THE EFFECT OF BLAST LOADING ON CONCRETE BLAST WALLS WITH DIFFERENT MATERIALS AND GEOMETRIES

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Abstract*– Blast loading tests have been developed in air by using ANSYS-AUTODYN program for simulation. The fourteen simulated models mainly conducted in four phases as first phase is discussing four models grouped in Group 1 consists of four concrete blast walls with double layer that subjected to four different masses of TNT (10, 50, 100, 500) kg. The main purpose for this group results to choose the proper TNT mass to use in the next phases of the research to make the comparison between models, involving pressure and damage, more obvious. The most appropriate mass is 100kg TNT to differentiate the results easier between the models. The second phase is discussing four models grouped in Group 2 consists of four different materials (Aluminum, Steel, Polycarbonate, Platinum) used in forming hexagon core between the concrete double layers (Sandwich Panel). Comparing their output results with the concrete double layer wall without core. However, Aluminum core showed the best output results. The third phase is discussing three models grouped in Group 3 consists of three blast walls models with three different angels of curvature. The best curvature observed is depending on the barrier's aspect ratio and it can resist better by its concave side not convex side.

***Keywords*-- Air blast testing; Blast loading; Finite element simulation; Impulse loads; Sandwich panels**

I. INTRODUCTION

The terrorism occurs all over the world not only in Egypt and especially the explosions became a huge threat towards safety of structures and security in general recently. To face this negative issue an enhancement through numerous searches have been studied to increase the ability of structure's resistance against blast load. Therefore, there are some structures proves to have a reduction in blast impact and can reflect some of it. One from the best structures that proves high results in absorbing energy and reflect blast waves through plastic deformation is sandwich panel walls. It has been used in numerous zones for example defence, aerospace, marine, automotive and industry of railway. It has a lot of advantages as high energy absorption, high capacity of thermal isolation and high protection for structures [1]. As same as the curved Blast walls that showed under research studies high ability in reflecting blast waves [2].

Several models used to be investigated by its performance in resisting against blast loadings against the mass of TNT. The analyses method, using ANSYS-AUTODYN, will be more economic than conducting these high explosive events in real life. All the experiments have the same standoff distance of the TNT, and its amount will be constant without any changing through all the "Finite Element Method (FEM)" models. AUTODYN-3D is a widespread program dealing especially for explosion difficulties. Many mathematical simulations were held for studying the effect of varying not only the core's material but also the geometric shapes of walls. Moreover, explored the effect of altering the curvature angle.

Blast wall can be described as a physical barrier structured for protecting highly important structures & buildings alongside with persons inside from any risk effects of a neighboring explosion. Researchers have been stated the barrier such as "a physical wall splitting a valued structure subjected to explosion danger which creates a structural damage; the barrier minimizes explosion loads parameters that effects on the secured structure." They made an image of the path for event of wave diffraction through the barrier &stated reduction in positive ultimate pressure after the barrier. Combined geometrical variables to find safety factors like distance in minor scaled investigational studies. Effectiveness of blast walls is reliant on its height, explosion height over ground, target's elevation, & stand-off distance from barrier into targeted building and from charge to the blast wall as shown in the figure below[3].

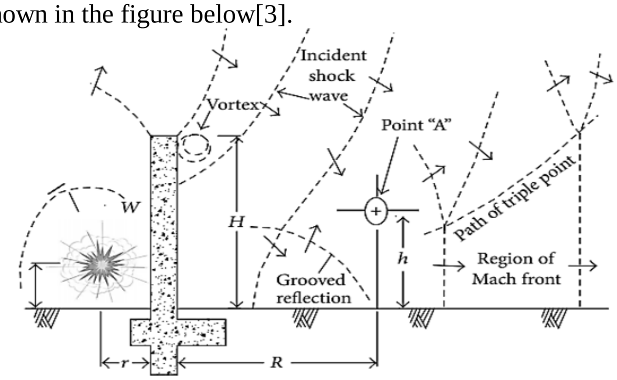

Fig. 1. Pressure waves diffraction over the blast wall.

Dangerous explosions are results of complex physical and compound cycles inside also, in the prompt region of the hazardous and are joined by a close momentary arrival of a measure of energy as warmth, light and sound [4]. The compound responses engaged with an explosion are consequently oxidation and exothermic responses on the grounds as for example: a) First kind, there are two reactants, a fuel with an oxidizer, that respond to form the blast.

b) The second sort of response includes a solo reactant as fuel & oxidizer are limited in one atom, that deteriorates through response and is changed to oxidized items. It is more normal in explosives.

