HiLL PUBLISHING

Scientific Access, 2026, 2(1), 49-61
https://www.hillpublisher.com/journals/sa/
ISSN Online: 3068-7500

Behaviour of the Metal Cladding Panel of a Steel Aircraft Maintenance Hangar Under the Stress of Highly Dynamic Loads from Explosive Impacts

G. Mageirou[1,*], D. Pantazopoulos[2]

[1]Hellenic Air Force Academy, Dekeleia Air Base, Dekeleia 13671 (1010), Athens, Greece.
[2]Hellenic Air Force, Dekeleia Air Base, Dekeleia 13671 (1010), Athens, Greece.

How to cite this paper: G. Mageirou, D. Pantazopoulos. (2026) Behaviour of the Metal Cladding Panel of a Steel Aircraft Maintenance Hangar Under the Stress of Highly Dynamic Loads from Explosive Impacts. *Scientific Access*, 2(1), 49-61.
DOI: 10.26855/sa.2026.03.006

Received: January 25, 2026
Accepted: February 27, 2026
Published: March 31, 2026

[*]**Corresponding author:** G. Mageirou, Hellenic Air Force Academy, Dekeleia Air Base, Dekeleia 13671 (1010), Athens, Greece.

© 2026 by the author(s).
This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial-NoDerivatives (CC BY-NC-ND) license, which permits non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited and is not modified or adapted.
https://creativecommons.org/licenses/by-nc-nd/4.0/

Abstract

Dynamic impacts caused by explosions from weapon systems are crucial in the design of Air Force structures, such as steel aircraft maintenance hangars. Blast loads are defined by high-intensity, short-duration pressure waves that exert considerable impulsive stresses on structural systems, frequently beyond the responses anticipated by traditional static analysis. Steel hangars, characterized by their elongated, lightweight design and dependence on slender components and joints, are particularly susceptible to local buckling, connection failure, and gradual collapse when subjected to dynamic loads. The influence of such loads on the response of structures depends on the distance of the explosion from the structure as well as on the weapon. This research investigates the influence of the distance of the explosion on a dynamic impact due to a GP750 (M117) bomb explosion on the response behaviour of a steel covering panel of a typical metal aircraft maintenance hangar. Parametric finite element analysis is conducted to demonstrate the effects of a GP750 bomb on the metal cladding panel of a typical hangar. The parameter that varies is the distance of the structure from the blast point.

Keywords

Aircraft maintenance hangars; steel frame; steel cladding panel; blast load; explosive load; ballistic threats; dynamic behaviour; explosion distance; structural failures

1. Introduction

Steel airplane maintenance hangars constitute essential infrastructure in both civil and military aviation, engineered to safeguard valuable aircraft assets while facilitating inspection, repair, and overhaul activities. In some operational settings—especially at airbases vulnerable to hostile conditions—these structures may face explosive and ballistic threats due to accidental detonations, sabotage, or direct assaults. Steel hangars, in contrast to traditional industrial structures, must meet not only functional and serviceability criteria but also heightened structural resilience against high-strain-rate loading, blast overpressure, fragment impact, and progressive collapse. The dynamic reaction of steel framing systems under high stress situations markedly differs from their behavior under static design loads, requiring specific analytical methods and performance-based design standards. This study examines the structural integrity and susceptibility of the steel cladding panel of a typical aircraft maintenance hangar to explosive and ballistic threats.

Explosives impacting airplane hangars generate air blast overpressure, reflected pressure, impulse, and ground shock. Elshenawy et al. [1] emphasized that mortar and artillery shells present a dual hazard: the primary blast wave induces a comprehensive structural response, while the high-velocity fragments inflict localized damage and

penetration. The cumulative effects significantly increase the probability of structural failure compared to loads that only produce blasts. Qi et al. [2] discovered that blast load characteristics significantly vary depending on charge weight, standoff distance, and structural shape. This underscores the significance of employing reliability-based blast load factors in the design of protective structures such as domed or arched airplane shelters.

Multiple studies have focused on the nonlinear dynamic response of HAS under high explosive stress. Zaghw et al. [3] performed a finite element analysis of a fortified aircraft shelter subjected to a general-purpose bomb explosion, employing nonlinear material models and explicit dynamic solvers. Their research demonstrated that reinforced concrete shelters experience considerable stress at the roof-wall connections, which may lead to cracking, spalling, and the potential for gradual collapse if energy absorption is insufficient.

Anas et al. [4] investigated a reinforced concrete blast-resistant shelter featuring a novel interior cylindrical design with vertical and inclined walls and a flat roof, constructed from M40 concrete and Fe500 steel. The analysis was conducted under two distinct blast scenarios: spherical air detonation (SAD) and hemispherical surface detonation (HSD), utilizing ABAQUS/Explicit code. Their findings indicated that conventional static design methodologies significantly underestimate the requisite strength of structures subjected to intense explosions.

Elshenawy et al. [1] introduced multi-layer protective systems that combine reinforced concrete, steel plates, and energy-absorbing layers to mitigate blast pressure and fragment impact. Their experimental and numerical results demonstrated substantial reductions in penetration depth and internal damage. Stevens et al. [5] present the development, underlying methodologies, field tests, and numerical simulations utilized in UFC 4–023-03 [6, 7].

Recent research has investigated the potential of novel materials to enhance the functionality of shelters. Gu et al. [8] conducted experimental and numerical studies on polyurea-coated shelters, revealing that elastomeric coatings significantly reduce spalling, extend fracture propagation, and improve energy dissipation under severe blast loading. These results are particularly relevant to the enhancement of current aircraft shelters, particularly in situations when increasing wall thickness is impractical. Contemporary advances in protective design prioritize materials that dissipate energy and mitigate injury rather than those that solely emphasize strength.

Employing LS-DYNA, AUTODYN, and ABAQUS for numerical simulations, explicit methods are often utilized to enhance design concepts for hardened aircraft shelters, as demonstrated in the literature. These methodologies provide a comprehensive understanding of blast wave propagation, the mechanics of contact detonation, the nonlinear behaviour of materials, and the dissemination of damage. Blast-resistant design frequently follows military design guidelines such as UFC 3-340-02 [6]. Conversely, peer-reviewed research evaluates, enhances, and supplements these criteria. Combining finite element analysis with real-world proven material models is crucial for safe shelter design against significant explosive risks.

