Engineering and Technology Journal e-ISSN: 2456-3358
Volume 11 Issue 04 April-2026, Page No.-9355-9366
DOI: 10.47191/etj/v11i04.05, I.F. – 8.595

Effect of Structural Thickness on the Failure Behavior of Door-Lock Systems Under Explosive Breaching

Van Hung Nguyen[1], Huy Thanh Nguyen[1], Viet Trung Nguyen[2], Minh Duc Hoang[3], Trac Dang Nguyen[3]
[1]Faculty of Special Equipment, Le Quy Don Technical University, 236 Hoang Quoc Viet, Nghia Do, Ha Noi, 100000, Viet Nam
[2]Training Center 125, Le Quy Don Technical University, Ha Noi, 100000, Viet Nam
[3]Center for Special Equipment, Ha Noi, 100000, Viet Nam

ABSTRACT: Explosive breaching is widely used to rapidly disable door-lock systems in military and emergency operations. This study investigates the structural response and failure behavior of door-lock systems subjected to explosive breaching charges, using a combination of numerical simulations and experimental validation. A three-dimensional numerical model was developed using explicit dynamic analysis to simulate the interaction between a C4 explosive charge and a steel door-lock system. The influence of structural thickness was examined for three configurations (2 mm, 3 mm, and 4 mm). The results show that the explosive loading generates extremely high stress levels, with peak von Mises stress reaching approximately 600–700 MPa, which is significantly higher than the yield strength of CT3 steel (235 MPa). This leads to rapid plastic deformation and structural failure. Increasing the thickness of the door-lock system reduces both deformation and stress concentration; however, failure still occurs in all cases. The results indicate that thickness primarily affects the severity of damage rather than preventing failure under the given loading conditions. Experimental tests were conducted to evaluate detonation reliability and breaching effectiveness. The explosive charge was successfully initiated in all tests, and all door-lock systems were effectively destroyed, confirming the breaching capability of the proposed design. The experimental observations show good qualitative agreement with the numerical predictions. Overall, the study provides insight into the role of structural parameters in explosive breaching and demonstrates that increasing thickness improves resistance but does not eliminate failure.

KEYWORDS: Explosive breaching; door-lock system; explicit dynamic analysis; structural failure; thickness effect.

I. INTRODUCTION

Explosive breaching is a critical technique widely employed by military units, special operations forces, and rescue teams to rapidly penetrate physical barriers such as doors and walls, enabling immediate access to confined spaces in emergency or urban combat scenarios [1–3]. Compared with mechanical or ballistic breaching methods, explosive breaching offers significant advantages in terms of speed, effectiveness, and the ability to overcome heavily reinforced structures.

The primary objective of explosive breaching is to disable key structural components of a barrier, particularly locking mechanisms and hinges. Various types of explosive charges have been developed for this purpose, including donut charges, linear charges, and push charges, each tailored to specific operational requirements [1]. For high-resistance doors classified under resistance classes (RC II–IV), which incorporate multiple active and passive locking points distributed along the frame, the destruction of a single locking cylinder is insufficient to achieve full access. Previous studies have suggested the use of upgraded or sealed linear charges placed along the entire edge of the door to simultaneously disengage all locking points, thereby improving breaching efficiency.

In addition to charge configuration, the structural characteristics of the target significantly influence the breaching outcome. For metallic doors, internal compositions such as polystyrene foam, polyurethane, or mineral wool cores, together with the thickness of steel layers, play an important role in determining deformation behavior and resistance to explosive loading [2]. Therefore, understanding the interaction between explosive loads and structural parameters is essential for optimizing breaching performance.

The effects of explosive loading on materials vary depending on their mechanical properties and structural configurations. For concrete and masonry structures, contact charges generate extremely high pressures that produce localized crushing (brisance) and form a crater on the front surface [5]. The resulting stress waves propagate through the material thickness and reflect from the rear surface, generating tensile stresses that lead to spalling and fragmentation [3]. A successful breach occurs when the front crater and rear spall region intersect. Numerical tools such as AUTODYN and XPLOSIM have been widely used to predict crater depth and breach dimensions based on explosive mass and geometry [2,5,6]. Moreover, previous studies have demonstrated that optimizing the ratio between charge diameter and thickness can significantly enhance breaching efficiency compared to merely increasing explosive mass [5].

For metallic materials, explosive loading induces high-strain-rate deformation and can accelerate metal fragments to extremely high velocities. In shaped charges or explosively formed penetrators (EFP), chemical energy is converted into kinetic energy, forming high-velocity metal jets capable of penetrating steel targets [7,8]. The effectiveness of such processes is commonly characterized by the Gurney velocity, which represents the maximum velocity imparted to metal fragments or liners by a given explosive [9,10]. Although breaching charges differ from shaped charges in configuration, similar physical principles govern the interaction between explosive energy and metallic structures.

Despite the extensive body of research on explosive effects in concrete and metallic targets, studies focusing specifically on door-lock systems remain limited, particularly in terms of the influence of structural parameters such as thickness on failure behavior. Furthermore, experimental investigations in this field are often constrained by safety and measurement limitations, leading to simplified validation approaches.

In this study, a parametric numerical investigation is conducted to analyze the deformation and failure behavior of door-lock systems subjected to explosive breaching charges. The Effect of target thickness is systematically examined through simulations using explicit dynamic analysis. In addition, experimental observations are employed to validate the numerical predictions based on a binary classification of failure and non-failure. The results of this study provide insights into the relationship between structural parameters and breaching effectiveness, contributing to the design and optimization of explosive breaching systems. Unlike previous studies focusing on penetration or complete structural resistance, this study emphasizes the role of thickness in controlling damage severity under explosive breaching conditions.