$2N \longrightarrow N_2$

$2H + O \longrightarrow H_2O$
$C + O \longrightarrow CO$
$CO + O \longrightarrow CO_2$

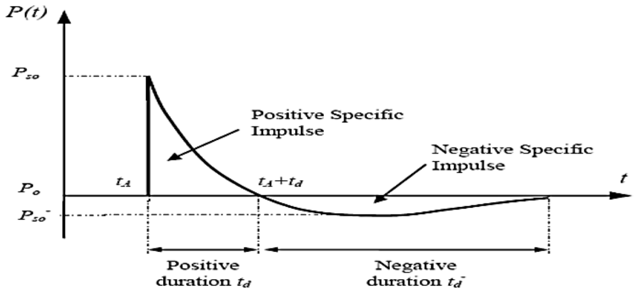

Fig. 2. Variation of overpressure with distance at a given time from centre of explosion.

II. BACKGROUND

A. Honeycomb Sandwich Panel

The need to protect structures from the high-intensity dynamic loads created by explosions has stimulated renewed interest in the mechanical response of metallic structures subjected to localized, high-rate loading [5].One promising approach utilizes sandwich panel concepts to disperse the mechanical impulse transmitted into structures, thereby reducing the pressure applied to a protected structure located behind the barrier (Dharmasena et al., 2018). They are designed to resist a particular explosion threat, usually defined in terms of peak overpressure in their lifetime and have different directional behaviours due to the particulars of section classification and connection arrangement [1].

Sandwich structures can be defined as laminated hybrid structures consisting of (top and bottom) typically made of stiff and strong materials, as concrete material in this research, and a sandwiched core (typically possessing a relatively low mass) as Aluminium for example. Sandwich panels have been extensively used in a wide range of areas, such as aerospace, automotive, marine, defence and railway industry. They have showed convincing advantages, such as high strength-to-weight ratio, high stiffness-to weight ratio, high thermal isolation capacity, and excellent energy absorption and structural protection characteristics [6].

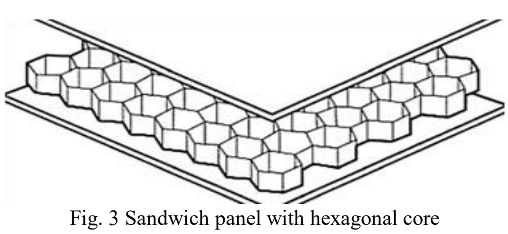

Fig. 3 Sandwich panel with hexagonal core

Polymeric foams, honeycombs, metallic foams, and functionally graded materials have been used as the core fillers of sandwich structures for explosion-proof applications, attributable to their lightweight, energy absorption efficiency, and high specific stiffness. In these candidate materials, the aluminium honeycomb has exhibited superior performance in the compressive modulus and shear strength [7].From the mechanical point of view, it is very similar to the I-beam with enhanced overall structural stiffness, stability, compressive capacity and bending characteristics [8].

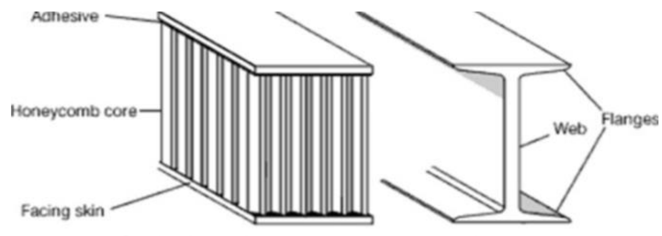

Fig. 3. Mechanical similarities between sandwich panel and I beam.

Metallic sandwich panels with a cellular core have the capability of dissipating considerable energy by large plastic deformation under impact or blast loading. Currently, sandwich structures with honeycomb cores have attracted a great deal of attention. Sandwich structures have been studied for a long time in experimental, analytic, and numerical methods. The shock resistance of engineering structures subjected to blast impact is of great interest to engineers, due to enhanced chance of blast threats [9].