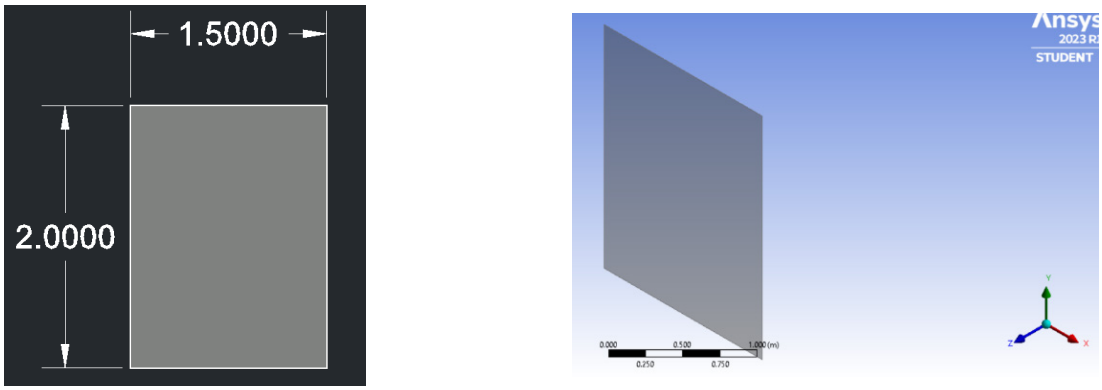
Despite major progress, there are still a number of issues in the literature, such as the lack of comprehensive experimental evaluations of Air Force structures such as steel aircraft maintenance hangars as well as reinforced aircraft shelters subjected to simultaneous explosive and ballistic impacts, the measurement of uncertainty (using probabilistic analysis) in threat parameters like charge mass, impact angle, and fragment dispersion, the assessment of structural behavior after partial destruction (progressive collapse), and retrofit technologies after multiple blasts. Confronting these challenges is essential for the future of Air Force structures design, especially considering the changing military threats

2. Metal Cladding Panel of a Typical Hangar

A parametric investigation of the behavior of a metal panel covering a typical metal aircraft canopy in a dynamic impact caused by the explosion of a general-purpose bomb, the GP 750 or otherwise M117, with the distance of the explosion from the structure as a parameter, is carried out. The parameter that varies is the distance of the structure from the blast point (20m, 10m, and 5m).

The geometry of the aircraft hangar was selected based on standard designs for aviation and military facilities [6], [9, 10]. The steel panel under consideration has dimensions of 1.5 m x 2 m x 5 mm and is discretized with surface finite elements (surface body).

S355 steel quality is selected for the metal canopy, in accordance with the regulatory provisions of Eurocode 3 [11]. The simulation of the influence of dynamic loading on material behavior – Cowper Symonds modelling [12] is presented by equation (1.1).



(a) (b)

Figure 1. (a) Geometry of the steel cladding panel of a typical aircraft maintenance hangar (dimensions in m), (b) model of the steel cladding panel – Ansys FEM software.

$$\sigma_d = (A + n\frac{B \cdot E}{E-B} \cdot \varepsilon_{eff}^{p}) \left[1 + (\frac{\dot{\varepsilon}}{D})^{1/q}\right] \quad (1.1)$$

where:
σd: dynamic yield stress
E: Elastic modulus or Modulus of Elasticity
εeffp; plastic strain
n: hardening coefficient
$\dot{\varepsilon}$: strain rate
A, B, D, q: experimentally determined coefficients

The aforementioned methodology is based on experimental measurements. In this study, the parameters presented in Table 1 were selected [13].

Table 1. Cowper-Symonds method parameters [13]

A	B	n	D	q
440MPa	865MPa	0.37	38370	2.395

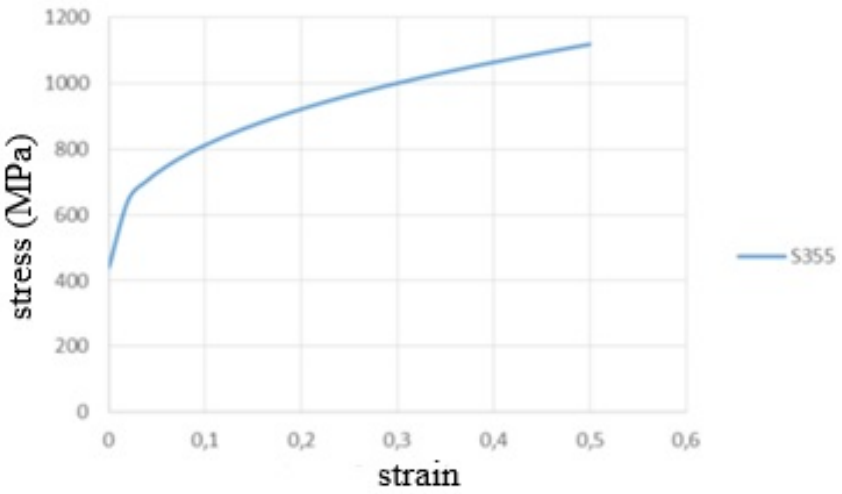
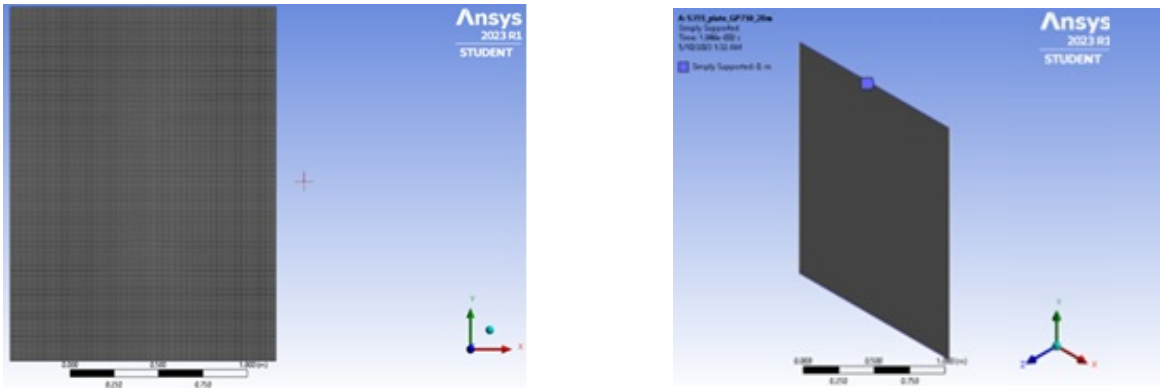


Figure 2. Stress-strain diagram for S355 steel (Cowper-Symonds model).

The discretization of the metal roof covering panel is performed using surface finite elements. The covering panel of the metal shed is considered simply supported.



(a) (b)

Figure 3. a) FEM Discretization and b) Supports of the steel cladding panel.

