent load factor CE, the rise time and duration of the equivalent pressure are obtained from figure 2-196 to 198 of UFC 3-340-02 for the respective wave length-span ratio LW/L. The length of the rear wall (L) is taken as height of the structure (HS). The drag coefficient for calculating the peak dynamic pressure on rear wall is taken from

Table 5. The pressure acting on the rear wall is determined by using the above relation.

6.5 Pressure on Columns

The pressure acting on the exterior column depends on flexibility of the supporting wall i.e. the reaction from wall for subjected particular blast pressure decreases with increase in flexibility of the wall. This reaction from the supporting wall acts as a uniformly distributed load on the column with different time-period, in addition to the direct blast pressure. In general, the load due to the reaction of wall will reduce with increase in time period as compared to incident pressure. In case of interior columns, the resistance (r_U) of the slab shall be applied as an axial load on the column, for this load conventional design methodology shall be carried out.

VII. DYNAMIC ANALYSIS

Rapidly varying application of blast pressure load in short period requires dynamic analysis. Due to the rapid application of the load with respect to time, inertia force plays an important role in dynamic analysis. Equilibrium equation for dynamic analysis is as shown below

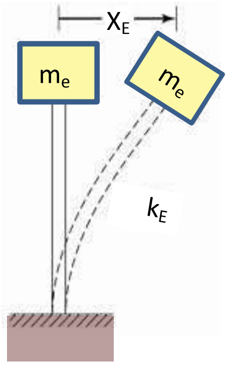
$$F - I = MA \quad (6)$$

Where, F is the external force, I is the internal force, M is the mass of the structure and A is the acceleration force. MA is the acceleration acting on the structure in direction opposite to the applied load. The dynamic response of the structure can be found by different type of analysis like Single degree of freedom (SDOF) analysis, Multi degree of freedom (MDOF) analysis, Pressure-Impulse (P-I) analysis and finite element analysis. In dynamic analysis, the mass of the structure (m) becomes an important factor in both the equilibrium and energy conservation equations. The SDOF analysis for a blast resistant design is presented here.

7.1 SDOF analysis

In SDOF system structure is replaced by an equivalent single degree of freedom system where the distributed masses and loads of the structure are replaced by concentrated mass and load which vary with time as shown in

Figure 11. The analysis method is based on the resistance-deflection concept employed using SDOF system. The dynamic design factors like load factor KL, mass factor KM are required for converting the actual system into idealized equivalent SDOF system. Based on the behavioral range of the system like elastic or plastic, the load mass factor for one way elements can be taken from Table 3-12 of UFC 3-340-02 and similarly for two way elements from Figure 3-44 and Table 3-13 for the actual deflection.



Where,
m_e is the effective unit mass
K_E is the equivalent elastic stiffness of system
X_e is the elastic deformation

Figure 11- SDOF System

7.2 MDOF analysis

A system with more than one degree of freedom to describe the motion of the system is said to be MDOF system in Figure 12. The newton's equation of motion applied in SDOF system can be applied here to find out the response of the structure.

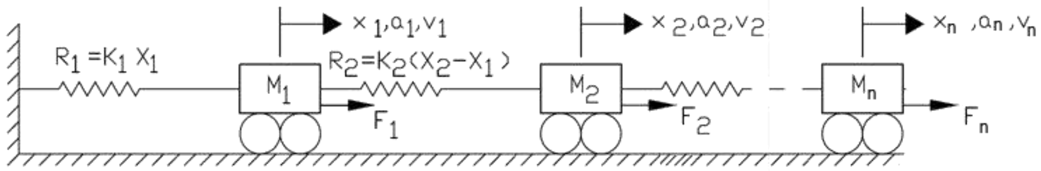


Figure 12 - MDOF System

7.3 P-I curves

A PI diagram is an iso-damage or iso-response contour plot consisting of a series of pressure–impulse combinations that generate the same level of structural response as shown in Figure 13. By generating a PI diagram for a given structural element and plotting specific pressure–impulse combinations corresponding to various anticipated explosive threats, the performance of a structure may be evaluated graphically [13].

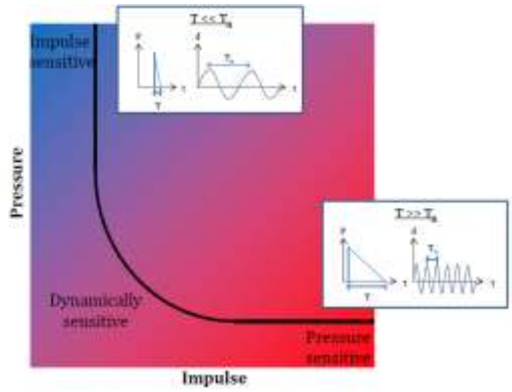


Figure 13 - PI Diagram [13]

VIII. DESIGN

The blast resistant design of a structure is based on the requirement as mentioned in the performance criteria and SDOF analysis. In design of a structure subjected to blast, the behavior of structure in plastic and elastic ranges is crucial. A Blast resistant structure undergoes large inelastic deformations, when it is exposed to blast pressure. Limiting the behavior of structures to only elastic range is not realistic as it is not economically feasible. Thus, the blast resistant structures are designed for high ductility to absorb energy in-elastically without failure. This section describes the procedure for designing the elements subjected to ductile mode and brittle mode of response. In blast resistant design, design ranges are classified into two types, far design range ($Z \geq 3$) and close-in range ($Z < 3$) depending on scaled distance. Important parameters used in the design are as follows

8.1 Section Capacity

Under blast load a structural element exhibits higher strength than static load, due to rapid strain rate variation under such dynamic event. Higher strength is obtained in both the reinforcement steel and concrete. The increase in material strength can be arrived from Table 4-1 and Table 4-2 of UFC 3-340-02 for the respective strain of the component. Based on the allowable deformations and failure criteria, the type of cross section required to protect against blast effects can be adopted as shown in Table 6. Depending on type of cross section, resistance (r_U) is arrived by choosing the optimum reinforcement to limit the deformation.