B. Curved Blast Wall

The curved barrier normally performs better than the flat barrier under uniformly distributed loading by developing compressive force and reducing the bending moment. This superiority is significant for the “Sandwich curved shell (SCS) ”, since the compressive strength of concrete is much higher than the tensile strength. Hence, the curved SCS sandwich panel wall has potential application in resisting blast loading and energy dissipation [9].

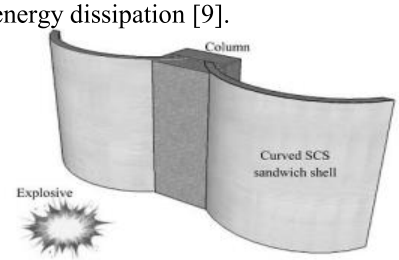

Fig. 4. Sandwich curved wall subjected to explosion.

It is important to understand the effect of curvature on the blast response of curved structures to seek the optimal configurations of such structures with improved blast resistance. The traditional blast-resistant structures are usually designed in a bulky and solid way, which leads to poor operational performance and high costs. Frequently metallic foam cored sandwich panels have attracted much attention as they have excellent characteristics as shock and impact energy absorbers with light weight and high strength [10].

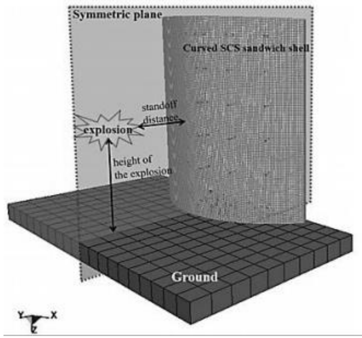

Fig. 5. Curved wall subjected to explosion.

C. *"Finite element modeling (FEM)"*

The FEM can be defined as numerical method that uses altered ways for detecting the expected forces and deformations with considerable accuracy and to produce reliable output solutions. The FEM approach is the invention of a group of processes that work together. The field experiments can be computed by computational model equations through FEM characterized by partial differential equations.

1) TNT simulation

The explosions that released through urban regions produce very rapid amount of energy generating pressure waves of finite amplitudes. Hot gases create pressures about 100-300 Kilo bar with temperatures at 3000- 40000 ˚C. These hot gases velocities can reach about 1800 to 9100 m/s, which influences atmospheric particle movements fast. So, a compressed layer of air forms before the hot gasses that are blast waves. The blast wave goes from the detonation point which has the highest-pressure value and decreases significantly to the same air pressure at a distance 40 to 50 times the charging diameter of the detonating point [4].

The blast in air can be modelled using one dimensional approach. In AUTODYN one dimensional simulation is modelled using 2Daxisymmetric solver in the shape of a wedge. The angle of the wedge is defined by AUTODYN. Only wedge inner radius and outer radius needs to be defined as shown in the equations below.

TNT volume = TNT mass/ TNT density

TNT density = 1.63 gm /cm^3

TNT volume = 4/3 * π *(R^3 - r^3)

Fig. 6. TNT cone simulation with detonation point indication

2) Blast wall simulation

The blast wall used is 4 m width and 3 m height with double layer and hierarchal core embedded between them.

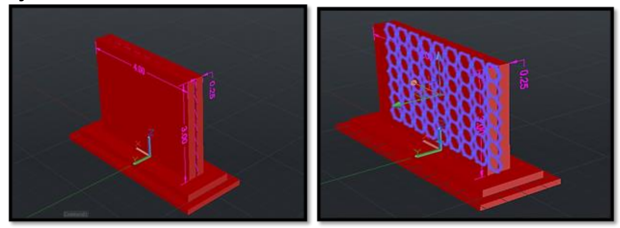

Fig. 7. Blast wall model in 3D-AUTOCAD

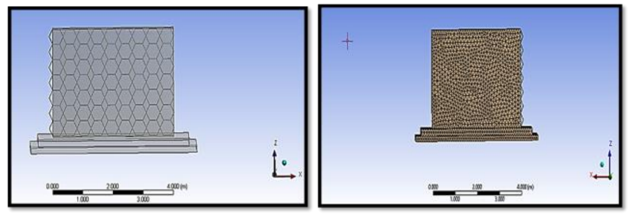

Fig. 7. Imported Blast wall into ANSYS-AUTODYN and its meshing

III. Model's Description

14 models were discussed through this research to get the best model to resist and reflect the blast waves. By mainly two important factors the material of the core that embedded between the concrete wall double layer and changing the angel of curvature for the barrier itself. The fourteen models are divided into mainly three groups to get an organized and accurate output as possible.

