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Using different mitigation materials to increase the resistance of underground concrete structure subjected to b last loads

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Abstract

In the last decades; the mass destructive weapons had been widely used like nuclear weapons. Nuclear bombs are destructive tool for human, weapons, equipment and all facilities. The development of the nuclear bomb is a challenge for civil engineer s to protect people, facilities and weapons against hazards of nuclear explosions. That led them to use the protective structures in military and civilian applications like underground concrete structures. It is difficult and sophisticated to use experimental nuclear test to predict behavior of buried concrete structure response.

The present paper presents a study to understand the behavior of underground concrete structure box section under blast load. Blast load resulted from a 2.0 kt (kiloton) "weapon yield" explodes at 200 m horizontal distance from the concrete structure, while the "weapon yield" is the measure of nuclear weapon, usually in kilotons or megatons of TNT equivalent. Numerical models were conducted using a 3-D nonlinear finite element program (AUTODYN).

For saving time, an equivalent weapon yield of 0.03125 kt explodes at 50 m range after ensuring that the pressure resulted is the same, using the well known "Scaling Law" $R/R_1=(W/W_1)^{1/3}$, where R and R_1 are the ranges of charges W and W_1 respectively.

Different mitigation material; half pyramid sandwich panel, honeycomb sandwich panel and aluminum foam were used to increase the resistance of underground concrete structure.

This paper proposed also the best thickness of half pyramid sandwich panel under pressure ranges between 345 kpa to 1172 kpa (50 psi to 170 psi) namely 345, 552,758, 965 and 1172 kpa.

Keywords: Underground concrete structure, 3D nonlinear finite element analysis, blast wave, honeycomb sandwich panel, half pyramid sandwich panel, aluminum foam.

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Introduction

The effects of nuclear weapons on human, equipments and facilities were learned at Hiroshima and Nagasaki [1]. The effects of nuclear explosion were summarized in three phases ; blast, thermal and radiation [2]. A number of analytical methods for predicting blast loading were developed . These analytical procedures are presented in several technical design manuals and reports , such as; TM5-855-1 (1986) [20], TM 5-1300 (1990) [21], CONWEP (1992) [22], and B. Luccioni and D. Ambrosini (2005) [3]. It is very expensive, difficult and sophisticated to use experimental nuclear test to predict behavior of buried concrete structures. Series experimental tests had conducted to predict the blast load on structure [4, 5]. The finite element simulation of structures or panels subjected to blast load were proposed in many researches using different softwares, as AUTODYN [6, 7, 8, 9 and 23]. Many researches present the using of different mitigation materials such as F iber Reinforced Polymer (FRP) [10,11,12], Glass Fiber Reinforced Plastics (GFRP) [13,14], Carbon Fiber Reinforced Polymer (CFRP) [15,16], Aluminum foam [17] and using sandwich panels as steel-concrete-steel sandwich panels [18] and metallic sandwich panels [19] to increase the resistance of structure against blast load.

3 D Finite Element Model

To examine the effect of different mitigation materials as mentioned above ; 0.03125kt weapon yield is placed vertically at 50 m distance above the ground surface where the structure is placed 10 m below ground surface as shown in figure (1). The outer dimensions of a box concrete structure were 794 cm, 394 cm and 794 cm in X, Y and Z directions, wile its thickness was 20 cm. The dimensions of the sand medium were 2000 cm, 2000 cm and 3000 cm in X, Y and Z directions. Eight nodes element, Lagrangian description was used to simulate concrete and soil materials [23]. The concrete was modeled by 256000 elements, and the sand medium was modeled by 96000 elements. The whole domain dimensions were 5000 cm, 2600 cm and 5000 cm in X, Y and Z direction respectively filled with air and modeled by 325000 eight nodes elements, Eulerian description [23]. A transmitting boundary condition is applied for the sand medium and a flow ou t boundary condition is applied for air medium. Reinforcing steel is smeared and modeled as shell element with number of elements to be 20208 elements.

Validation of the finite element model

To demonstrate the accuracy of the proposed model parameters, a field tests conducted by Baylot [1] to study the soil-structure interaction for a high explosive charge placed close to the wall of a buried structure is simulated by the proposed model. The structure was buried in nearly saturated clay. Explosive charge of 13 kg TNT is exploded at range of 1.5m. The clear span of the test slab is 1m vertical and 4.0 m horizontal and 0.2 m thickness. The slab was overlapped with a reaction structure in the end of the vertical direction as shown in figure (2). Also results are compared with the finite element model proposed by Loay [2]. Figure (3) show the comparison between pressure time histories resulted from proposed model and field test and figure (4) show the comparison between pressure time histories resulted from proposed model and finite element model conducted by Loay [2].