II. Numerical Mode

A. Geometry and configuration

A three-dimensional numerical model was developed to simulate the interaction between an explosive breaching charge and a door-lock system. The breaching device consists of an explosive charge (C4), a casing, and a protective cover made of ABS plastic. The geometric model of the breaching device was created using CAD software and imported into the simulation environment (Figure 1).

The target structure represents a door-lock system made of CT3 steel. To investigate the effect of structural parameters on failure behavior, three different thicknesses were considered: 2 mm, 3 mm, and 4 mm.

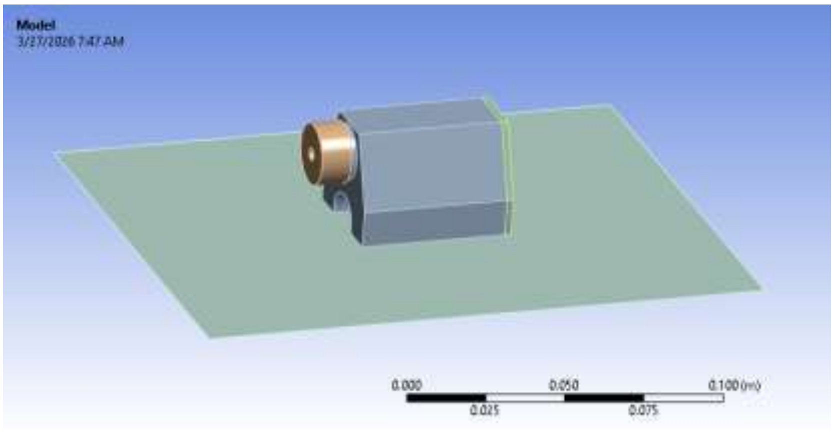


Fig. 1. Numerical model of the explosive breaching charge and door-lock system

B. Material models

The explosive material was modeled as C4 using a high-explosive model to capture detonation behavior and pressure generation. The casing and protective components were modeled as ABS plastic, which primarily serve as structural support.

The door-lock system was assumed to be made of CT3 steel and modeled as an elastic–plastic material. The material properties allow the evaluation of deformation and stress evolution under high-strain-rate loading conditions (Table 1).

Table 1. Material properties used in the numerical simulation

Material	Density (kg/m³)	Young's modulus (GPa)	Yield strength (MPa)	Model
C4	1600	–	–	High explosive (JWL)
ABS	1050	2.0	40	Elastic

Material	Density (kg/m³)	Young's modulus (GPa)	Yield strength (MPa)	Model
CT3 steel	7850	210	235	Elastic–plastic

C. Mesh and numerical discretization

The computational domain was discretized using a finite element mesh. A finer mesh was applied in regions near the explosive charge and the contact interface with the door-lock system to ensure accurate capture of stress waves and deformation gradients (Figure 2).

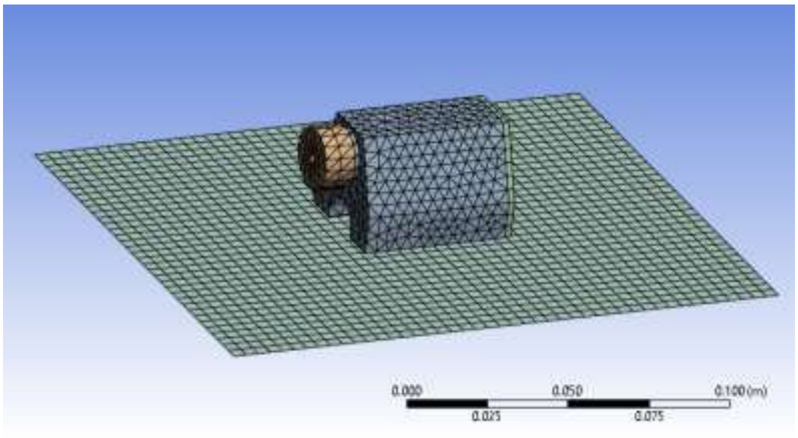


Fig. 2. Finite element mesh of the numerical model

D. Boundary and initial conditions

The detonation point was defined at the location of the detonator embedded within the breaching charge. Upon initiation, a high-pressure wave is generated and propagates toward the door-lock system.

Contact interactions between the explosive charge and the target surface were defined to ensure realistic transmission of pressure and momentum. The surrounding boundaries were assumed to allow free deformation of the structure under explosive loading (Figure 3).

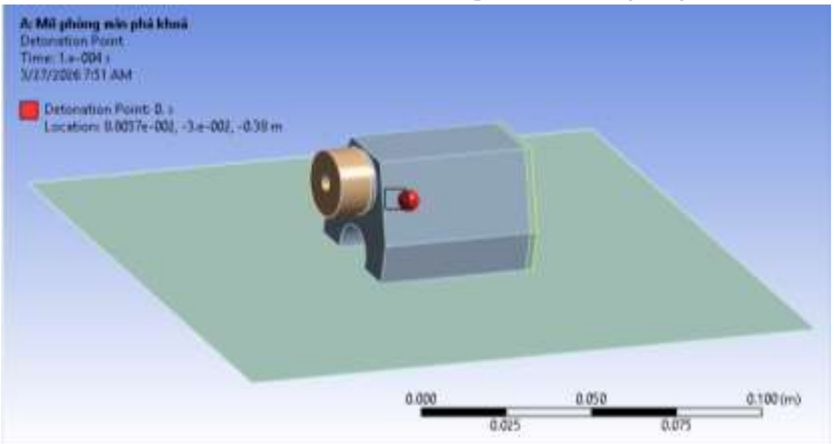


Fig. 3. The detonation point of the numerical model

E. Failure criterion

The failure behavior of the door-lock system under explosive loading was evaluated based on the equivalent stress and deformation response of the material. Due to the high-strain-rate nature of explosive events, the von Mises yield criterion was adopted as a suitable measure to assess the onset of plastic deformation in ductile metals.