A. *Concrete blast wall double layer (Group 1)*

Group 1 consists of four models of concrete blast wall double layer that subjected to four different masses of TNT with the same stand-off distance and having the same coordinates of gauges points as to measure the output results in the same locations to have fair comparison. The masses of TNT used will be equivalent to these cases:

Table. I. TNT masses used

Bomb	***Explosive Capacity (Kg)***
Hand carry bomb	10
Motorcycle	50
Passenger car	100
Van	500

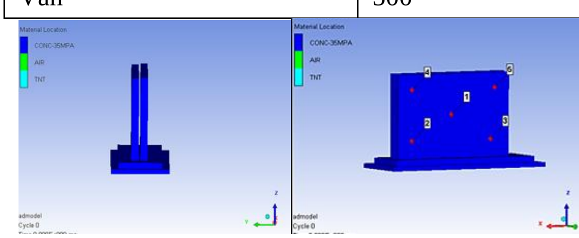

Fig. 8. Concrete double layer with gauge points

The same barrier will be subjected to four different masses of TNT with same stand- off distance (X=0, Y=1000 mm, Z=1000) and same gauges points.

B. Concrete double layer barrier with Honeycomb core (Group 2)

Group 2 consists of four models of concrete double layer blast wall with hexagon cells core embedded between the two layers. Comparing different cores materials with the same mass of TNT, the same stand-off distance and same coordinates of gauges points as (Group1).

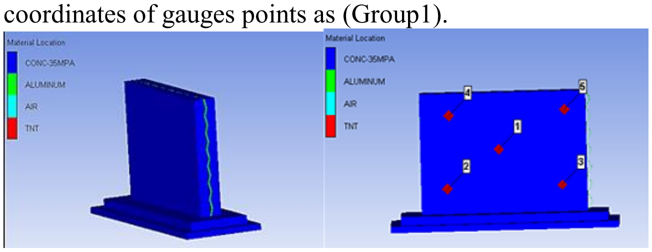

Fig. 9. Concrete double layer with hierarchal core and locations of gauge points

Table. II. Group 2 models

Group 2 models	
Sandwich wall with Alumnium core	Subjected to 100 Kg TNT with Stand-off distance 1 m
Sandwich wall with Steel core	Subjected to 100 Kg TNT with Stand-off distance 1 m
Sandwich wall with Platinum core	Subjected to 100 Kg TNT with Stand-off distance 1 m
Sandwich wall with Polycarbonate core	Subjected to 100 Kg TNT with Stand-off distance 1 m

C. Curved concrete blast wall (Group3)

Group 3 consists of three different blast wall models with different angels of curvatures. As the curvature will enhance the resistance and reflecting ability for the barrier, comparing it to the ordinary flat barrier, against blast waves.

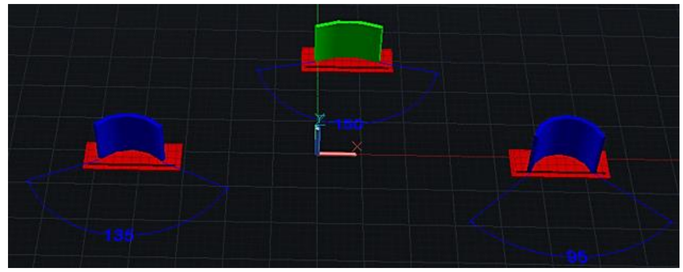

Fig. 10. Curvature angels for the three models.

Each model in this group will be subjected to the TNT blast twice, as the first time in front of the concave side and the second time in front of convex side to form six models. To know the best orientation between these models.

Table. III. Group 3 models

Group 3 models		
curvature angel	TNT Position	
95	1 m from the concave	1 m from the convex
135	1 m from the concave	1 m from the convex
150	1 m from the concave	1 m from the convex

IV. Results and Discussion

This section will discover the output results of numerical models' analysis. Output results are presented in mainly 3 parameters as Pressure, Damage, as well as the displacement in the Y direction. Each model is analyzed with outcomes that clarified and compared to other models in each group. Therefore, getting the best model in each group and form one model having the best characteristics from materials, curvature angel and its orientation.