Blast resistance of the structure using different mitigation sandwich panel

Three different mitigation materials were used; two sandwich panels; a half pyramid sandwich panel and a honeycomb sandwich panel and aluminum foam sheets are placed on the structure facing the explosion to increase the resistance of concrete structure. Figure (5) show the shape and dimension of half pyramid sandwich panel and figure (6) show the shape and dimension of honeycomb sandwich panel. Figure (7) to figure (10) show the comparison between pressures, stresses, velocities and displacement verses time with and without using mitigation materials. Where target point is placed at the center of roof of the concrete structure. The thickness of these mitigation materials is taken as 10 cm. All elements of half pyramid sandwich panel and honeycomb sandwich panel is modeled as shell element and elements of aluminum foam is modeled as solid element.

Choose the best thickness of half pyramid sandwich panel subjected to blast load

To choose the best thickness of half pyramid sandwich panel as shown in figure (11) that resist a given pressure range. The pressure considered in this study ranges between 345 kpa to 1172 kpa (50 Psi to 170 Psi) namely 345, 552, 758, 965 and 1172 kpa. This pressure resulted from explosion of different charges at 50 m from the target point. These charges are 33380 kg, 61940 kg, 94450 kg, 130500 kg and 170000 kg TNT. The stresses at the target point were evaluate on condition of the different thickness of half pyramid cores have the same weight of 26.8 kg / m^2 and the same angle of inclination of the surface of the core as 38.87^o. Five different thicknesses of half pyramid sandwich panels were taken to choose the best thickness that withstand to a different pressure rang.

These thicknesses are 5 cm, 10 cm, 15 cm, 20 cm and 25 cm. figure (11) summarize the results of this study.

Conclusions

Using the half pyramid sandwich panel reduce the pressure, stresses, velocity and displacement by 11.3 %, 66.7 %, 74.3 % and 96 % respectively. While using honeycomb sandwich panel the reductions were 28.8 %, 17.6 %, 74.3 % and 7 % respectively. While using aluminum foam the reductions were 53.5 %, 85.7%, 30.2 % and 17.9% respectively.

The results show that; a 15 cm layer thickness is the suitable thickness of half pyramid sandwich panel for pressure ranges up to 1172 kpa (170 Psi) while a 12 cm thickness of half pyramid sandwich panel is relevant for other lower pressur e ranges, however table (1) presents the best thickness for pressure ranges.