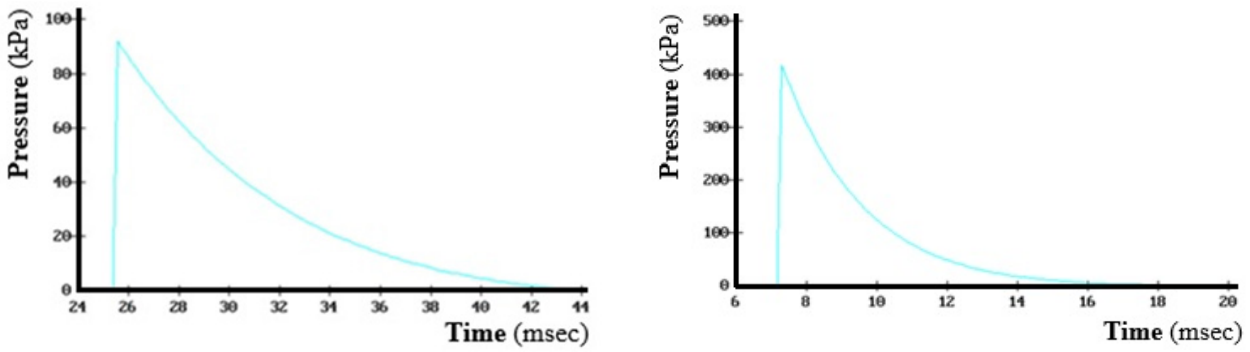
3. Threat Details

The dynamic impact is caused by an explosion from a general-purpose bomb, the GP 750 (M117). This weapon is a particularly realistic choice as it can be mounted on a variety of aircraft and is designed to strike targets such as shelters and aircraft hangars. It has an explosive charge of 175 kg of Tritonal, equivalent to 221 kg of TNT, while the design fragment weighs 38.6 g. Its total weight is 332 kg. The explosion is considered to occur at ground level (reflective surface of the blast wave) and is followed by a hemispherical wave.

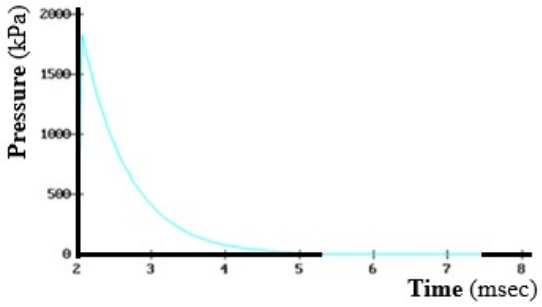
The pressure-time diagrams for a dynamic impact from a GP 750 (M117) bomb, at distances of 20 m, 10 m, and 5 m from the structure, are shown in the figures below.

Table 2. Characteristics of the impact of a GP 750 (M117) bomb at various distances from the structure

	Explosion distance - Range (m)		
	20	10	5
Charge Weight (kg)	175.10	175.10	175.10
Equivalent Weight of TNT (kg)	221.50	221.50	221.50
Peak Pressure (kPa)	94.58	440.40	2004
Impulse (kPa msec)	514.20	968.10	1251
Time of arrival (sec)	25.390	7.182	2.013
Duration (msec)	18.460	12.600	5.475
Decay coefficient	9.994	2.824	0.7187



(a) (b)



(c)

Figure 4. Time pressure diagram for dynamic impact from an M117 bomb explosion at a distance of a) 20m, b) 10m and c) 5m from the structure.

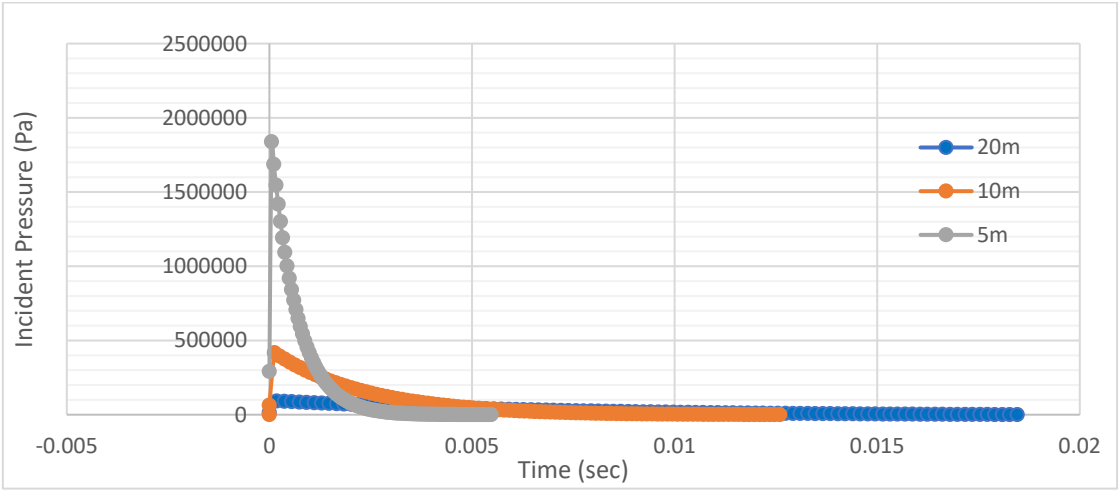


Figure 5. Time pressure diagrams for dynamic impact from an M117 bomb explosion at distances of 20m, 10m, and 5m from the structure.

A nonlinear dynamic analysis of the above models was performed using Ansys finite element software. The steel cladding panel is loaded by the dynamic impact of the explosion with a pressure that decreases with time. Due to the impact, the cladding sheet initially moves towards the negative of the Z axis and then performs a decreasing oscillation.

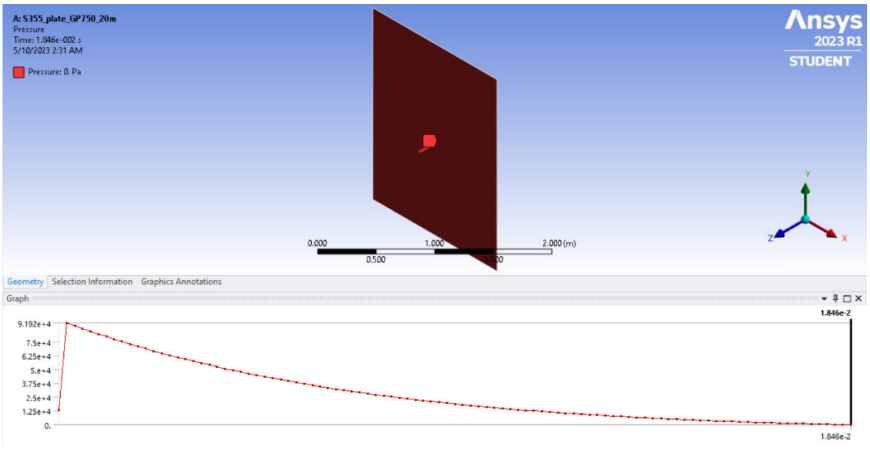


Figure 6. Dynamic impact load on the surface of the steel covering panel for an explosion at a distance of 20m.