A. Results of Group 1 models

Group 1 consists of 4 double layer concrete wall models subjected to four different masses of TNT to get the effects for increasing TNT mass on the barrier model. Moreover, to choose the suitable TNT mass that will be used in Group 2 and Group 3 models' analysis.

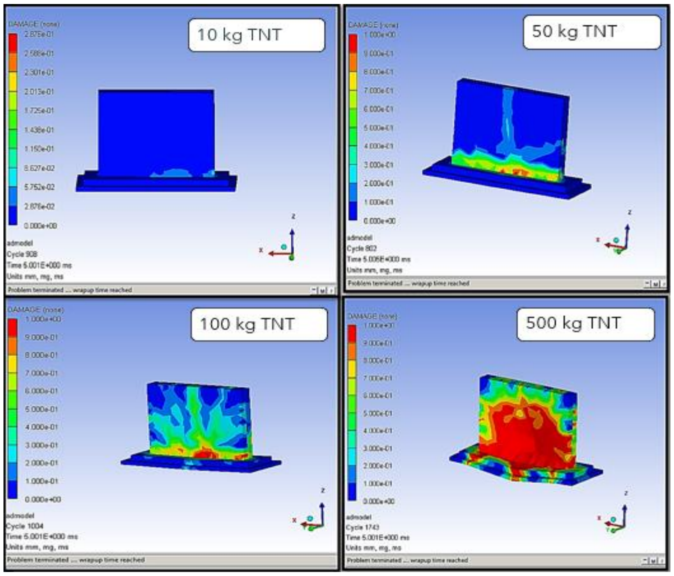

Fig. 11. Damage simulations

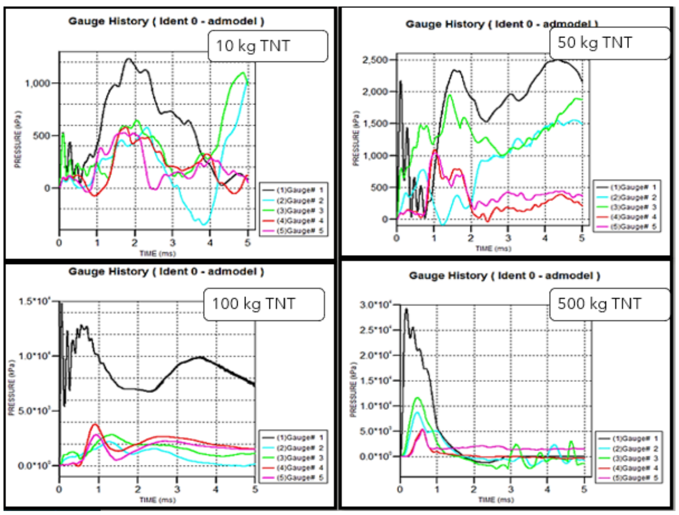

Fig. 12. Output pressure graphs

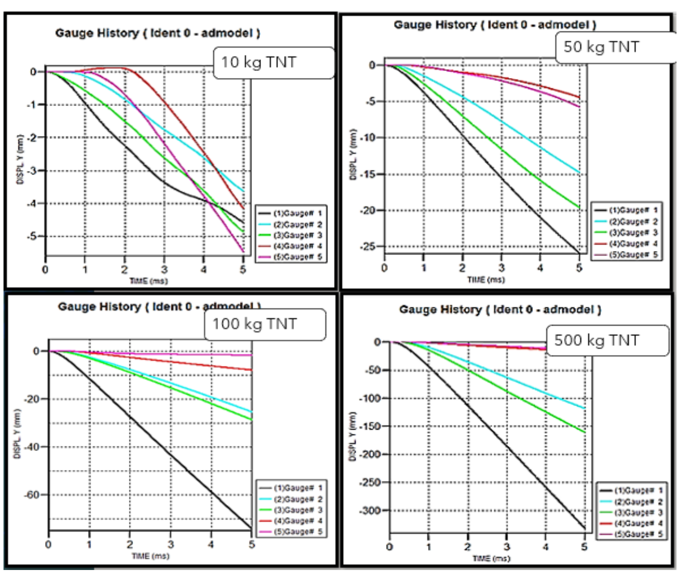

Fig. 13. Output displacement graphs

The calculated displacement in the Y-direction taken at fixed time for all the models at 5(Ms) and the pressure taken is the maximum pressure achieved within this duration. As shown in the table the pressure and the displacement are directly proportional with the TNT mass. Therefore, to compute comparisons between blast wall models a mass of 100kg TNT is chosen. Because the smaller mass having very small values of damage and the larger mass having very large value of damage that can reach to cause total damage. In both values it is not easy to detect differences in output results between different models subjected to TNT blast.