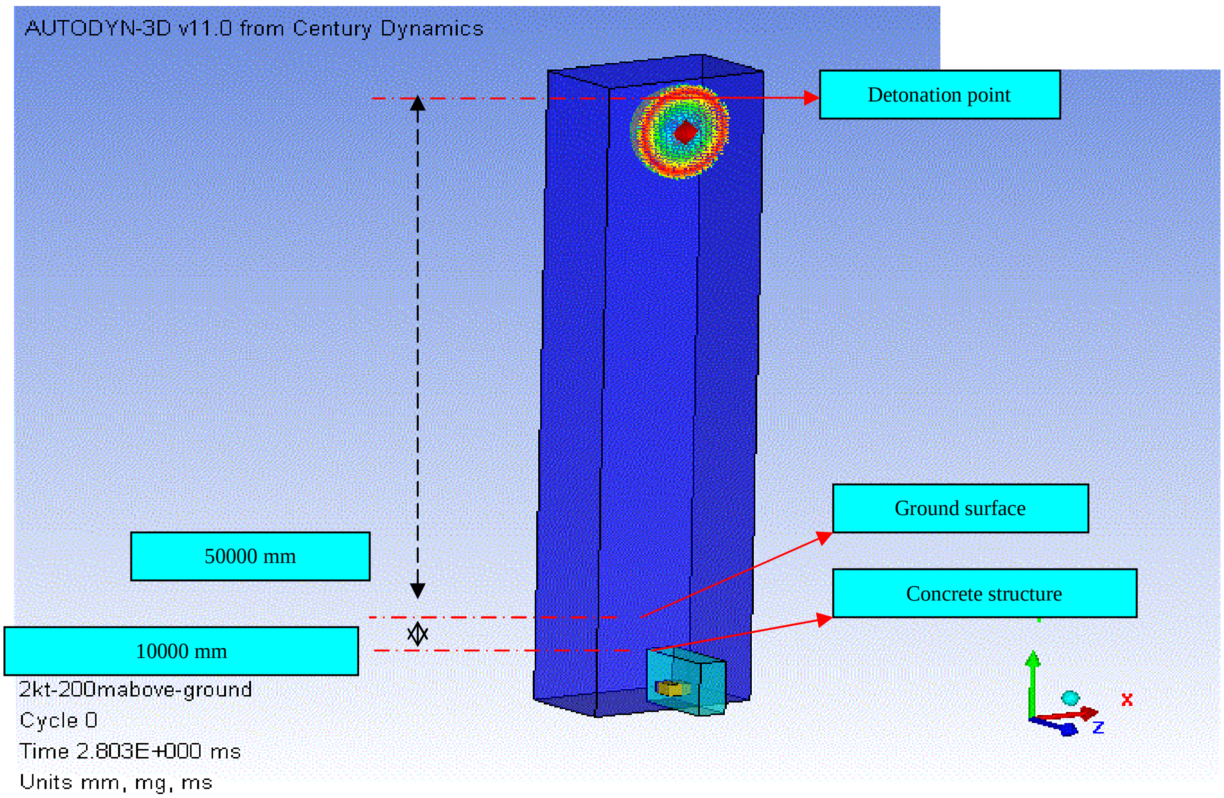

Figure (1): A charge 0.03125kt TNT is placed at 50 m vertical distance from the ground surface.

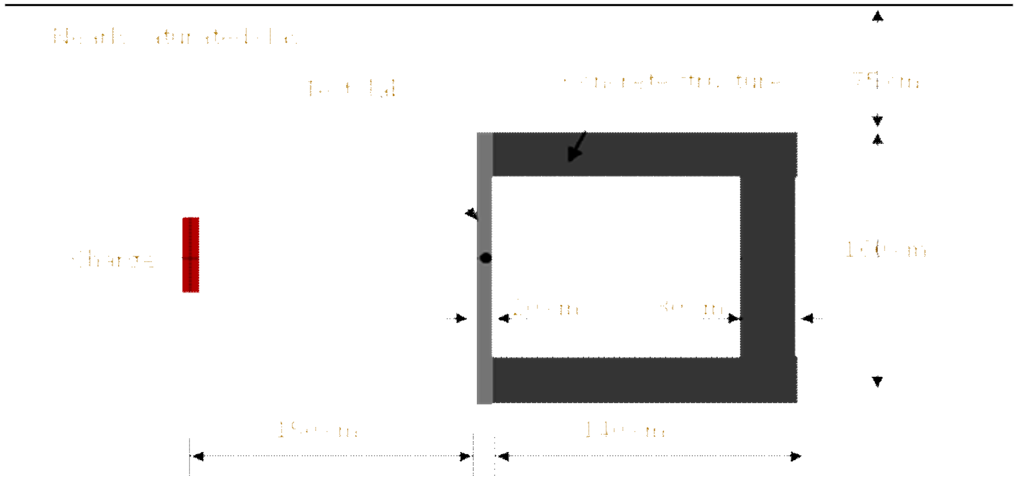

Figure (2): layout for the field test by Baylot [4].

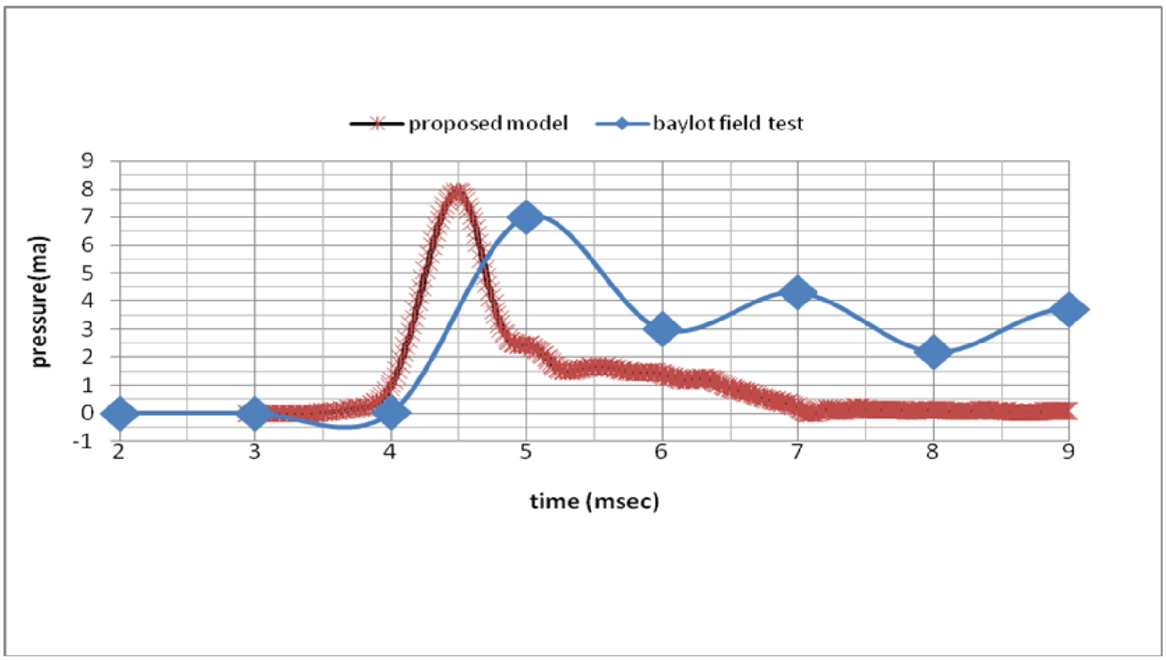

Figure (3): The comparison between pressure time histories resulted from propo sed model and Baylot field test.