According to the von Mises criterion, yielding occurs when the equivalent stress reaches the yield strength of the material:

$$\sigma_{eq} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]} \geq \sigma_y$$

where: σ_{eq} is the equivalent (von Mises) stress; $\sigma_1, \sigma_2, \sigma_3$ are the principal stresses, and σ_y is the yield strength of the material

For CT3 steel, yielding is assumed to initiate when the equivalent stress exceeds the yield strength, indicating the transition from elastic to plastic behavior. Under explosive loading conditions, this transition is typically followed by rapid plastic deformation and potential structural failure.

In addition to the stress-based criterion, deformation was also considered as an indicator of failure. Excessive deformation implies loss of structural integrity and functional failure of the locking mechanism. Therefore, a combined failure criterion was adopted in this study: the door-lock system is considered to fail when the equivalent stress exceeds the yield strength and the deformation reaches a critical level associated with structural instability.

This approach enables a practical evaluation of failure behavior and provides a direct basis for comparison with experimental observations, where the results are classified into failure and non-failure categories.

The simulations were performed using an explicit dynamic analysis approach, which is suitable for modeling high-strain-rate events such as explosions.

Time-dependent responses, including total deformation, equivalent elastic strain, and von Mises stress, were extracted for further analysis. These results are used to evaluate the dynamic response of the door-lock system and the influence of thickness on failure behavior.

III.RESULTS AND DISCUSSION

A. Baseline case: 2 mm door-lock system

The baseline configuration with a thickness of 2 mm exhibits the most severe structural response under explosive loading.

Immediately after detonation, a high-pressure shock wave is generated and propagates toward the door-lock system, resulting in rapid deformation over a very short time scale (10^{-5} - 10^{-4} s). This rapid response reflects the impulsive nature of explosive loading, in which a large amount of energy is transferred over a short period (Figure 4).

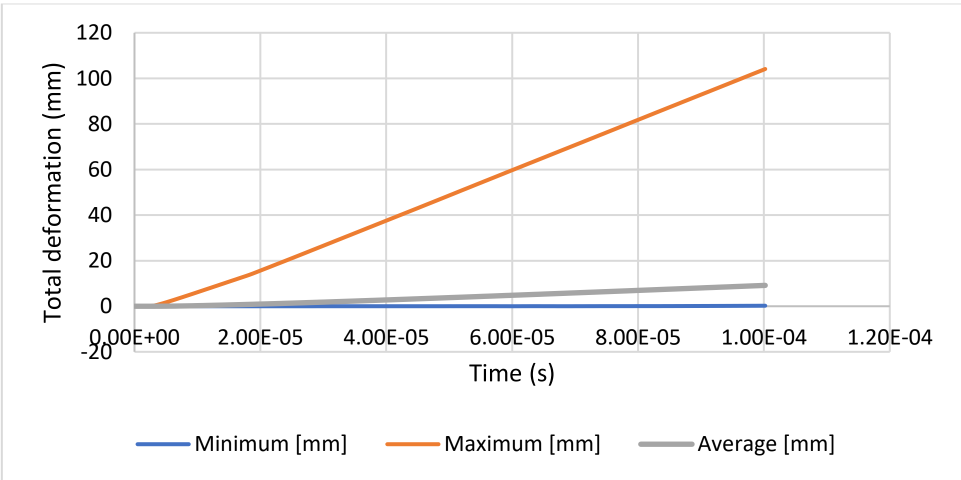


Fig. 4. Time history of total deformation for the 2 mm door-lock system

The von Mises stress distribution (Figure 5) shows that the peak stress is approximately 600–700 MPa, which is 2.5–3 times the yield strength of CT3 steel (235 MPa).

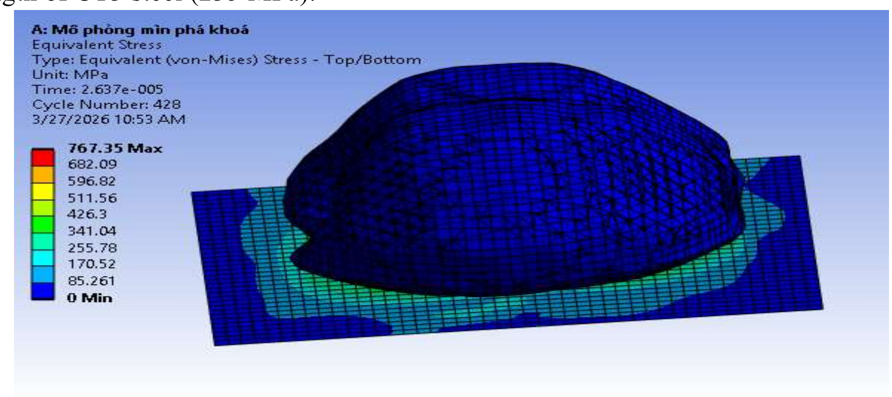


Fig. 5. Distribution of von Mises stress for the 2 mm door-lock system at peak loading condition

Furthermore, the stress and deformation fields are highly localized near the contact region between the explosive charge and the lock. This suggests that the failure mechanism is governed by localized shear and bending, rather than uniform deformation.

The strong localization of stress is attributed to the direct contact detonation, which generates highly concentrated pressure and steep stress gradients in the target material.