Table. IV. Group 1 results

Group1 Results Summary			
Model number	Gauge point	Pressure (Kpa)	Displacment Y-direction (mm)
Model 1 (10kg)TNT	1	1220	4.5
	2	1050	3.5
	3	1100	4.8
	4	500	4.2
	5	400	5.5
Model 2 (50kg)TNT	1	2500	26
	2	1500	15
	3	1900	20
	4	1100	4
	5	1000	6
Model 3 (100kg)TNT	1	$1.5x10^4$	74
	2	$2x10^2$	25
	3	$2.2x10^2$	29
	4	$3x10^3$	8
	5	$3.5x10^3$	2
Model 4 (500kg)TNT	1	$2.9x10^4$	370
	2	$8x10^3$	115
	3	$1.2x10^4$	160
	4	$5x10^3$	20
	5	$5x10^3$	15

B. Results of Group 2 models

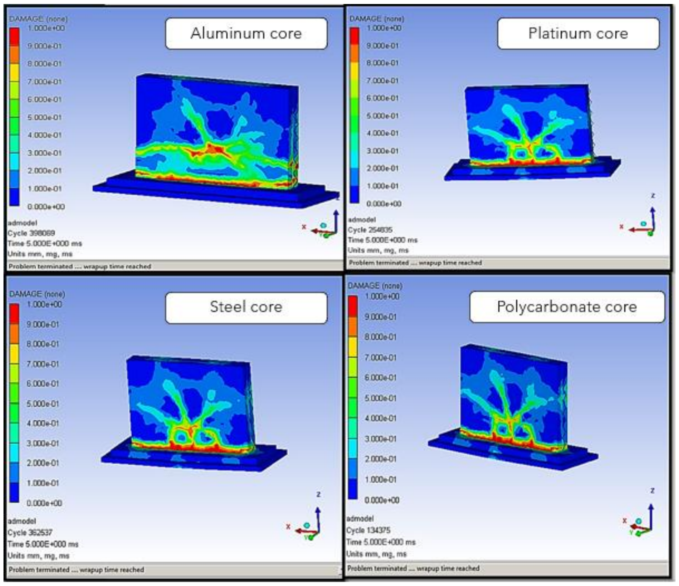

Fig. 14. Sandwich walls damage simulations

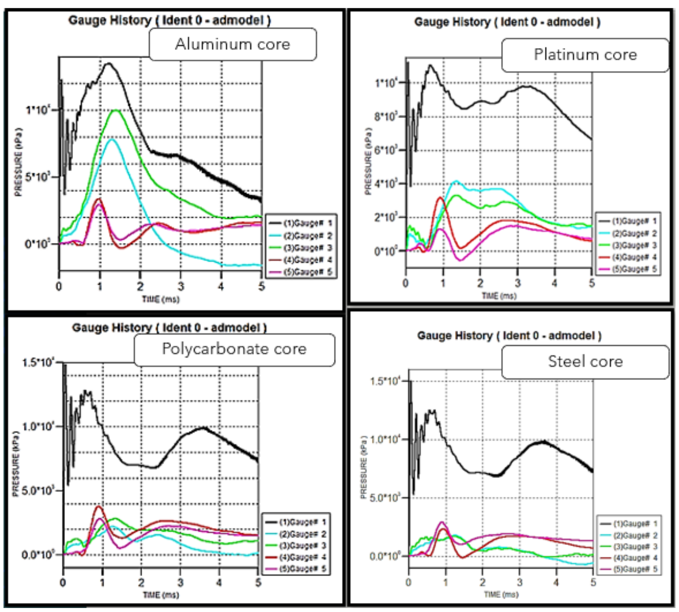

Fig. 15. Sandwich walls output pressure graphs

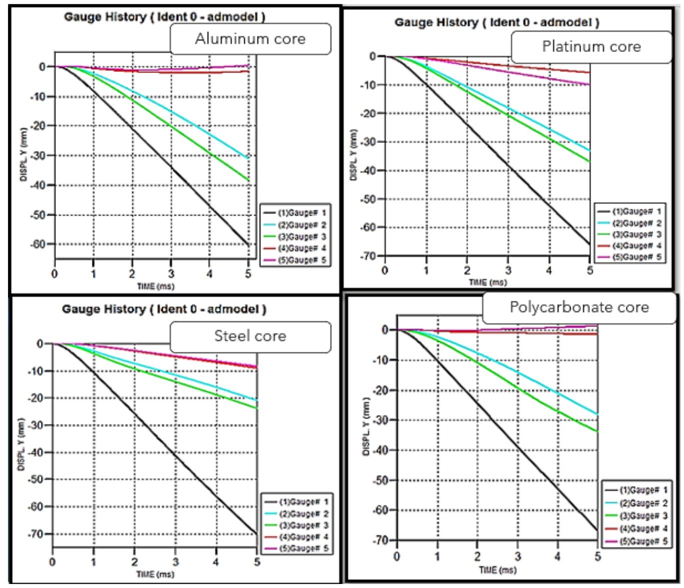

Fig. 16. Sandwich walls output displacement graphs

It is obvious that the enhancement made for the blast wall by the metal core increase its resistance and decreases the displacement in the gauge points than in concrete blast wall. The best core material is made from Aluminum as it output the least displacement in the Y-direction. The second is Polycarbonate, the third Platinum and the least effective material is Stainless Steel.

C. *Results of Group 3 models*

This group mainly consists of three blast walls models with three different angels of curvature. The TNT mass with 100kg location will be within 1 meter stand-off distance from the barrier with two different orientations for each model. As each model will resists the blast wave two times by the concave angel and convex angel to know the best orientation for the curvature barrier.