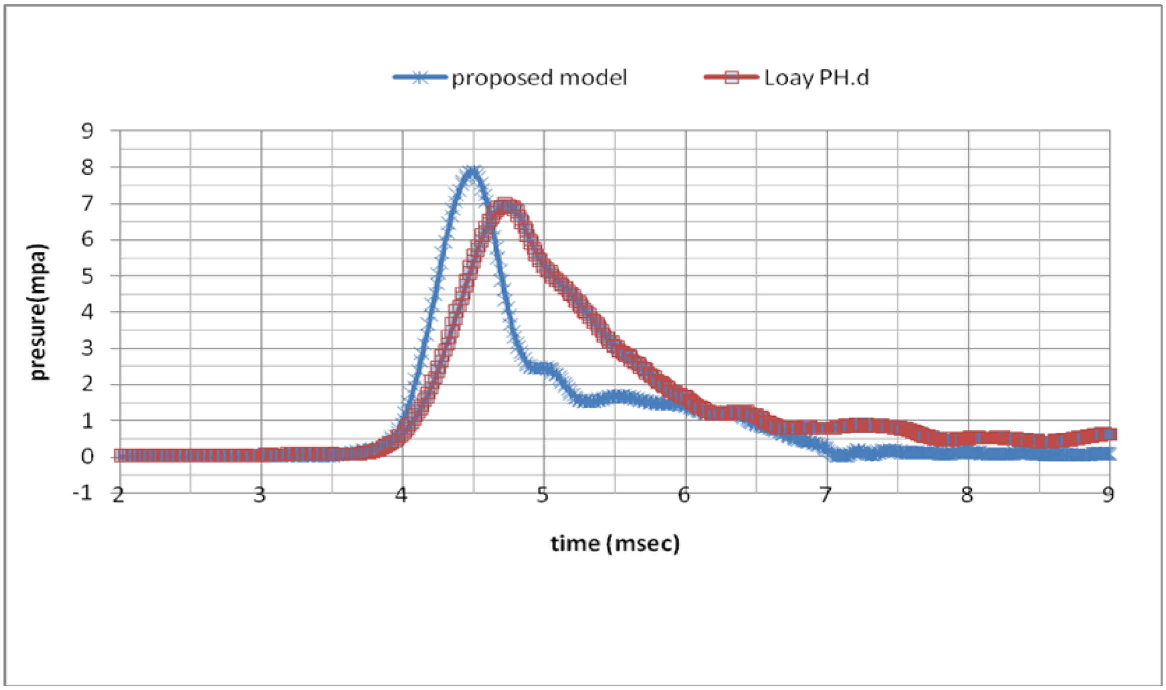

Figure (4): The comparison between pressure time histories resulted from proposed model and Loay numerical model.

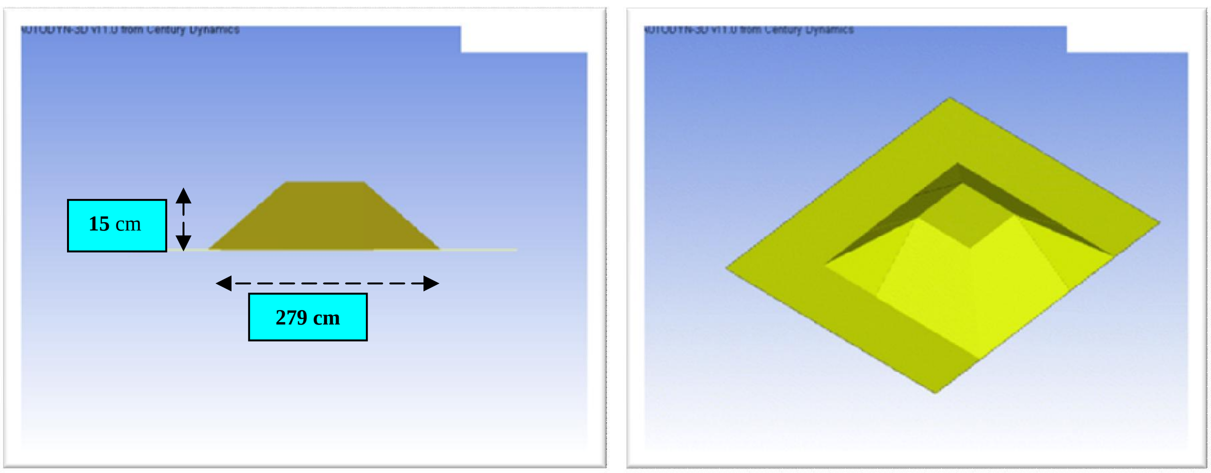

Figure (5): The shape of half pyramid core.