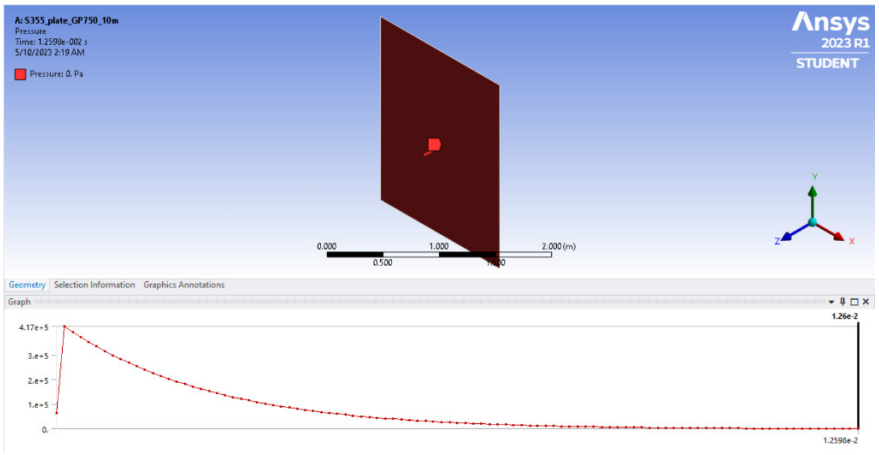


Figure 7. Dynamic impact load on the surface of the steel covering panel for an explosion at a distance of 10m.

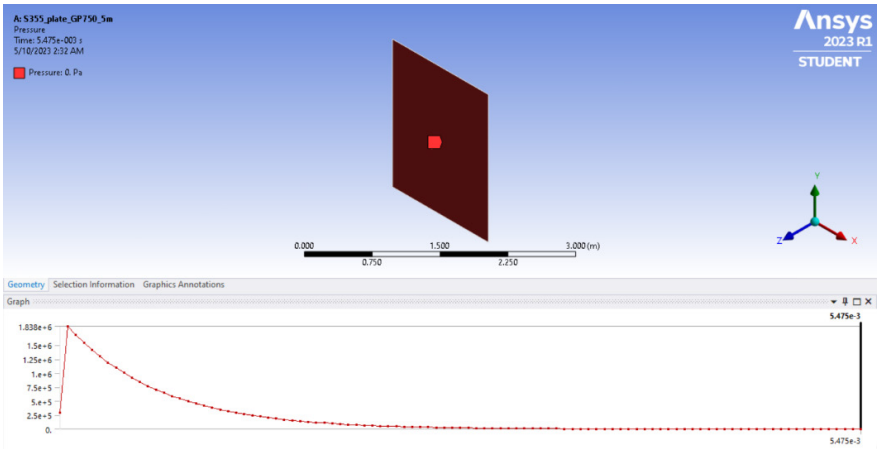


Figure 8. Dynamic impact load on the surface of the steel covering panel for an explosion at a distance of 5m.

4. Results of Nonlinear Dynamic Parametric Analysis

A nonlinear dynamic analysis of the above models was performed using Ansys finite element software.

4.1 Explosion distance 20m from the structure

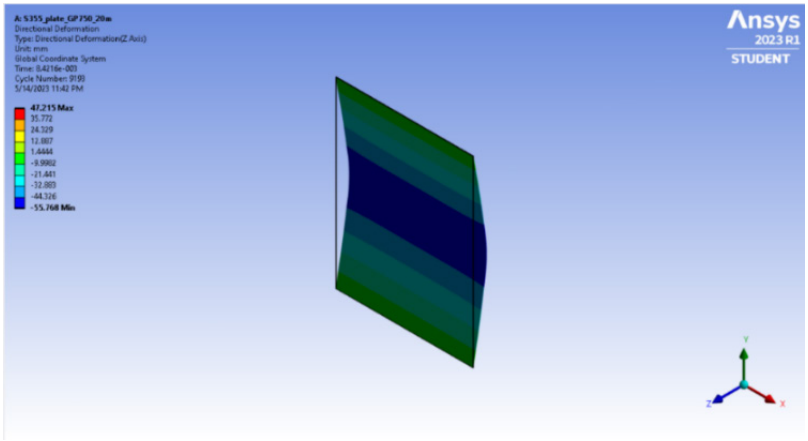


Figure 9. Maximum deflection for the panel of the steel structure, in the negative Z axis, explosion distance (range) 20m from the structure.

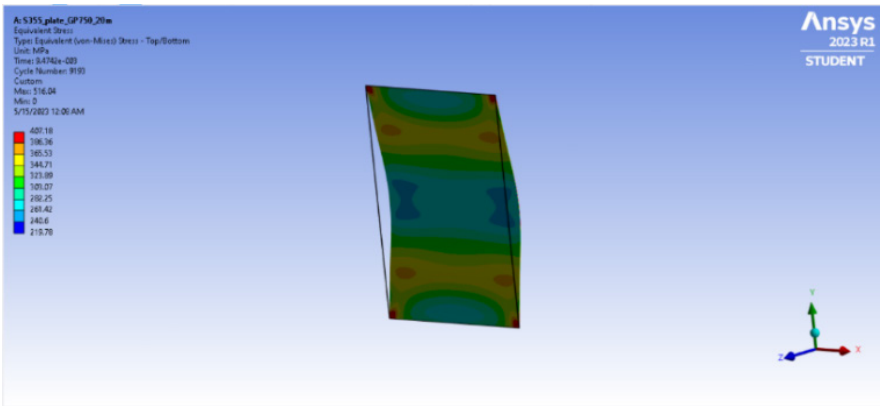


Figure 10. Von Mises Stress distribution for the panel of the steel structure, explosion distance (range) 20m from the structure.