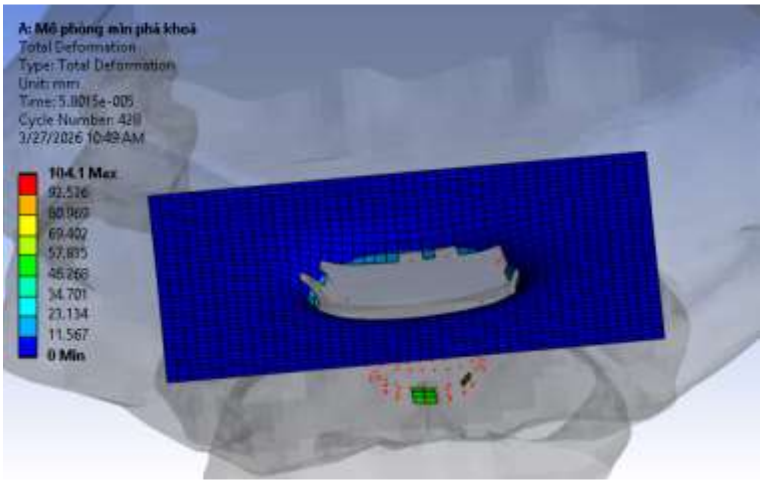
B. Effect of thickness on structural response

The influence of thickness on structural response is clearly demonstrated in Figures 6–8.

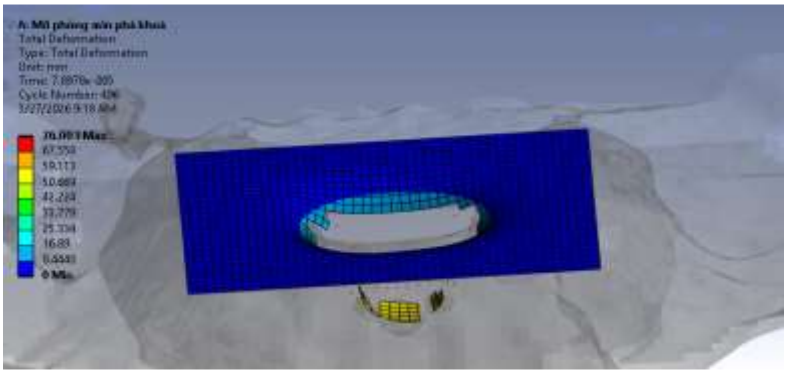
As the thickness increases from 2 mm to 3 mm and 4 mm, both deformation and stress levels decrease noticeably. This trend can be explained by the increased stiffness and load-bearing capacity of thicker structures, which reduces the amplitude of stress waves and limits deformation.

For the 3 mm configuration, the maximum stress is reduced compared to the baseline case, but still exceeds the yield strength in localized regions. This indicates that plastic deformation still occurs, although the severity of damage is reduced.

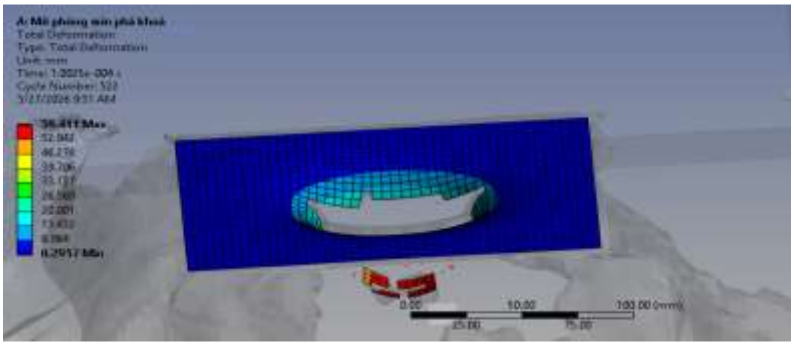
For the 4 mm configuration, the structural response is further attenuated. The deformation is significantly lower, and the stress distribution becomes less localized. However, the peak stress still approaches or exceeds the yield strength in critical regions.