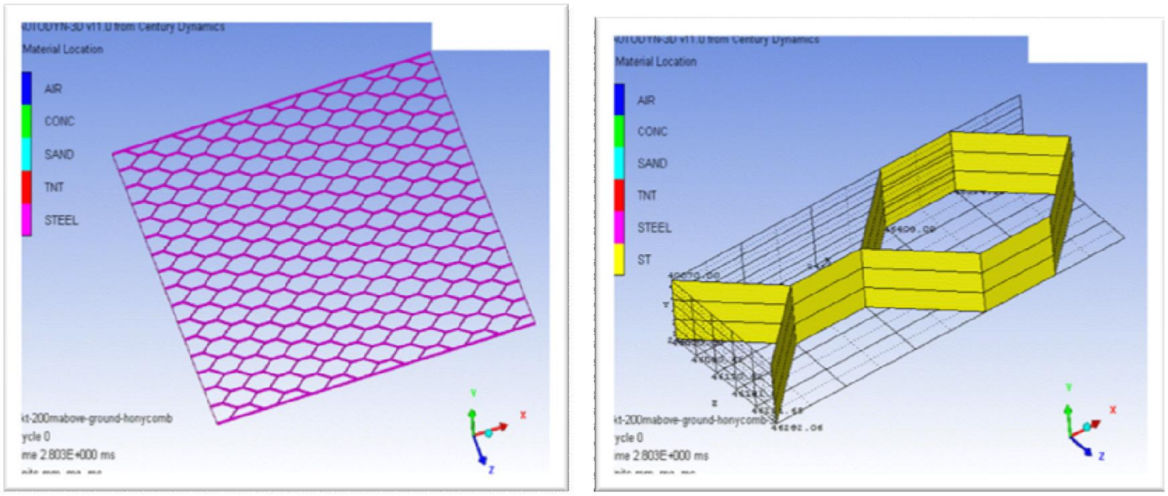

Figure (6): The shape and dimension of honeycomb core .

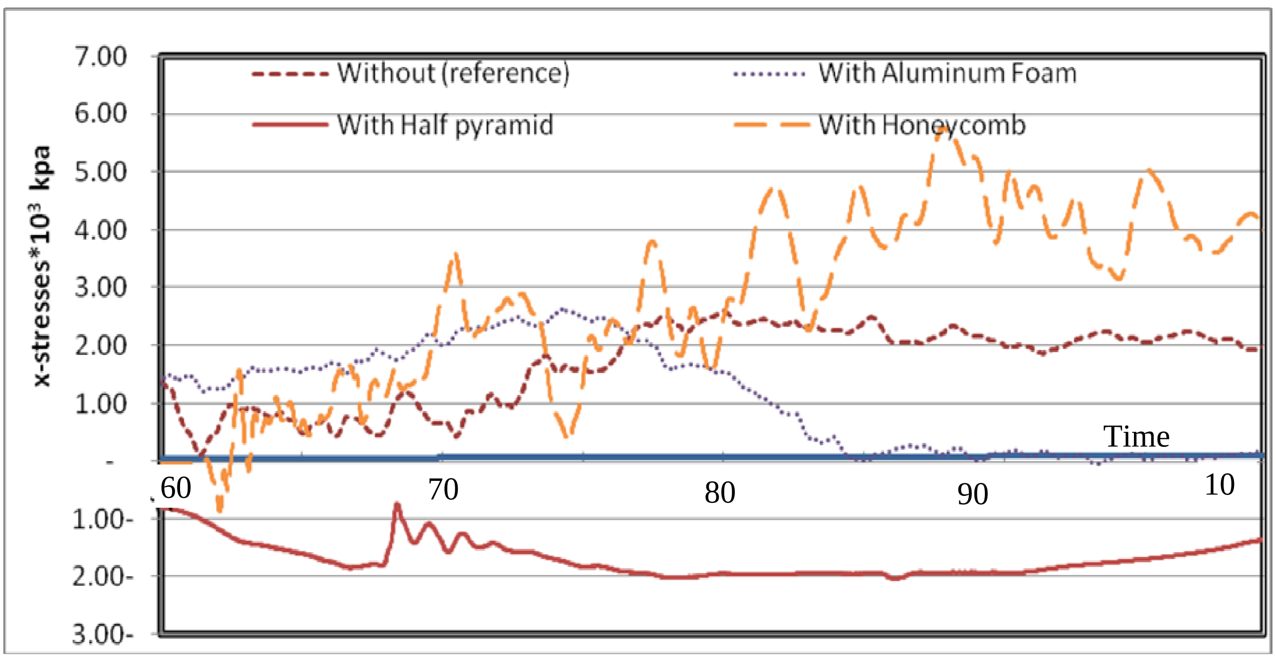

Figure (7): The stress time histories with and without mitigation materials .