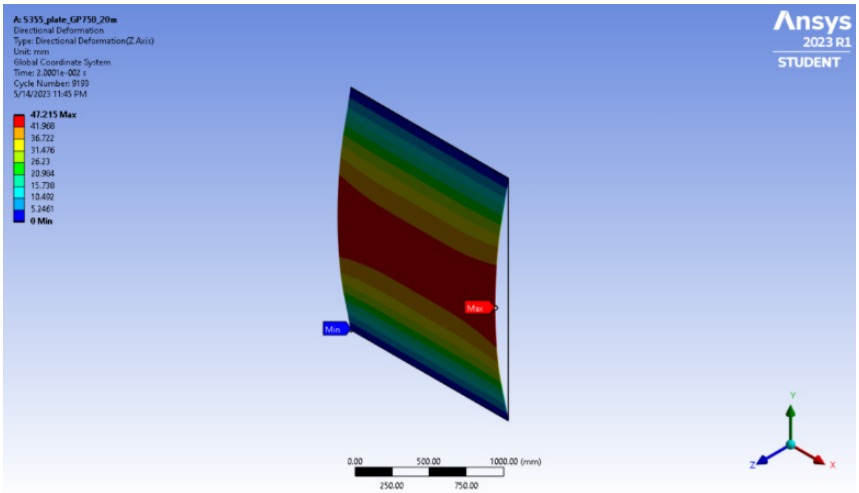


Figure 11. Maximum deflection for the panel of the steel structure, in the positive Z axis, explosion distance (range) 20m from the structure.

4.2 Explosion distance 10m from the structure

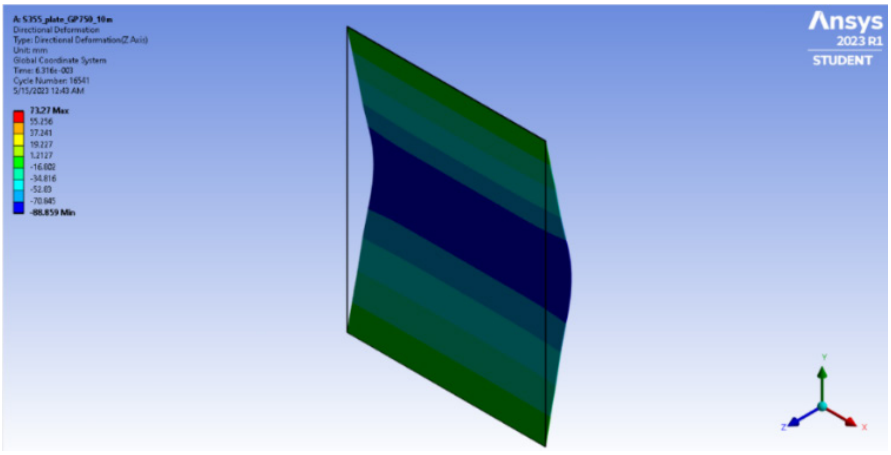


Figure 12. Maximum deflection for the panel of the steel structure, in the negative Z axis, explosion distance (range) 10m from the structure.

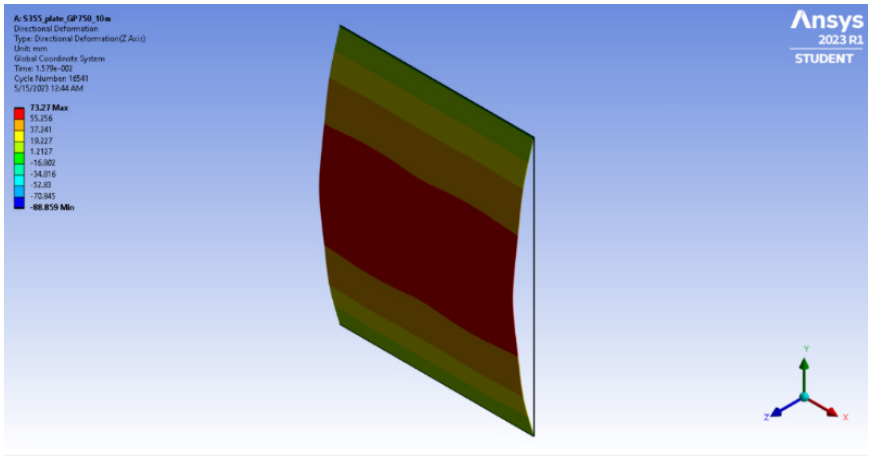


Figure 13. Maximum deflection for the panel of the steel structure, in the positive Z axis, explosion distance (range) 10m from the structure.

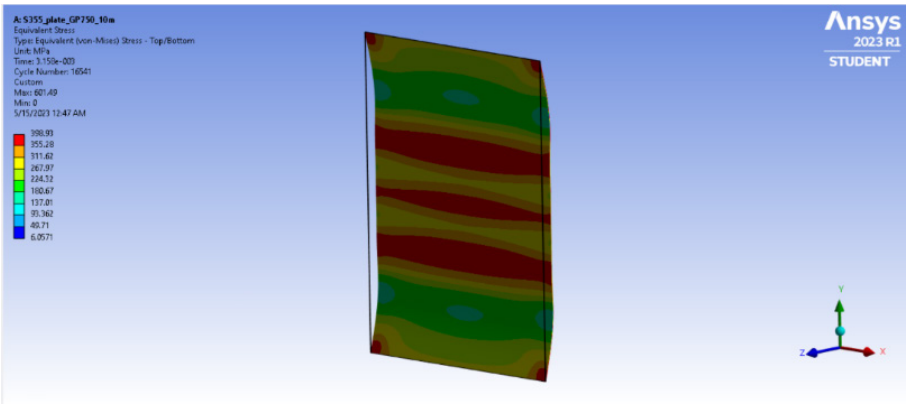


Figure 14. Von Mises Stress distribution for the panel of the steel structure, explosion distance (range) 10m from the structure.

The areas on the support sides of the panel are experiencing plastic deformation. The equivalent Von Mises Stress in these areas has far exceeded the yield stress of the material.

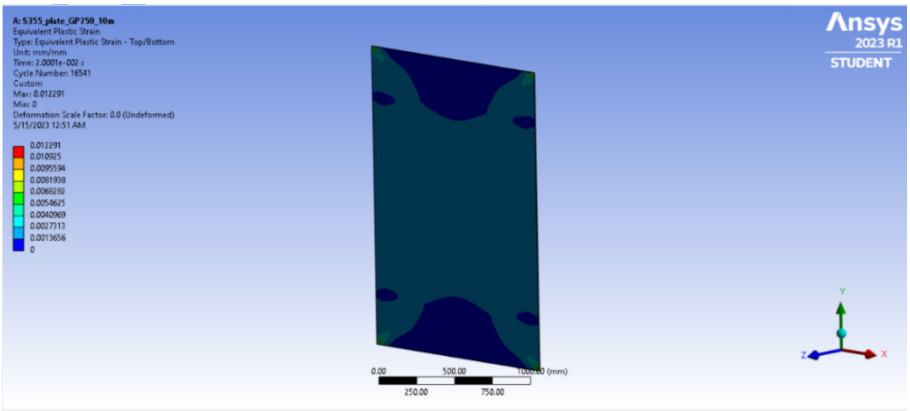


Figure 15. Plastic strain distribution for the panel of the steel structure, explosion distance (range) 10m from the structure.

