The Numerical Investigation of Aluminum Foam-protected Reinforced Concrete Slabs under Blast Loading Using AUTODYN-3D

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Abstract. Aluminum foam is a lightweight material with high energy absorption capacity. In this study A Nonlinear three-dimensional hydrocode numerical simulation was carried out using *autodyn-3d*, which is an extensive code dealing with explosion problems. In this simulation, a high explosive material (comp B) is blasted against several concrete panels. The model was first validated using experimental tests carried out by Chengqing and has shown good results. Several numerical tests were carried out to study two parameters that affect the deflection of reinforced concrete panels. The parameters included are the thickness of concrete target and the thickness of steel plate. The results showed that increasing the thickness of the steel plate has an insignificant effect on the deflection of the reinforced concrete target while increasing the thickness of the concrete panel has a significant effect on the deflection of the concrete target.

1 Introduction

Structural buildings can be exposed to blast loadings including accidental gas explosions or terrorist attacks during their service life, which might cause heavy human and economic losses. Over the last several decades, there has been great interest shown by the military and other governmental agencies in designing structures to withstand blast loadings. A variety of protective techniques are developed against increasing accidental explosion and terrorist attacks [1,2].

The entire chain involved in the design and construction of structures has shown keen interests in the performance assessment of existing as well as new civilian structures when subjected to blast loading due to the increase in the number of intentional and accidental blast events throughout the world.

Blast events produce short duration high magnitude loadings which can greatly influence structural blast response. When compared to conventional loads, the frequencies of explosive loads are usually much higher. The action applied to a structural member when subjected to an explosive detonation is in the form of an impact shock wave. The parameters that define the shock wave are the reflected pressure and the duration of the positive phase. The time integral of the reflected pressure over the duration of the positive phase is known as reflected impulse. Public buildings, such as railway stations, embassies and airports, should be designed to ensure as much safety of the occupants as possible.

Furthermore, counter-measures need to be taken to reduce the severity of the explosion, indirect means such as using blast barrier to protect important infrastructures and people inside them are widely used. However, several recent terrorist attacks have proven that such indirect methods cannot effectively prevent attacks initiated by suicide bombers or suitcase bombs. Therefore, there is an urgent need to directly enhance the blast-resistance of important structures through using new structural types or new materials.

Newly developed mobile and lightweight materials such as aluminum foams are very attractive for use as protective layers in many applications because they have lightweight, are cheaper, and have greater energy absorption capacities than traditional technologies[3-7].

Metallic foam consists of a matrix of aluminum filled with pockets of air. Because of its long, plastic plateau in compression, metallic foam allows high energy absorption at a nearly constant stress level, making it an ideal material for mitigating the effects of explosive loads on a structural system.

When an explosion occurs near a foam cladded reinforced concrete member, the foam layer compresses and absorbs a large amount of energy and offers protection for the members against blast loads [8].

Studies conducted by Schenker [9] have shown that foam protected specimens efficiently mitigated the effects of the blast loading on reinforced concrete walls. Schenker also conducted two full-scale blasts on foam-protected reinforced concrete walls [10], which have shown the effect of foam on protecting concrete from blast loads.

Results from tests conducted by Hanssen have shown that when field blast tests have been conducted with a ballistic pendulum, the aluminum foam layers added as a protective layer have negative effect on energy and impulse. Where the energy and impulse have increased instead of decreasing as expected [11].

2 Numerical Simulations

In the current study, a numerical model was made to simulate the effect of blast wave on different configurations of concrete slab covered with aluminum foam and steel plate.

2.1 Numerical Tool: Hydrocode

A computer program that is capable of computing strains, stresses, velocities and propagation of shock waves as a function of time and position is known as a hydrocode. In a hydrocode simulation, the response of a continuous media subjected to dynamic loading is governed by the conservation of mass, momentum and energy, and also the equation-of-state and constitutive relation of the media. The equation-of-state takes into account the effects of compressibility of the continuous media and is a function of internal energy and density, whereas the constitutive relation represents the media's resistance to shear. In this study the hydrocode simulations on the explosion effect on a concrete target are performed using AUTODYN-3D [12], a fully integrated and interactive hydrocode.

In AUTODYN-3D the fundamental equations together with the initial and boundary conditions are solved using a finite difference scheme.