Thicknesses of 2 mm

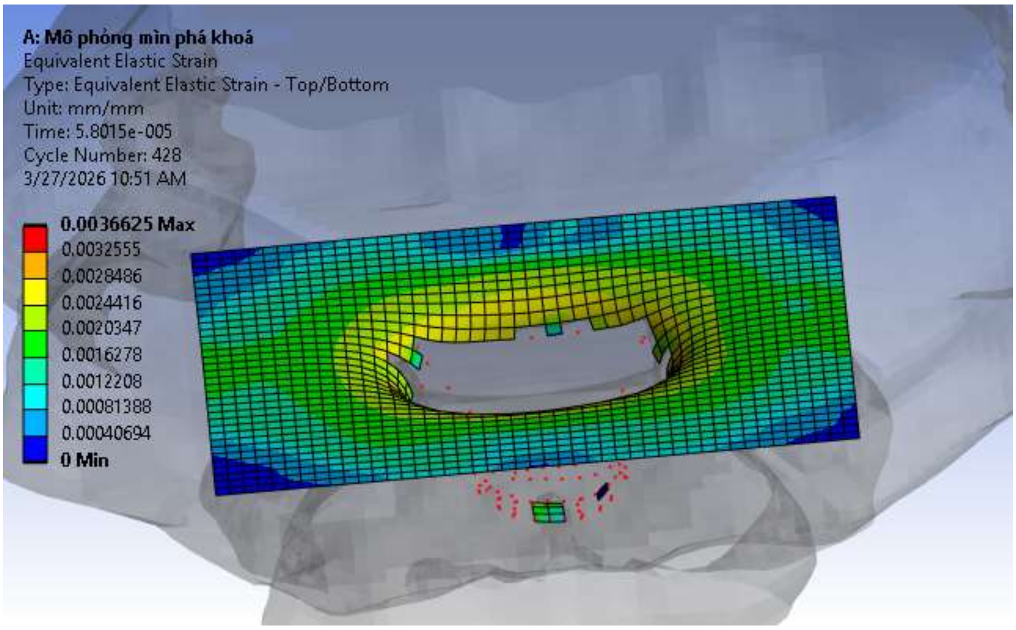


Thicknesses of 3 mm

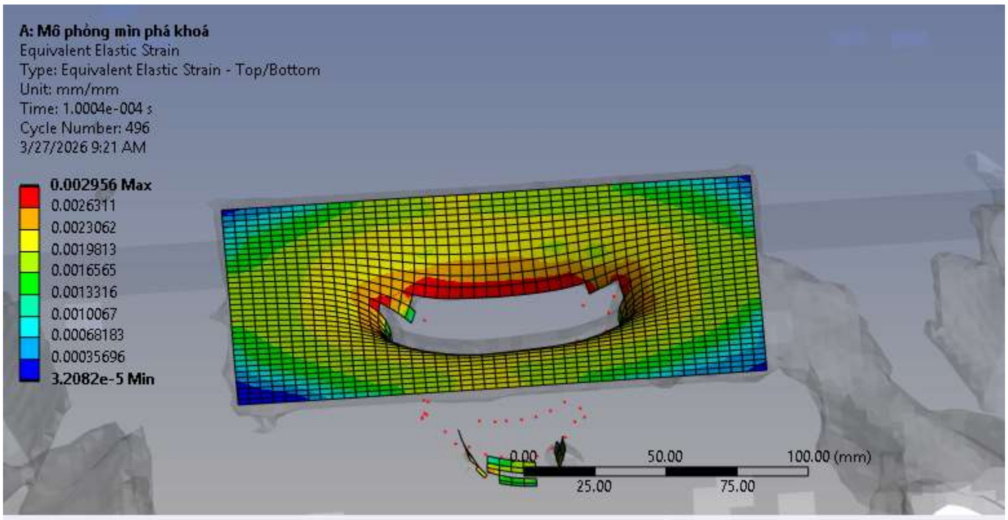


Thicknesses of 4 mm

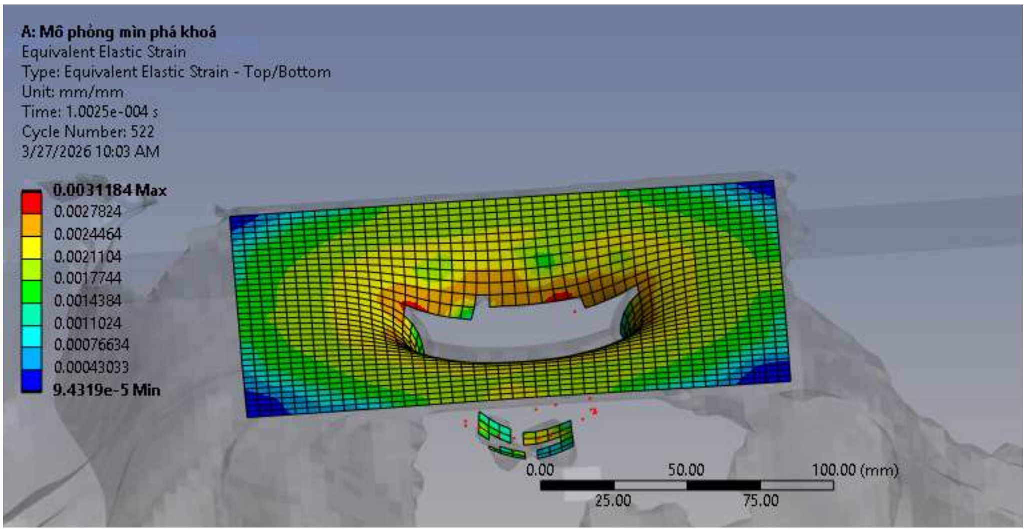
Fig. 6. Comparison of deformation distribution for different thicknesses (2 mm, 3 mm, and 4 mm)