The deflection from the explosion at a distance of 10m from the metal shed is in the order of 7.5 cm, with intense plastic deformations. Our structure will be particularly stressed while at the same time functionality is likely to be affected since equipment destruction is possible due to displacements.

4.3 Explosion distance 5m from the structure

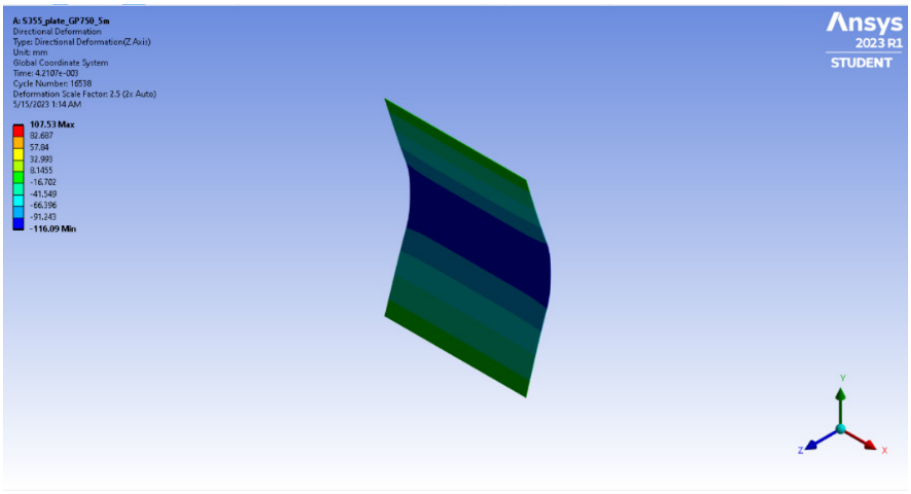


Figure 16. Maximum deflection for the panel of the steel structure, in the negative Z axis, explosion distance (range) 5m from the structure.

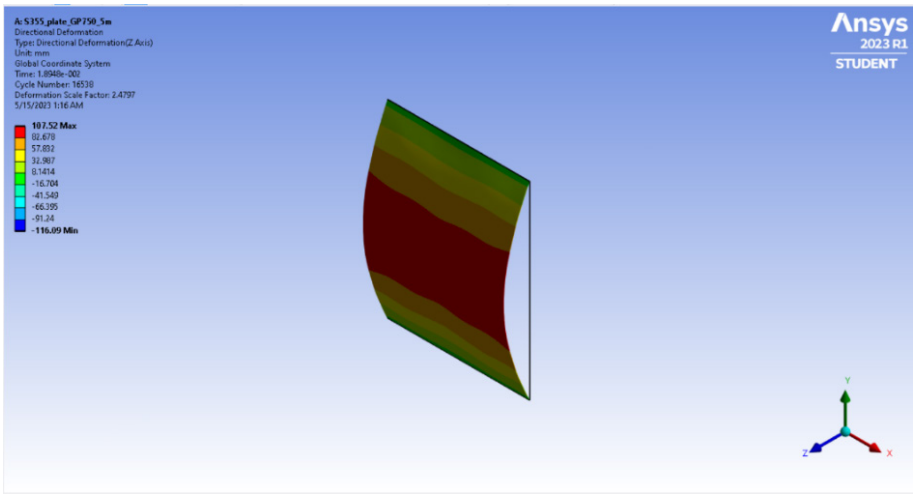


Figure 17. Maximum deflection for the panel of the steel structure, in the positive Z axis, explosion distance (range) 5m from the structure.

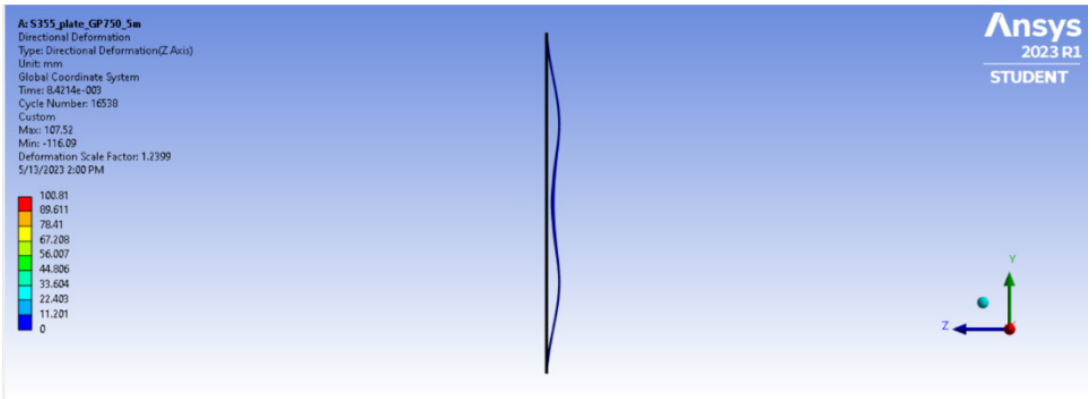


Figure 18. Snapshot of the oscillation of the steel panel.

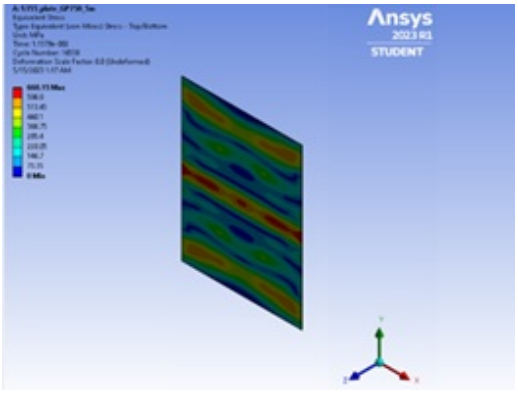


Figure 19. Von Mises Stress distribution for the panel of the steel structure, explosion distance (range) 5m from the structure.

The equivalent stress in this analysis reaches up to 660MPa, thus far exceeding the dynamic yield strength limit of the steel. Similar to before, a large percentage of the plate surface is plastified.