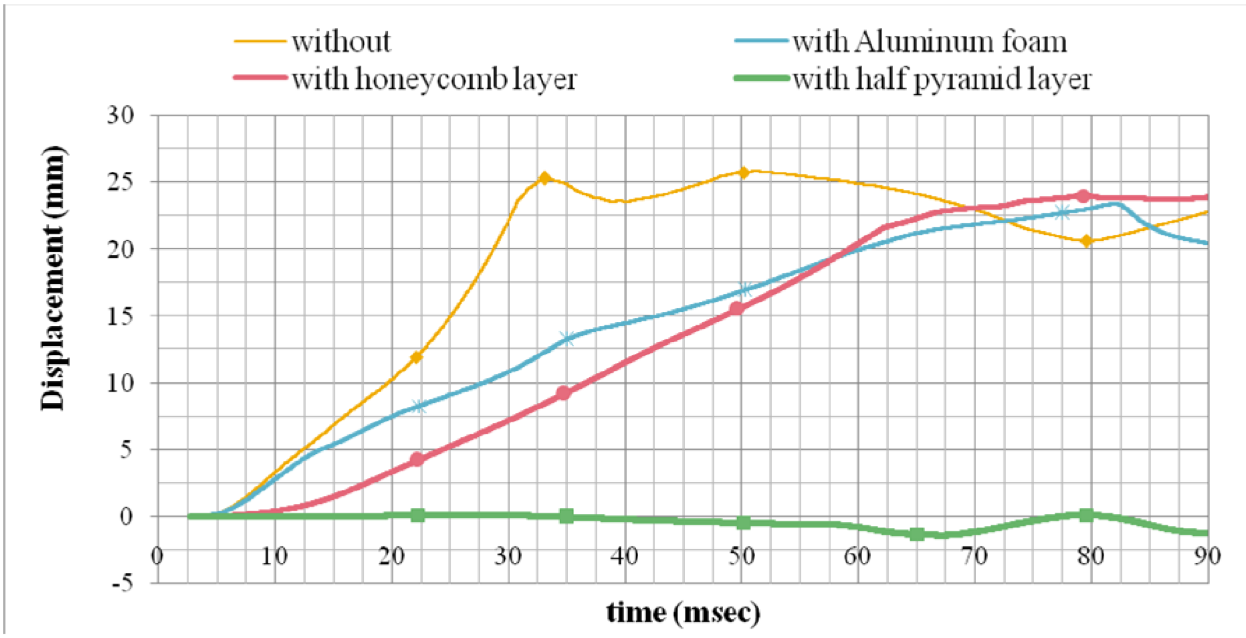

Figure (8): The displacement time histories with and without mitigation materials .