2.2 Model Validation

This paper presents a 3D hydrocode simulations using autodyn-3d [13] on the effect of explosion on a reinforced concrete target as shown in Fig.1. The set of experimental data published by Chengqing Wu [14] for concrete slab target covered with an aluminum foam sheet and a steel plate is used for validation.

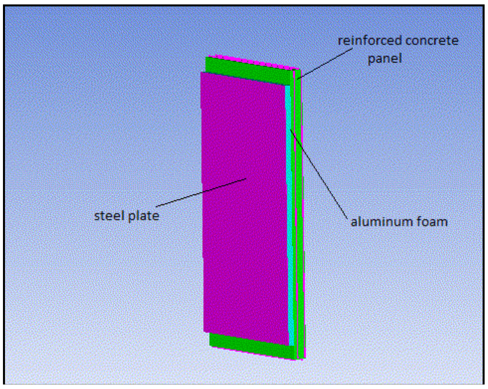


Figure. 1 Structural configuration of the proposed model

These experiments aimed at testing the performance of aluminum foam-protected RC slabs. Five foam protected slabs were tested against blast loads with two different types of aluminum foams and different weights of explosive charge.

The dimensions of the tested concrete slab was 2000×1000×100 mm. the slabs were reinforced both in the tension and compression faces with a 12mm diameter mesh that was spaced at 100mm in the major bending plane and at 200mm in the minor plane as shown in Fig. 2. The concrete slab's cover was 10mm. The concrete's compressive strength was 39.5 MPa , tensile strength was 8.2 MPa and young's modulus was 28.3 GPa. The reinforcement had yield strength of 600 MPa and young's modulus of 200 GPa.

A 1.15 mm thick steel plate sheet was attached to the outer face of the aluminum foam. The explosive used in the air blast was of weight 8.05 kg and 14.0 kg.

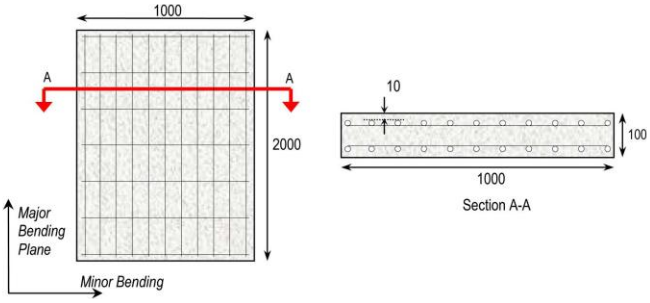


Figure. 2 Reinforced concrete target

2.2.1 Finite Element Model

In this model the concrete target is modeled with 7956 nodes and 6250 element, the aluminum foam part is modeled with 7956 nodes and 6250 elements, the steel plate part is modeled with 2652 nodes and 1250 elements while the air domain is modeled with 574488 nodes and 553800 elements.

Remap technique was used during numerical simulation [15]. The initial detonation and blast wave propagation of the explosive in free air were first calculated in a 2D domain, the result was then remapped into a 3D space as shown in Fig.3. This technique is used to save time and make the model more efficient.

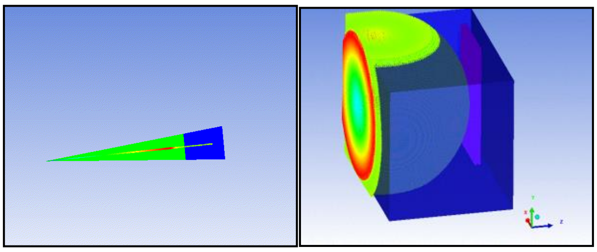
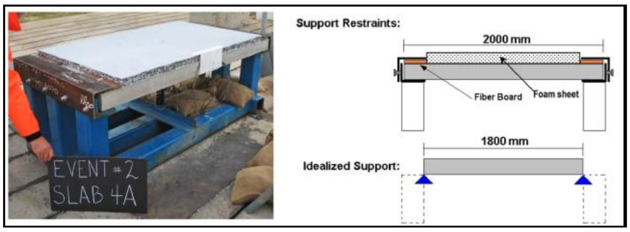