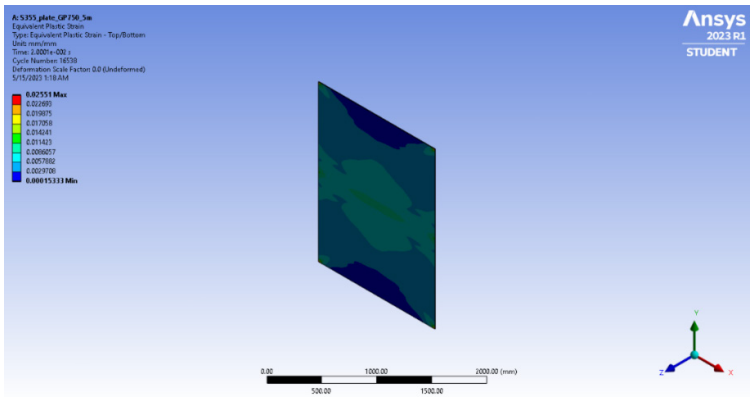


Figure 20. Plastic strain distribution for the panel of the steel structure, explosion distance (range) 5m from the structure.

The bending deflection is in the order of 11cm, with intense plastic deformations. This means that our structure will be particularly stressed, while at the same time, functionality is likely to be affected, since equipment destruction is possible due to displacements.

The comparative diagrams from the aforementioned parametric analyses are presented, with the distance of the explosion from the structure as a parameter.

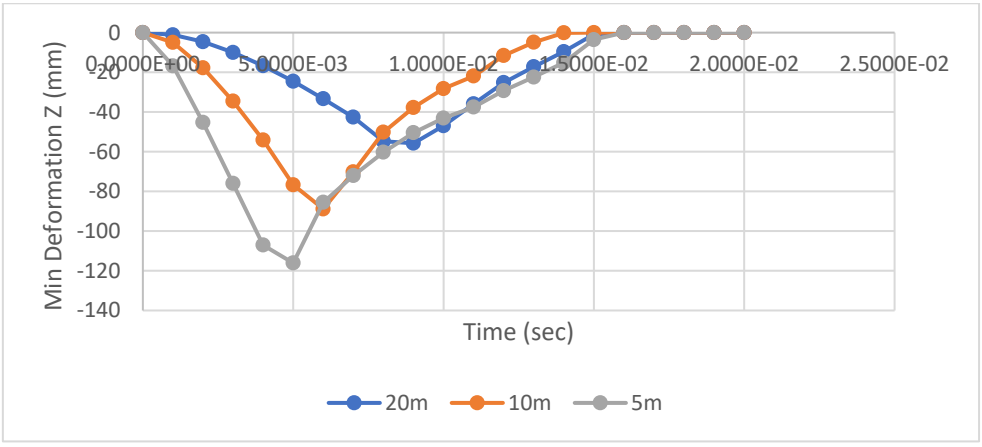


Figure 21. Deformation in the negative Z axis vs time diagram for the panel of the steel structure, for different explosion distances (range) from the structure.

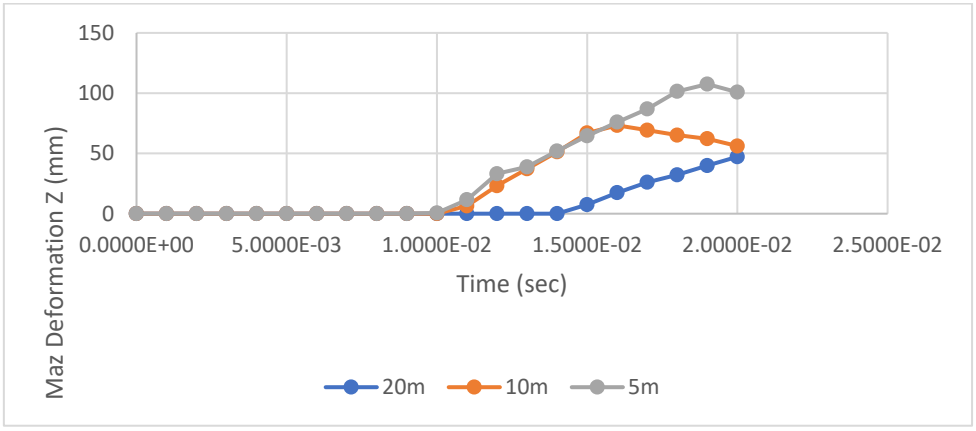


Figure 22. Deformation in the positive Z axis vs time diagram for the panel of the steel structure, for different explosion distances (range) from the structure.

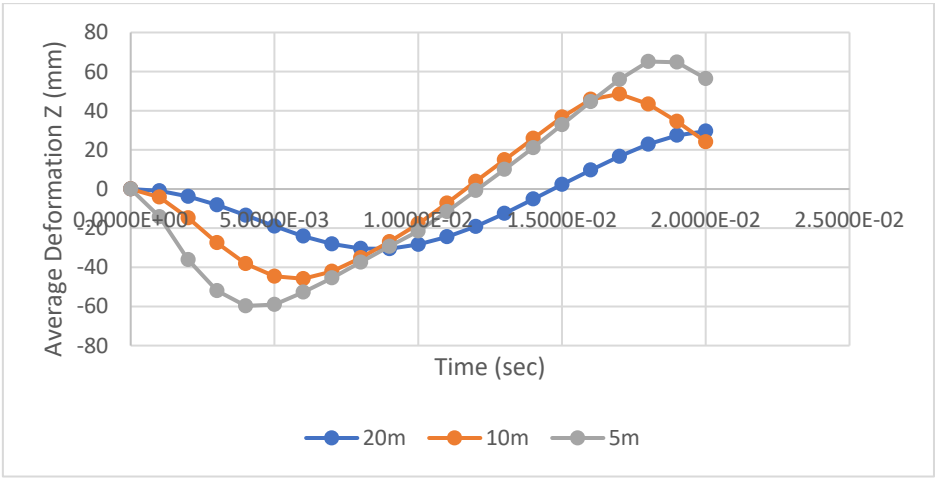


Figure 23. Average deformation vs time diagram for the panel of the steel structure, for different explosion distances (range) from the structure.

The last diagram shows the oscillation of the overlay sheet due to the dynamic impact. The period is proportional to the amplitude of the oscillation and inversely proportional to the distance from the explosion. This is justified by the fact that the characteristics of the oscillation depend on the properties of the material. Thus, the greater energy through the pressure caused by the explosion at a short distance creates a larger amplitude of oscillation and therefore a longer period.