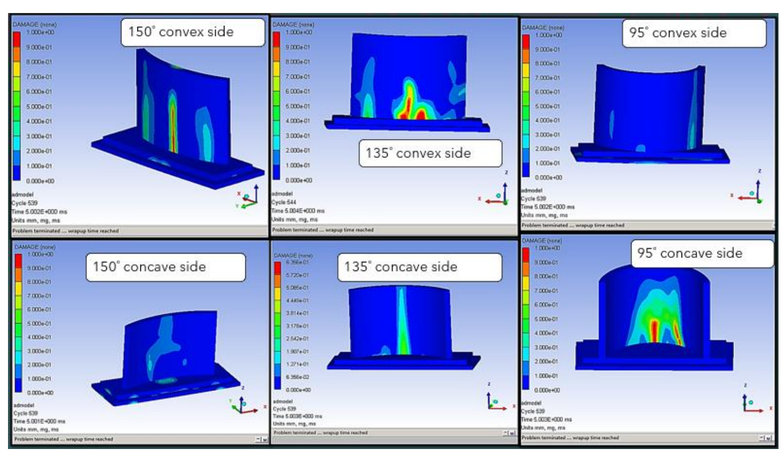

Fig. 17. Curved walls damage simulations

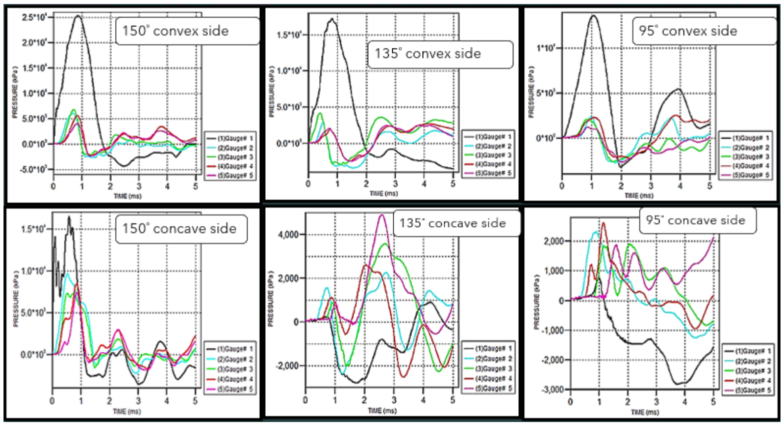

Fig. 18. Curved walls output pressure graphs

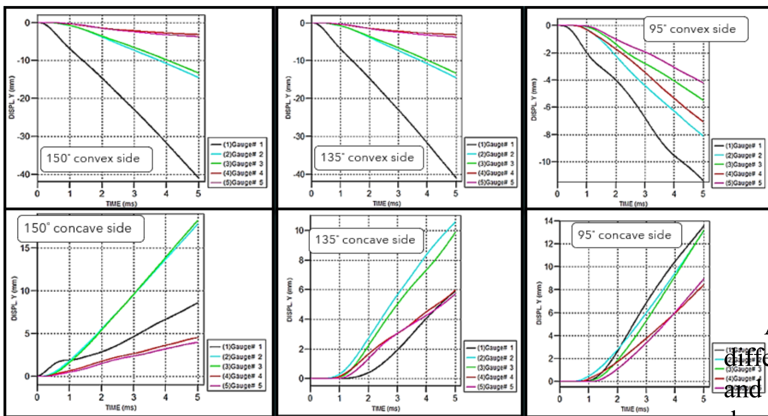

Fig. 19. Curved walls output displacement graphs

It is clearly obvious the effect of curving the barrier on its behavior against the blast waves. This appears in the decreasing of the values for gauges points' displacement in the Y-direction. Moreover, it is not only depending on the curvature but also the orientation is having a large effect. As the resistance ability is higher when the TNT placed in front of the concave side of the blast wall than when it placed in front of the convex side. Furthermore, as the angel decreases the efficiency increases but to a certain limit. This limited angel is related to the aspect ratio for the barrier. As in this case the blast wall is 3:4 m and the best outcome result got from the angel 135° which is ($\frac{3}{4} x 180°$).

Table. V. Group 3 results

Group3 Results Summary						
Model number	Gauge point	TNT in front of Convex side		TNT in front of Concave side		
		Pressure (Kpa)	Displacment Y-direction (mm)	Pressure (Kpa)	Displacment Y-direction (mm)	
Model 1 (150°)	1	$2.5x10^4$	40	$1.6x10^4$	8	
	2	$6x10^3$	15	$1x10^4$	18	
	3	$6.5x10^3$	14	$7.5x10^3$	19	
	4	$5.5x10^3$	3	$8x10^3$	4.5	
	5	$4x10^3$	4	$7x10^3$	4	
Model 2 (135°)	1	$2x10^4$	32.5	$1x10^3$	6	
	2	$3x10^3$	10	$2.2x10^3$	11	
	3	$4x10^3$	15	$3.6x10^3$	10	
	4	$2.5x10^3$	4	$2.5x10^3$	6	
	5	$2x10^3$	6	$5x10^3$	5.5	
Model 3 (95°)	1	$5x10^4$	12	$0.8x10^3$	13.8	
	2	$3x10^3$	8	$2.2x10^3$	13	
	3	$2x10^3$	5	$1.8x10^3$	13	
	4	$2.5x10^3$	7	$2.8x10^3$	8.5	
	5	$1.5x10^3$	4	$2x10^3$	9	

V. Conclusion and Recommendations

A. Conclusion