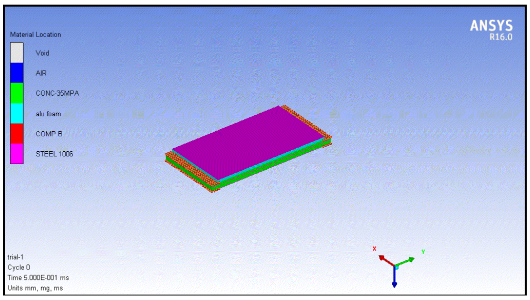
Figure.3 Remapping technique

Flow-out boundary conditions were applied on the outer surfaces of the air domain to allow the pressure of the blast to be dissipated outside the air domain without reflecting and affecting the concrete target.

Boundary conditions are applied on the concrete target preventing the motion of the concrete target in x and y direction and making the effective span of the concrete target equal to 1.8 m according to the details of the experimental work as shown in Fig.4.



a) Experimental configuration



b)Numerical configuration

Figure.4 Boundary conditions

The concrete target is described with the Lagrange solver and the reinforcement bars are defined as beam element. Comp B is modeled using Jones-Wilkins-Lee equation of state which models the pressure generated by chemical energy in an explosion. Air was modeled by an ideal gas equation of state, which is one of the simplest forms of equation of state.

The first specimen used for verification is specimen 2B where as shown in Fig. 5 the overpressure for specimen 2B measured from experimental work is compared to the overpressure measured from numerical model. Specimen 2B is a reinforced concrete slab covered with 25mm aluminum foam layer where the explosive used is of weight 8.070 kg at standoff distance of 1.47m.

The overpressure measured from experimental work was 1420 kPa while the one measured from the numerical model was 1169 kPa with a percentage of error of 17.6%.

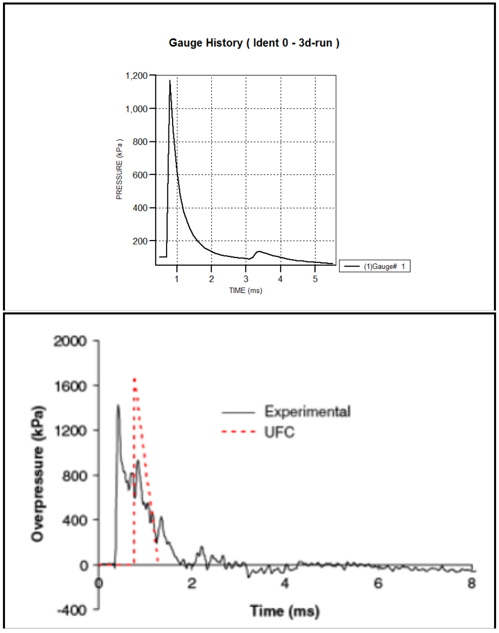


Figure. 5 Overpressure for specimen 2B

Specimen 4A is also used for verification, the displacement of specimen 4A measured from experimental work is compared to the displacement from the numerical model as shown for Fig.6.

Specimen 4A is a reinforced concrete slab covered with 43.2mm aluminum foam layer where the explosive used is of weight 8.084 kg at standoff distance of 1.50m.

The displacement measured from experimental work was 31mm while the one measured from the numerical model was 26.8mm with a percentage of error of 13.5 % as shown for Fig.6.

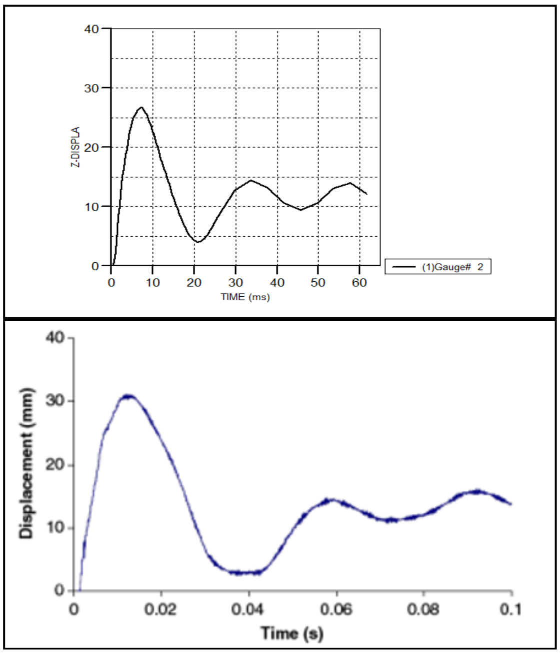


Figure. 6 Displacement of specimen 4A

3 Parametric studies and results

The effect of two factors on the displacement in the middle point of the reinforced concrete target is studied as follows:

3.1. Thickness of concrete target

In this section the effect of the thickness of the concrete target is studied. The thickness of the concrete slab in the experimental tests and the validated numerical model was constant (100mm).

