COMPUTATIONAL INVESTIGATION OF DYNAMIC FRACTURE BEHAVIOR OF MULTI-LAYERED STRUCTURES AGAINST MULTIPLE BALLISTIC IMPACTS

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Abstract
Since, the protection of military structures against ballistic impacts is of grave concern. Protective structures made up of homogeneous concrete or fiber-reinforced concrete might not be sufficient to resist repeated ballistic impacts. Therefore, there is a need to develop and analyze functionally graded layered composite structures with varying material properties. Additionally, conducting experimental studies on such full-scale layered composite structures is extremely time-consuming and expensive. Analysis of such structures by developing a computational framework will provide realistic solutions. Hence, multi-layered structures comprising reinforced concrete, boulder-mixed soil, shredded rubber, and hot-rolled steel plates are proposed for bunkers which can safely protect military personnel against repeated ballistic impacts. The investigation presents the development of finite element models using ABAQUS–EXPLICIT to study the dynamic fracture behavior and to check the structural integrity of the multi-layered structures against ballistic impacts.

1. Introduction
Recently, the need to protect people and structures against attacks from terrorists has been on the high increase. Therefore, protecting military bunkers against multiple projectile impacts is of serious concern. These bunkers are developed utilizing locally accessible materials. Expanding the number of psychological oppressor assaults focusing on military dugouts has uncovered the tactical weakness and featured the requirement for analysts to foster more compelling and practical shelters that can endure outrageous loadings, for example, ballistic impact loads for military applications. Consequently, there is a need to design and develop high-velocity kinetic energy projectiles to defeat these hardened targets. The greater part of the research papers published on the ballistic impact forces on the penetration behavior of reinforced concrete members. As various layers are added to the defensive designs, a different mode of failure shows up, and material properties change with the depth of penetration. Furthermore, directing an experimental study on such full-scale layered composite designs is very tedious and costly. Hence, numerical simulations would give conceivable plausible arrangements for advancing the multi-layered composite design to give obstruction against high-velocity ballistic impacts compared to reinforced concrete and steel fiber-reinforced concrete. Therefore, this paper investigates the dynamic fracture behavior of multi-layer structures as a bunker and their performance under multiple ballistic impact loadings. Boulder mixed soil acts as an anti-penetration layer; hence it is kept as a first layer in the direction of the ballistic impact. Shredded rubber acts as a kinetic energy absorption layer, and steel plates are used to increase the ballistic resistance of the reinforced concrete target. The multi-layered target has been subjected to the ballistic impact of a 5.15 *kg* ogive-nose hard steel cylindrical projectile having a 64 *mm* diameter and length of 285 *mm*. Additionally, a reinforced concrete mono-layer target of equivalent thickness has been considered for the performance evaluation and comparison with the layered composite target. The mechanical performance in terms of the velocity profile of the projectile, residual velocity, penetration depth, crater diameter, plastic deformation, shear band, and damage of different targets have been quantified through numerical simulations. Compared with the mono-layer counterpart, a multi-layered target has been observed to provide enhanced protection against multiple ballistic impacts.

2. Results
The experimental findings of Hanchak et al. were utilized as a preliminary analysis to validate the numerical model. In their study, Hanchak et al. took into account an ogival-nose steel projectile with an ogive radius of 76.2 mm and a caliber of 30 mm that hit the targets at a velocity ranging from 330 m/s to 1100 m/s. The

projectile weighs 0.50 kg in total. The goals are unconfined compressive strengths of 48 MPa and 140 MPa for reinforced concrete. The reinforced target is assumed to be 610 mm X 610 mm X 178 mm in size, and 5.69 mm diameter reinforcements are used in the concrete. Figure 1 shows the mesh convergence curve for the validation by Hanchak et al. of the 48 MPa reinforced concrete target of 749 m/s impact velocity, for which the experimental residual velocity is 615 m/s, and numerical residual velocity is 629.8 m/s.

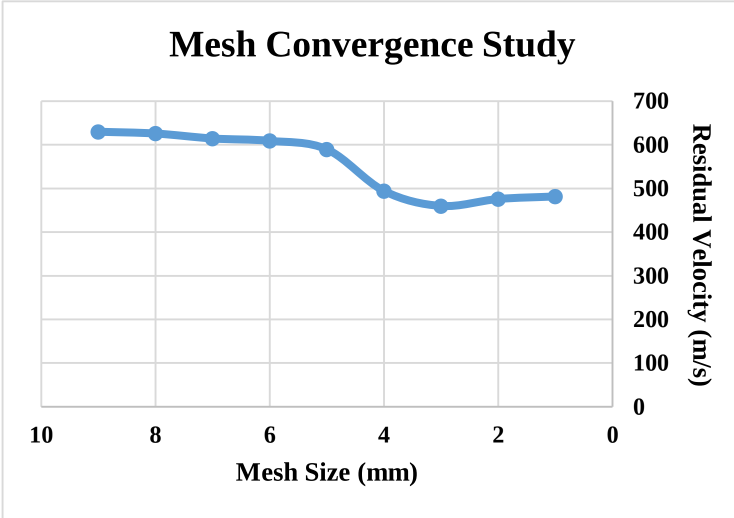

Fig.1- Mesh convergence plot for an impact velocity of 749 *m/s.*

In this study, the projectile impact velocity adopted is 500 *m/s*, and the grade of concrete is 50*MPa*. One, two, and three projectile impact loading effects are studied on the following targets:

a. Mono-layer reinforced concrete (500 *mm* × 500 *mm* × 510 *mm*).
b. Layered composite (500 *mm* × 500 *mm* × 510 *mm*) target comprising of 1st layer- boulder-mixed soil layer (150 *mm*). 2nd, 4th, and 6th layer- steel plates (20 *mm*). 3rd, and 5th layer- reinforced concrete (150 *mm*).

The residual velocity of the projectile was found to be 124 m/s, while the front crater diameter was found to be 134.8 mm, and the back crater diameter was 118.1 mm after spalling of the concrete target.

3. Conclusions

Compared to mono-layer reinforced concrete, the multi-layered target offers improved protection against multiple ballistic impact loading. The boulder-mixed soil layer, which also serves as an anti-penetration layer in the multi-layered target, helped withstand the impact loading from several ballistic impacts, while the mono-layer reinforced concrete target had a deeper penetration depth for the projectile. Prior to striking the reinforced concrete layer, the projectile first strikes the steel plates, which reduces spalling and scabbing in comparison to mono-layer reinforced concrete. Steel plates are plastically deformed, and boulder-mixed soil is locally accessible, inexpensive, and increases the penetration resistance of the multi-layered target against multiple ballistic impact loading. As a result, the multi-layered target can replace the mono-layer reinforced concrete target when subjected to multiple ballistic impacts.

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