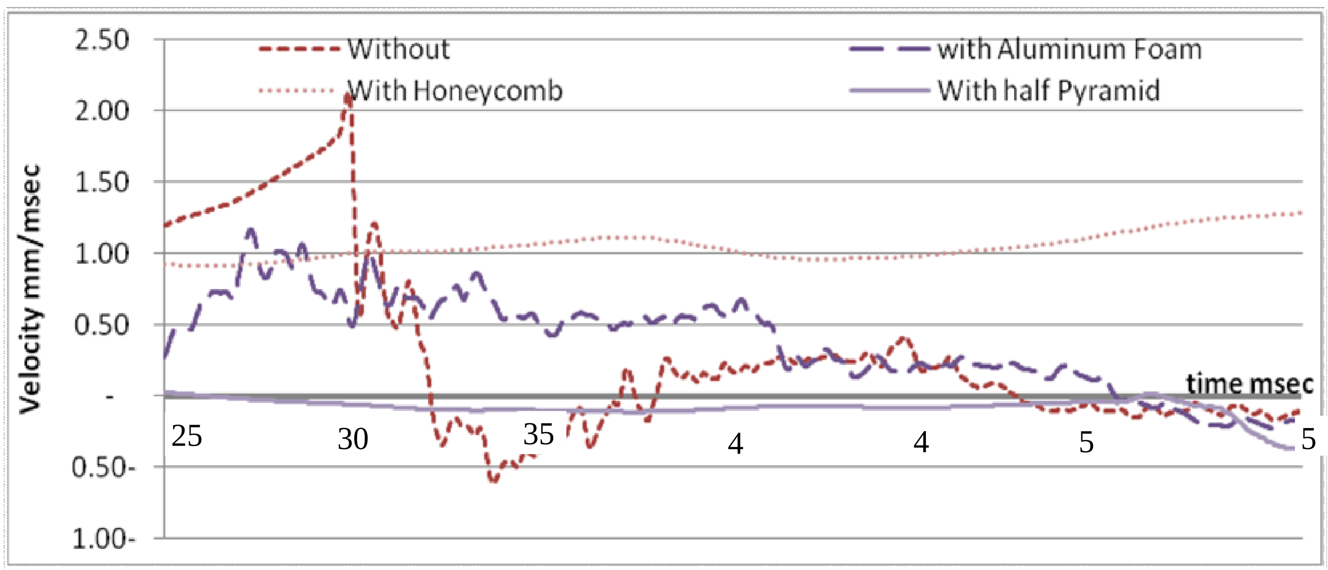

Figure (9): The velocity time histories with and without mitigation materials.

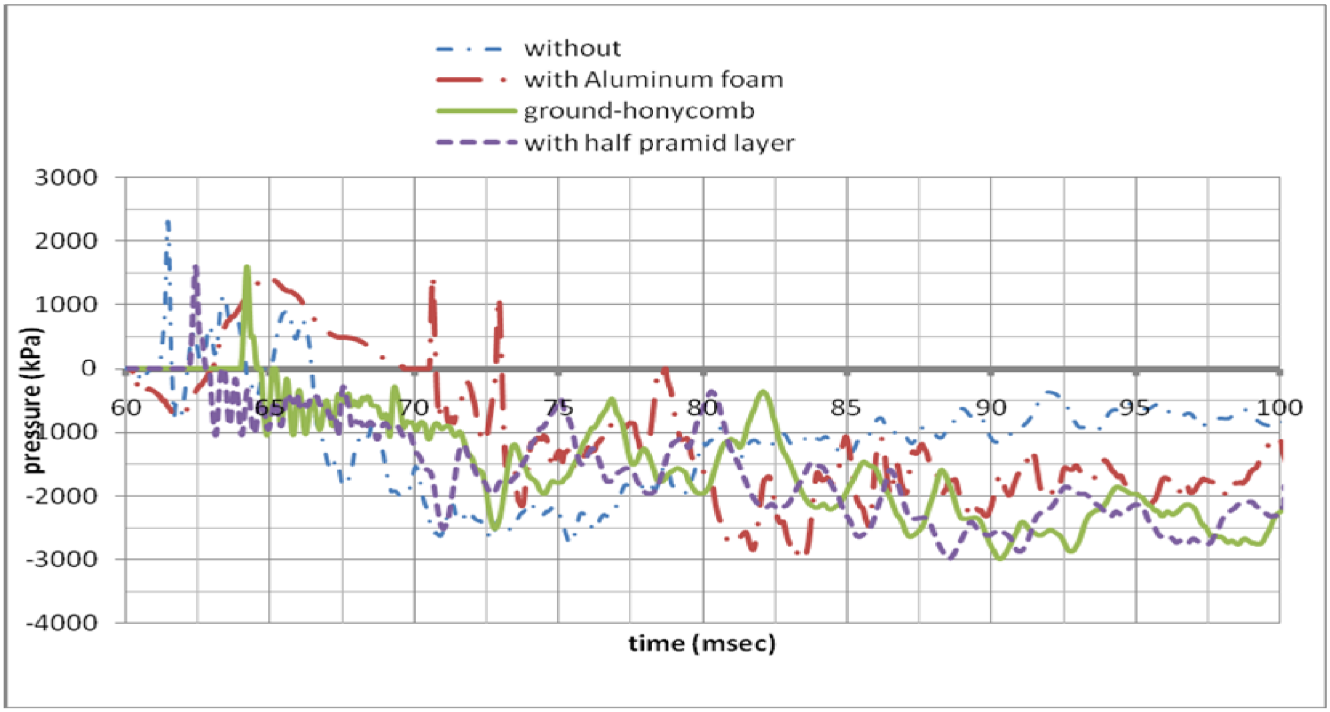

Figure (10): The pressure time histories with and without mitigation materials .