Two numerical models were made with two different thicknesses of concrete target (150 &200 mm) to investigate the effect of increasing the concrete slab thickness on the deflection of it. The results were as shown in table 1.

Table 1. The effect of thickness of concrete target on deflection

Thickness of steel plate(mm)	Deflection (mm)
1.15	26.8
5	25.68
10	25.48

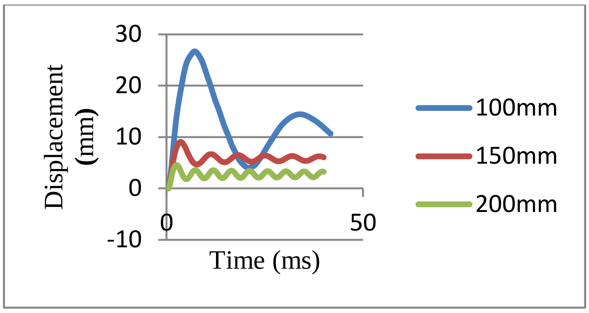


Figure.7 Relation between thickness of concrete target and deflection

The increase in the thickness of the concrete target greatly influences the amount of deflection in it as shown in Fig.7 as when the thickness of the concrete target increased from 100mm to 150mm, the deflection decreased from 26.65mm to 9 mm and when the thickness increased again from 150mm to 200mm, the deflection decreased once more to reach 4.5mm.

3.2. Thickness of steel plate

The influence of increasing the thickness of steel plate was also studied where the thickness of steel plate in the experimental work and in the validated numerical model was 1.15mm.

Two numerical models were made with two different thicknesses of steel plate to investigate the effect of increasing the steel plate thickness on the deflection of the concrete target. The results were as shown in table 2.

Table 2. The effect of the thickness of steel plate on deflection

Thickness of conc. Target (mm)	Deflection (mm)
100	26.8
150	9
200	4.5

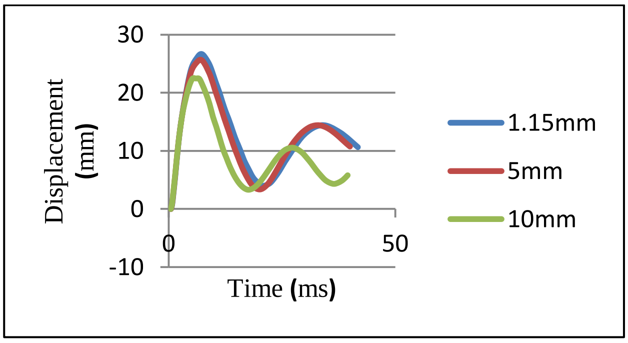


Figure.8 Relation between thickness of steel plate and deflection

The increase in the thickness of the steel plate has insignificant effect on the deflection of the mid-span of the concrete target as shown in Fig.8 as when we increased the thickness of the steel plate from 1.15mm to 5mm the deflection decreased to 25.68mm and when we increased the thickness again to 10mm the deflection decreased to 25.48mm.

4 Conclusion

The present study investigates the dynamic response of composite panels containing aluminum foam against blast waves and a non-linear 3d model is used to model the proposed configuration. The effect of increasing the thickness of concrete panel and the thickness of steel plate is examined. The main findings of this paper are as follows:

The numerical model presented has a good agreement with the experimental work. Using numerical simulation in studying the effect of blasting loads is a very effective way in studying different parameters. Increasing the thickness of the concrete target has a great influence on the deflection of the concrete target. Increasing the thickness of the steel plate has a slight influence on the deflection of the concrete target.

Some future researches can be made about using some other new materials instead of using aluminum foam and studying the response of a complete structural member against blasting.

5 References

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