Thicknesses of 2 mm

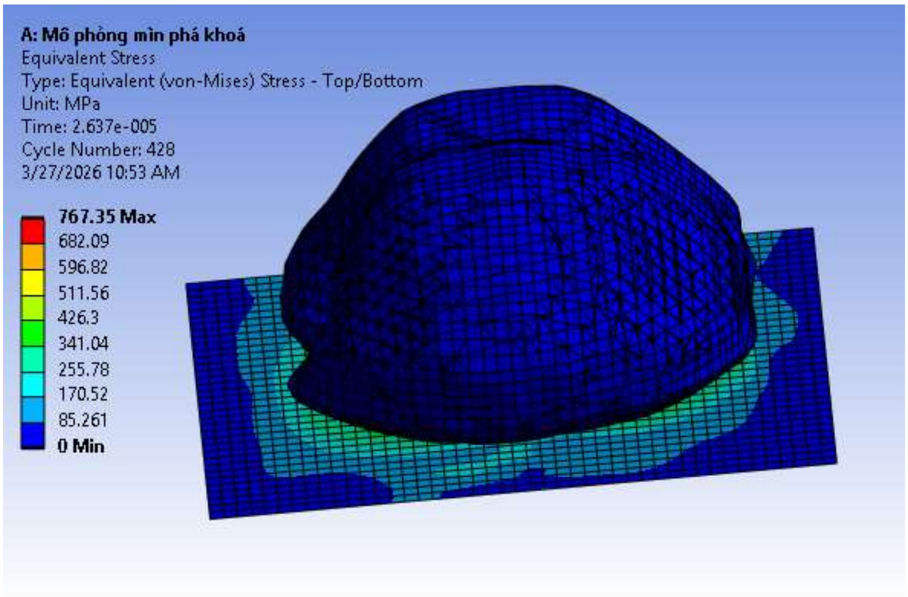


Thicknesses of 3 mm

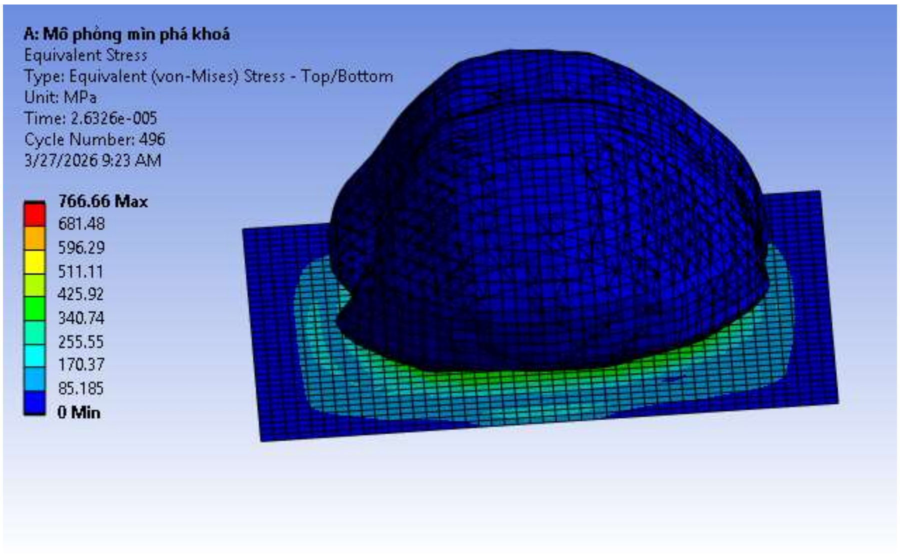


Thicknesses of 4 mm

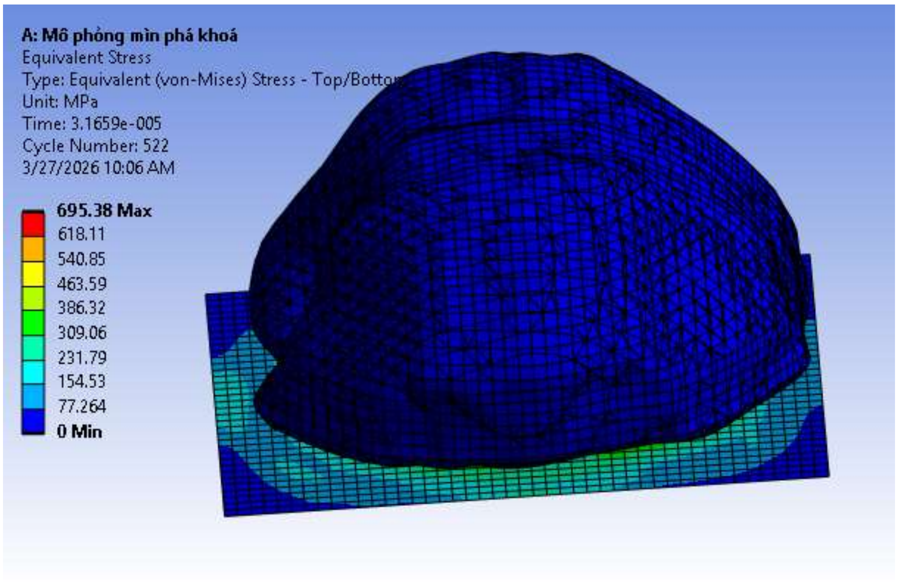
Fig. 7. Comparison of equivalent elastic strain for different thicknesses (2 mm, 3 mm, and 4 mm)



Thicknesses of 2 mm



Thicknesses of 3 mm



Thicknesses of 4 mm

Fig. 8. Comparison of stress distribution for different thicknesses (2 mm, 3 mm, and 4 mm)

Table 2. Summary of numerical results

Thickness (mm)	Peak stress (MPa)	Relative to yield	Deformation level	Failure
2	~700	~3σy	Severe	Yes
3	~650	~2.8σy	Moderate	Yes
4	~600	~2.5σy	Limited	Yes

These results (Table 2) indicate that increasing thickness reduces the severity of damage but does not prevent failure under the considered explosive loading conditions.

C. Time-dependent response and physical interpretation

The time-history results (Figures 9–11) provide deeper insight into the dynamic response of the system.

The stress-time curves show that peak stress occurs immediately after detonation, corresponding to the arrival of the primary shock wave. This is followed by a rapid decrease as the stress wave propagates and dissipates.

The oscillations observed in the stress curves are associated with wave reflections within the structure, which are more pronounced in thinner configurations.