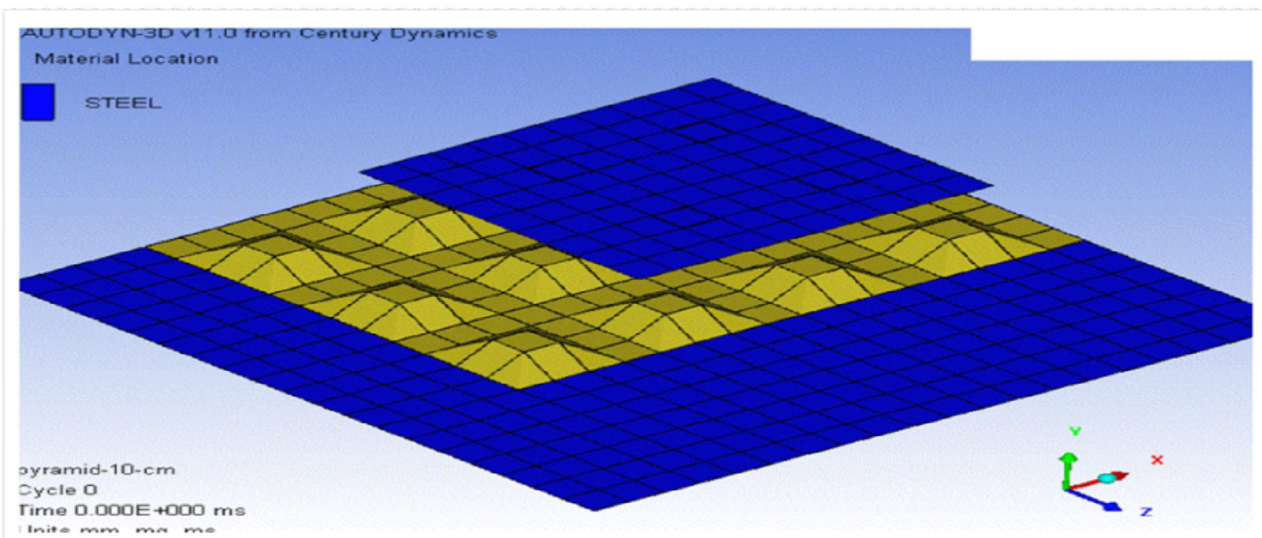

Figure (10): Half pyramid sandwich panel.

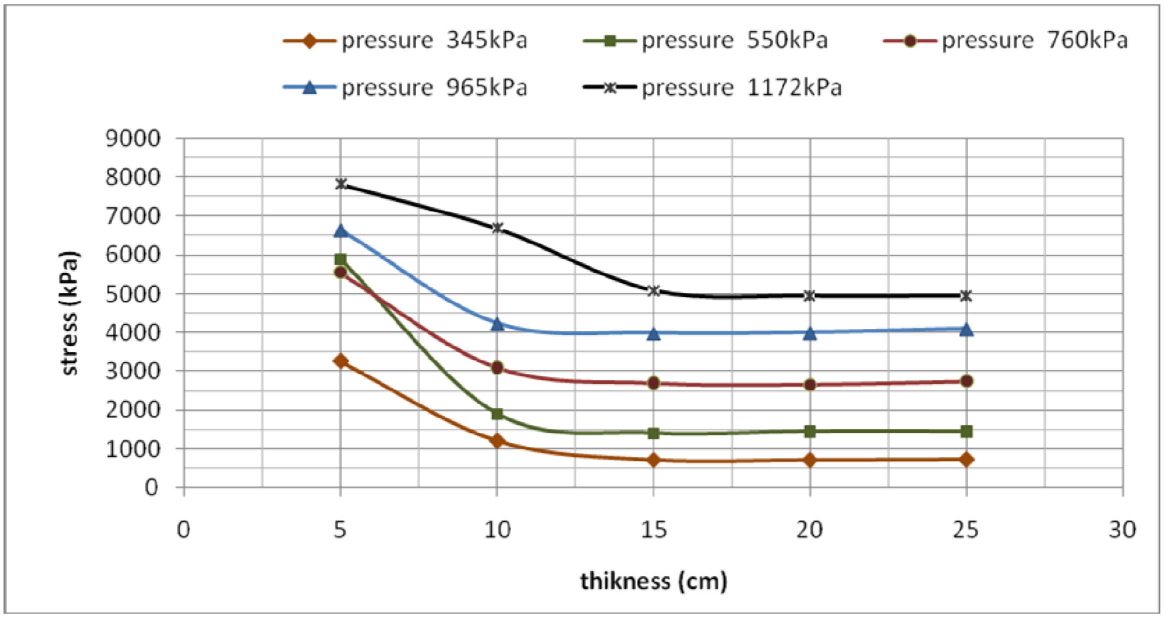

Figure (11): Show the Stresses resulted due to differ ent pressure ranges.

Table (1): The best thickness corresponding to the pressure ranges.

pressure range		Best thickness
kPa	**Psi**	**cm**
up to 345	**up to 50**	**10**
345 to 550	**50 to 80**	**12**
550 to 760	**80 to 110**	**12**
760 to 965	**110 to 140**	**15**
965 to 1172	**140 to 170**	**18**

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