8.2 Determining Response (μ and □)

For the designed capacity of the section rU, response (μ) of the structural element is found out from Figures 3-1 to 3-266 of UFC 3-340-02 as the function of to /TN and P/rU. The time to reach the maximum deflection, tm of the element is also calculated from the same graph, to identify the structure to be designed for impulse (tm/to > 3) or pressure time (0.1 < tm/to < 3).

The actual support rotation (θ) for the maximum deflection, Xm is arrived based on the equation described in section 5 of this paper.

8.3 Shear Capacity

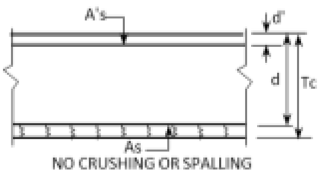
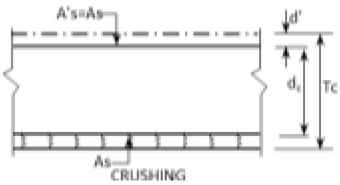
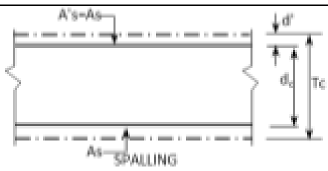
A structural element experiences a high force due to blast; it may fail by punching shear. So, it is necessary to check the element for the direct and diagonal shear to avoid sudden collapse of the structure. A direct shear failure is the one which the crack propagates vertically throughout the depth of the section. This shear failure can be avoid by providing diagonal reinforcement.

IX. DETAILING

Proper detailing of structure is important especially the reinforcement detailing in blast resistant design. So that the structure resist the blast pressures and yield up to plastic state. Specific detailing has to be considered for blast resistant design as follows

- Structural elements undergoing large deflections should be designed with the minimum compressive strength of concrete as 27 Mpa.
- The minimum grade of steel shall be ASTM A 706 Grade 60.
- Reinforcement bars shall be of minimum 10 mm diameter for flexural action.
- The maximum spacing of reinforcement should not be greater than 380 mm to ensure confinement of concrete.

Table 6 - Cross section type

S.no	Type of cross-section	Description	Min.Comp rebar	Rotation limitation	Failure criteria
1	Type I	Concrete cover over the reinforcement remains intact and it is effective in resisting moment.	A’s≥0.5*As	$\theta \le 2^{o}$	
2	Type II	Concrete cover over the both surfaces of the reinforcement is crushed but remains intact and not effective in resisting moment.	A’s = As	$\theta > 2^{o} \le 6^{o}$	
3	Type III	Concrete cover over the reinforcement on both surfaces completely disengaged (spalled) and not effective in resisting moment.	A’s = As	$\theta > 6^{o} < 12^{o}$	 **11.2.**

- The lap length shall be calculated as per ACI 318 building code, but it should not be less than 600mm.
- For large deflections i.e. $6 < \theta < 12$, lap length shall be 30 % higher than the development length defined in the latest ACI 318 building code.
- The shear shall be resisted by providing lacing reinforcement or shear links which are classified into Type A, Type B and Type C.

i) Type A stirrup will be 90˚ hook on one side and 135˚ hook on other side.
For elements designed for blast loading on one face alone, then 90˚ hook shall be provided on blast loading face.
If blast acting on either face of the element, then the stirrup should be alternated with 90˚ and 135˚ hook.
ii) Type B stirrup will be 135˚ hook on either side.
iii) Type C stirrup will be 180˚ hook on either side.

- Type C stirrups or lacing reinforcement can be adopted for the structures experiencing close-in detonations.
- The minimum and maximum size of lacing and stirrup reinforcement shall be 10mm and 25mm respectively.
- The wall to floor or wall to slab should be connected by diagonal bar in order to avoid direct shear failure.

X. CONCLUSION

In this paper, following are the important key points inferred and discussed for the design of blast resistant design of protective structure subjected to an unconfined explosion.

1. Classification of protective structures as per its design strategy and purpose of the facility.
2. Identification of level of protection based on risk level from the risk assessment process.
3. Limitation of performance criteria for protective structure in line with the level of damage.
4. Summary of performance criteria for concrete structures as per DOD, ASCE and UFC 3-340-02.
5. Computation of pressure-time loading considering the dynamic pressure for different blast scenario.
6. SDOF analysis and design procedure for structural components subjected to an unconfined explosion.
7. The types of cross-section for capacity computation based on the importance of the structure, magnitude of pressure, allowable deformations and failure criteria.
8. Reinforcement detailing provision for concrete structure subjected to blast loading.

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