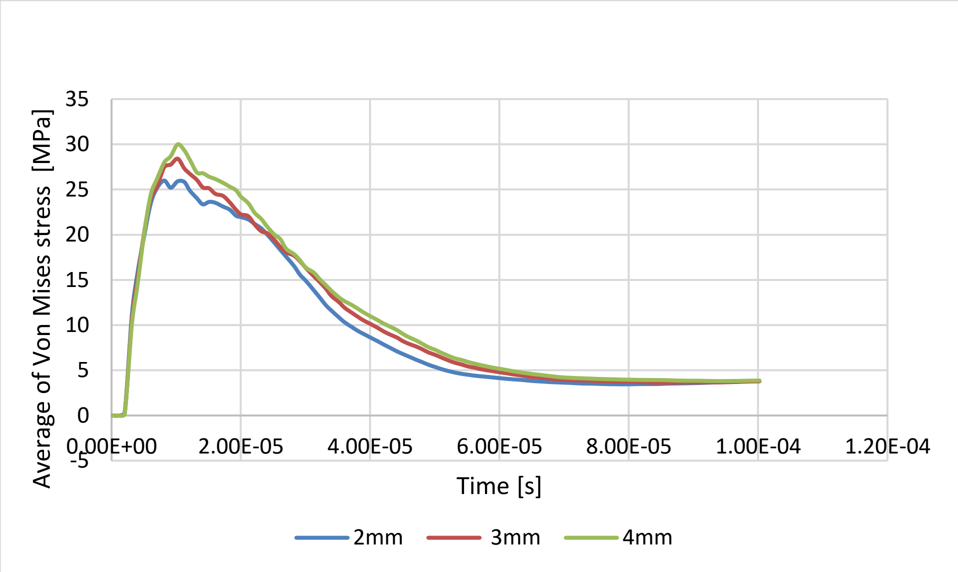


Fig. 9. Time history of average Von Mises stress for different thicknesses

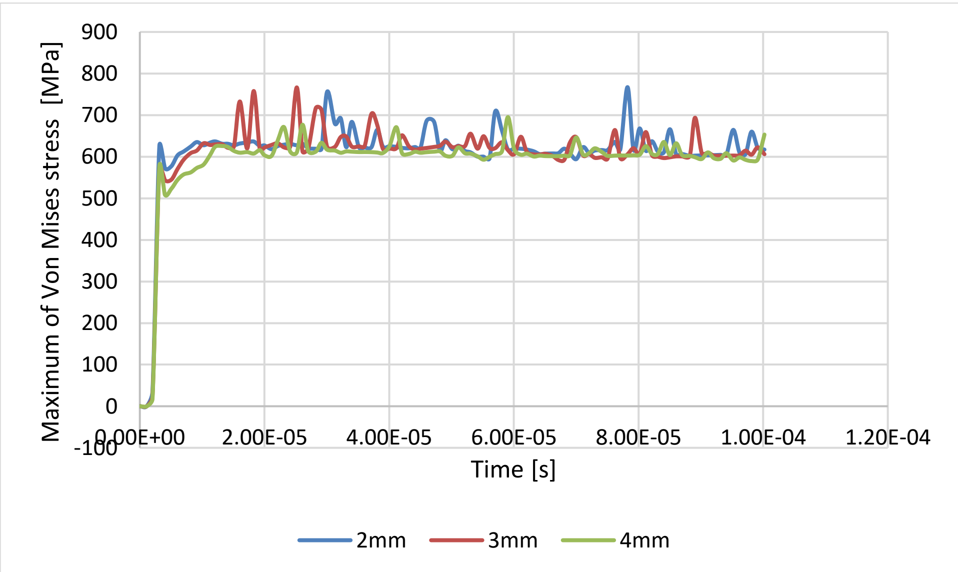


Fig. 10. Time history of the maximum von Mises stress for different thicknesses

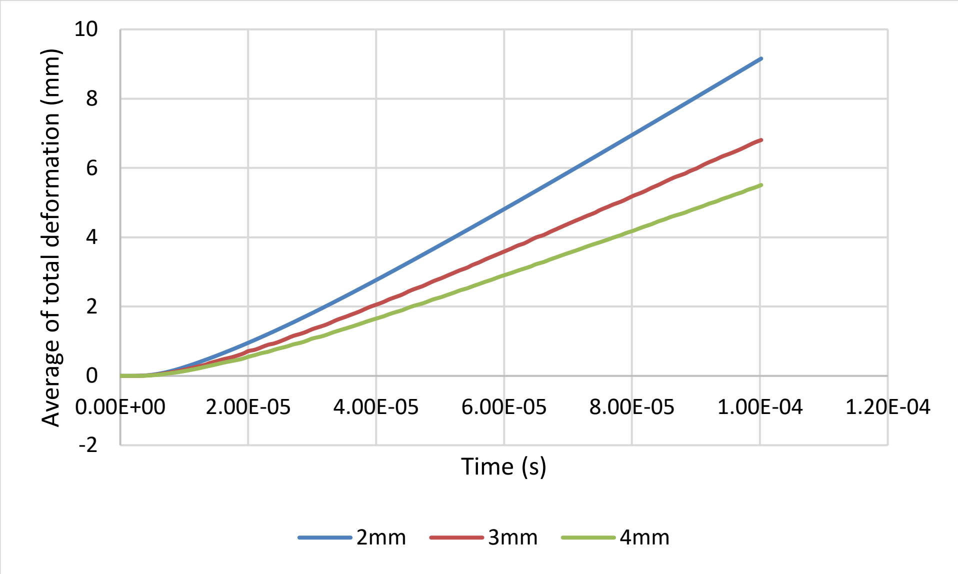


Fig. 11. Time history of average total deformation for different thicknesses

In contrast, deformation continues to increase even after the peak stress has been reached. This indicates that Plastic deformation accumulates after the initial shock loading, governing the final failure state of the structure.

Additionally, thicker configurations exhibit smoother stress-time curves, indicating reduced wave intensity and better energy absorption capacity.

To further quantify the Effect of thickness, the peak von Mises stress and maximum deformation values were extracted from the simulation results.

The results show that increasing the thickness from 2 mm to 4 mm leads to a noticeable reduction in both stress and deformation. Specifically, the peak stress decreases from approximately 700 MPa (2 mm) to around 600–650 MPa (4 mm), indicating a reduction of about 10–15%.

Similarly, the maximum deformation decreases with increasing thickness, confirming that thicker structures are more effective at dissipating the energy of the explosive load. However, despite this reduction, the stress levels in all cases still exceed the yield strength of the material, resulting in structural failure. This quantitative analysis further confirms that thickness influences the severity of damage rather than preventing failure.

D. Discussion

The results demonstrate that a combination of stress concentration and plastic deformation mechanisms governs the failure behavior of the door-lock system.

The baseline case (2 mm) exhibits severe stress concentration and large deformation, leading to rapid and extensive structural damage. Increasing thickness significantly reduces stress intensity and deformation magnitude, indicating improved structural resistance.

However, the results clearly show that all configurations (2 mm, 3 mm, and 4 mm) still experience failure under the given explosive loading conditions. This suggests that, for the considered charge configuration, structural thickness alone is insufficient to prevent failure.

Instead, thickness primarily affects: the severity of damage, the extent of plastic deformation, and the distribution of stress.

Therefore, thickness acts as a mitigating parameter rather than a failure-controlling parameter in explosive breaching scenarios.

IV. EXPERIMENTAL VALIDATION

A. Experimental setup

Experimental tests were conducted to evaluate the detonation reliability and breaching effectiveness of the proposed explosive charge.

Three types of detonators were employed, including a No. 8 electric detonator, a pre-assembled ignition system, and a connected ignition system. A total of six explosive charges were tested. The experiments were carried out at the testing field of the Special Forces Officer College.