ANSYS-AUTODYN 3D modeling program is an effective different way for investigational works in saving time and cost and output as much as possible precise results when modeling dynamic performance of concrete blast walls that are subjected to blast loading. It is very important to have this technique nowadays as the terrorist attacks increases, so we need to decrease the effects of these villain events by enhancing the defensive structural elements as in this research specifically blast walls. Especially this finite element modeling observes the structural elements behavior without putting people's life in risk.

The effective mechanical properties of the hierarchal shape of the core obviously observed through this research in resisting blast loadings and decreasing damage and displacement less than the ordinary concrete barrier without that core. The best core has been observed is made from Aluminium material. Moreover, more enhanced results have been observed when some changes made to the blast wall angel and change it from flat barrier to curve barrier. The best angel observed was depending on the aspect ratio regarding the barrier to have best attitude against the blast loadings.

The output results concerning the model's simulations and comparisons have been characterized, taking into consideration that all the models were simulated under identical circumstances. The comparison results established on some parameters as pressure, damage and displacement take place for each barrier model. All the output results of the barrier models have been presented by graphs figures exported from AUTODYN, damage simulation for each case and theoretical information created from the output results for the models.

B. Recommendations

1) Studying the recommended models under another type of explosion as C4 material.
2) Analyse one model having the best core material and best angel of curvature at the same time against blast loading.

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