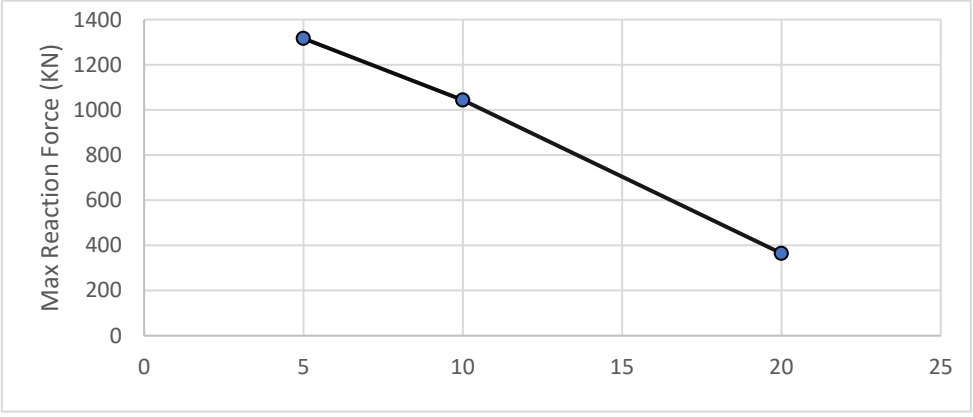


Figure 24. Reaction vs explosion distances (range) diagram.

The reactions of the steel panel supports are stressed with forces many times greater than their design forces if the explosive shock is not taken into account. Therefore, it is considered appropriate, when designing the support connections of the cladding sheet, to take into account the dynamic shocks due to the explosive load because, in the event of failure, the cladding sheet can be carried away and thrown by the explosive wave.

5. Conclusion

Air Force infrastructure, such as fortified steel aircraft maintenance hangars and aircraft shelters, depends on the dynamic impacts of armament system explosions. The influence of these pressures on structural response depends on the distance of the explosion from the structure and the kind of weapon used. This study investigates the impact of explosion distance on the dynamic response of a steel covering panel in a conventional metal aircraft maintenance hangar after a GP750 (M117) bomb detonation. A parametric finite element study is conducted to demonstrate the effects of a GP750-M117 bomb on a metal cladding panel of a conventional hangar. The variable parameter is the distance of the structure from the explosion site.

The dynamic impact of explosions from weapons systems is crucial in the design of Air Force facilities, such as steel aircraft repair hangars and fortified aircraft shelters. The influence of these pressures on structural response depends on the distance of the explosion from the structure and the kind of weapon used. This study investigates the impact of explosion distance on the dynamic response of a steel covering panel in a conventional metal aircraft maintenance hangar after a GP750 (M117) bomb detonation. A parametric finite element study is conducted to demonstrate the effects of a GP750-M117 bomb on a metal cladding panel of a conventional hangar. The variable parameter is the distance of the structure from the explosion site.

The proximity of the explosion site to the structure significantly influences its response. A structure impacted by an explosion exhibits periodic motion characterized by diminishing oscillations. The connections through bolts or welds to the primary steel frames of the metal shelter are crucial to the performance of the metal covering panel during an explosive impact. Furthermore, one can ascertain the vulnerabilities of a structure and subsequently investigate methods to mitigate them.

It is beneficial to propose specific recommendations for the enhancement of current structures and/or the potential design of future protected edifices. Facilities can be safeguarded from debris by many methods, one of which involves the installation of protective walls surrounding the structures to be defended. These materials will not only absorb a significant portion of the blast wave's energy but will also safeguard the structure from damage caused by both primary and secondary debris generated by the explosion. This protects not only the structure and its apparatus but, most importantly, the lives of its occupants. An alternative method would be to employ backfill around an airplane maintenance hangar. The combination of backfill and a concrete slab would serve as an exceptionally effective protective measure.

References

[1] Elshenawy TA, Seoud MA, Abdo GM. Ballistic protection of military shelters from mortar fragmentation and blast effects using a multi-layer structure. Def Sci J. 2019;69(6):538-544. doi: 10.14429/dsj.69.13269.

[2] Qi S, Huang G, Zhi X, Fan F, Flay R. External blast load factors for dome structures based on reliability. Def Technol. 2022;18(2):170-182. https://doi.org/10.1016/j.dt.2021.01.004.

[3] Zaghw AI, Metwally KG, Emarah AM. Nonlinear dynamic finite element analysis of hardened aircraft shelter subjected to blast load. N Y Sci J. 2017;10(10):70-78. Available from: https://www.researchgate.net/publication/320083376_Nonlinear_Dynamic_Finite_Element_Analysis_of_Hardened_Aircraft_Shelter_Subjected_To_Blast_Load.

[4] Anas SM, Alam M, Umair M. Reinforced cement concrete (RCC) shelter and prediction of its blast loads capacity. Mater Today Proc. 2023;74(4):547-568. https://doi.org/10.1016/j.matpr.2022.09.125.

[5] Stevens D, Crowder B, Sunshine D, Marchand K, Smilowitz R, Williamson E, et al. DoD research and criteria for the design of buildings to resist progressive collapse. J Struct Eng. 2011;137(9):870-880.

[6] U.S. Army Corps of Engineers, Naval Facilities Engineering Command, Air Force Civil Engineer Support Agency. UFC 3-340-02 Structures to Resist the Effects of Accidental Explosions - Unified Facilities Criteria. USA; 2008.

[7] U.S. Department of Defense. UFC unified facilities criteria – design of buildings to resist progressive collapse. USA; 2009.

[8] Gu M, Wang H, Chen G, Yu A, Dang W, Ling X. Experimental and numerical study on explosion resistance of polyurea-coated shelter in petrochemical industry. Sci Rep. 2024;14(1):12397. doi: 10.1038/s41598-024-71339-w.

[9] North Atlantic Treaty Organization. Bi-SC Directive 85-5. NATO approved criteria and standards for airfields. 2010.

[10] Hansson H, Skoglund P. Simulation of concrete penetration in 2D and 3D with the RHT material mode: technical report. Sweden: Swedish Defense Research Agency, Weapons and Protection; 2002.

[11] European Committee for Standardization. Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. Brussels, Belgium: CEN; 2005.

[12] Hernandez C, Maranon A, Ashcroft IA, Casas-Rodriguez JP. A computational determination of the Cowper–Symonds parameters from a single Taylor test. Appl Math Model. 2013;37(7):4698-4708. https://doi.org/10.1016/j.apm.2012.10.010.

[13] Ostadhossein H, Lotfi S. Performance of infill stiffened steel panel against blast loading. Lat Am J Solids Struct. 2018;15(2):1-15. https://doi.org/10.1590/1679-78254429.