The explosive charge was mounted directly onto the door-lock system using adhesive material to ensure proper contact between the charge and the target. The detonation was initiated either a remote control system or a direct electrical source.

Fig. 12. Installation of the explosive charge on the door-lock system

B. **Detonation reliability**

The experimental results show that all detonators operated reliably. In all tests, the explosive charge was successfully initiated, and complete detonation of the explosive material was achieved.

The observed detonation delay time was within the acceptable range of approximately 5–7s, indicating stable ignition performance. No misfires or incomplete detonations were observed during the experiments.

C. **Breaching performance**

The effectiveness of the explosive charge was evaluated based on the observed damage to the door-lock system after detonation.

Fig. 13. Door-lock system after explosive loading

The results indicate that the explosive charge was capable of destroying the door-lock system in all tested cases. The lock mechanisms were completely disabled after detonation, confirming the effectiveness of the breaching device under practical conditions.

Although quantitative measurements such as deformation or stress were not directly recorded in the experiments, the observed structural damage provides qualitative evidence of failure.

D. Comparison with numerical results

A comparison between the numerical predictions and experimental observations was performed to assess the validity of the simulation model (Table 3).

Table 3. Comparison between numerical predictions and experimental results

Thickness (mm)	Deformation level	Predicted failure	Experimental result
2	Severe	Yes	Yes
3	Moderate	Yes	Yes
4	Limited	Yes	Yes

The numerical results indicate that increasing the thickness reduces both deformation and stress levels, while failure still occurs in all cases. This trend is consistent with the experimental observations, where all tested locks were successfully destroyed.

The agreement between simulation and experiment demonstrates that the numerical model is capable of capturing the overall breaching behavior. In particular, both approaches confirm that the explosive charge is sufficient to cause structural failure, while structural thickness primarily influences the severity of damage rather than preventing failure.

V. CONCLUSIONS

This study investigated the deformation and failure behavior of door-lock systems subjected to explosive breaching charges through numerical simulation and experimental validation.

The main conclusions are summarized as follows:

Explosive loading generates a rapid, high-intensity stress wave, resulting in peak von Mises stress of approximately 600–700 MPa, which significantly exceeds the yield strength of CT3 steel and causes immediate plastic deformation.

The structural response is highly localized near the explosive contact region, indicating that failure is dominated by localized stress concentration and deformation mechanisms.

Increasing the thickness of the door-lock system reduces both stress levels and deformation magnitude, demonstrating improved structural resistance to explosive loading.

Despite this reduction, all configurations (2 mm, 3 mm, and 4 mm) still experience structural failure under the given explosive conditions. This indicates that thickness alone is insufficient to prevent failure.

Structural thickness primarily influences the severity of damage, rather than determining whether failure occurs.

Experimental results confirm the reliable detonation of the explosive charge and demonstrate that all tested door-lock systems were successfully destroyed, showing good qualitative agreement with numerical predictions.

Overall, the proposed numerical approach provides a useful framework for analyzing explosive breaching performance. At the same time, the findings highlight the importance of considering structural parameters in the design and evaluation of breaching systems. The findings of this study can serve as a reference for the design and optimization of explosive breaching devices in practical applications.

ACKNOWLEDGMENT

The authors would like to thank the Center for Special Equipment for its technical assistance.

REFERENCES

1. Sedláček, M., & Palasiewicz, T. (2023, May). Unification of explosive charges in breaching for different door resistance classes. In the *2023 International Conference on Military Technologies (ICMT)* (pp. 1-5). IEEE. https://doi.org/10.1109/ICMT58149.2023.10171299

2. Lupoae, M., Cotovanu, A., Casapu, A. C., Baciu, C., Constantin, D., Berechet, D. C., & Murzea, P. (2025). Experimental investigations on explosive breaching mechanisms for exterior metal doors and explosive effects on room occupants. *International Journal of Protective Structures*, 20414196251378664. https://doi.org/10.1177/20414196251378664
3. Remennikov, A., Mentus, I., & Uy, B. (2015). Explosive breaching of walls with contact charges: theory and applications. *International Journal of Protective Structures*, *6*(4), 629-647. https://doi.org/10.1260/2041-4196.6.4.629
4. Danielson, K. (2005, January). Numerical Simulations of Explosive Wall Breaching. In the *Users Group Conference*. https://doi.org/10.1109/DODUGC.2005.45
5. COSTA, M., & Doz, G. N. (2019). A numerical analysis of a concrete slab breaching using high explosives. *Revista IBRACON de Estruturas e Materiais*, *12*(01), 122-138. https://doi.org/10.1590/s1983-41952019000100010
6. Gebbeken, N., Greulich, S., Pietzsch, A., & Landmann, F. (2004). The engineering tool XploSim to determine the effects of explosive loadings on reinforced and fibre reinforced concrete structures. In *Proc. of 18th Int. Symp. Military Aspects of Blast and Shock*.
7. Khalifa, M., Riad, A. M., Kandil, S., & Alshenawy, T. A PRELIMINARY DESIGN OF A WALL BREACHING DEVICE USING AUTODYN-2D HYDROCODE.
8. Elshenawy, T., Abdo, G. M., & Elbeih, A. (2024). Effect of explosive charge types on the jet characteristics, penetration performance, and fragmentation patterns of shaped charges. *Scientific Reports*, *14*(1), 26282. https://doi.org/10.1038/s41598-024-75727-0
9. Frem, D. (2020). Estimating the metal acceleration ability of high explosives. *Defence Technology*, *16*(1), 225-231. https://doi.org/10.1016/j.dt.2019.07.002
10. Štimac, B., Bohanek, V., Dobrilović, M., & Sućeska, M. (2020, April). Prediction of Gurney velocity based on EXPLO5 code calculation results. In the *23rd Seminar New Trends in Research of Energetic Materials* (pp. 1-3).