Numerical Analysis of 3-D Sandwich Walls Under Blast Loading

S. Monika Sri, P. Polu Raju, Sanjay Deori

Abstract: ***The swift in population development and urbanization have made a huge interest in the safe house and development of new materials. Masonry walls are the real segment in the housing sector and it has fragile attributes and shows poor performance against the uncertain loads. The 3-D sandwich walls are such system, which is more suitable for ease and speedy wall construction. The idea of a sandwich 3-D wall is to combine thin and durable facings with a light-weight core material, i.e. EPS (expanded polystyrene) which is suitable for sound and heat Insulation. Shear connectors are introduced to provide integrity and to transfer the loads. This paper reports the numerical evaluation concerning the effects such as energy absorption of core material, transfer of shock wave and the displacement of adaptable sandwich walls subjected to blast loading. The numerical model is generated using ABAQUS software to determine the dynamic response of sandwich 3-D walls under the blast loading and is compared with the response of masonry wall.***

Index Terms: ***Blast design, External Explosion, Energy absorption, Masonry wall, 3-D sandwich wall.***

I. INTRODUCTION

Sandwich structures mostly used in civil, aerospace, marine and military constructions because they have more strength, corrosion resistance, better energy absorption and very low maintenance cost compared to conventional structures. Nowadays, the resilience of sandwich structures when exposed to blast loading and its effects are of extraordinary demand in engineering constructions to counter the terrorist attacks. A sandwich structure is a structure comprising of two thin layers outwardly, called the facings/skins, attached to a thick core material in the center. The outward faces are thin solid and the core material is thicker and lighter. During the explosion the pressure developed will possess high peak pressure and due to this the structure undergoes large plastic deformations and absorbs energy before failure. A study was conducted to understand the relationship of blast load and the structural deformation to evaluate the structure enhanced energy absorption and blast resistance performance using code (TM5-1300 1990). In this paper, the topics include modelling of sandwich 3-D wall under blast loadings and the analysis of dynamic response of sandwich 3-D wall are studied. The performance of composite materials such as concrete and core material i.e., EPS (Expanded polystyrene) and steel wire used as shear connectors which bear high relevance are achieved and are implemented in construction practices. The blast response of a sandwich 3-D wall will be simulated with ABAQUS Explicit to study the dynamic response of the sandwich 3-D wall structure and is compared with the masonry wall.

Finite-element simulation was conducted on sandwich panel and found that energy absorption of shock wave mainly depends on the core material and an elaborate design is provided [1]. A blast experiment is performed on square sandwich panels with hexagon aluminum honeycomb cores to investigate the displacement history of ballistic pendulum [2].From the results, it is observed that the core has the capacity to absorb energy from the blast wave and hence the design for the sandwich structures to resist blast loading is required [4]. when analysis is conducted in ABAQUS it is discovered that non-composite sandwich panels compromise of SFRC slabs and cenosphere aluminium compound foam composite sandwich panels have incredible protection from impact reaction when contrasted with steel plate, plain and strenghthened solid and polyurethane and dytherm foam cored composite sandwich structures [5]. The study illustrates that load bearing precast wall panels are recommended when compared with conventional walls and a design criterion for blast loading is recommended [7]. Effects of blast loading on various design parameters such as ratio of side lengths, relative density of core, and core thickness were considered [11]. The curves of blast waves are developed which indicated that the panel resists a low risk of ballistic with 100% certainty, yet, it has a high blast threat. The wave has 86.5% chance of perforating through-wall system [12].

II. RESEARCH SIGNIFICANE

Due to recent reports on terrorist incidents, it is essential to design military, government, and commercial tall buildings against blast loading. In this research, sandwich structures are considered as they have high insulation capacity and resistance to loadings. The aim of this research is to study the performance of finite element modelling of 3-D Sandwich walls using ABAQUS software under blast loading to evaluate the dynamic response of structure.

III. BLAST WAVES AND THEIR EFFECTS

A detonation causes a liberation of huge amount of energy to the surrounding air. Some part of this energy is transformed into thermal energy and some part is coupled as air blast shock waves that expand radially. A shock wave is created due to the detonation in the surrounding air, which causes shock wave and is shown in Figure.1.

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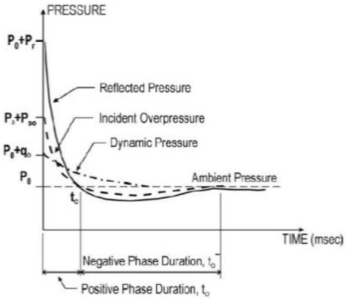

Figure. 1: Blast pressure vs. time graph

Figure.1 represents a blast overpressure and time profile of the shock wave (TM5-1300 1990), the characteristic of blast wave is indicated by different parameters i.e., Arrival time ta Ambient pressure P_o, Peak side-on positive overpressure P_{so}, t_0 is the time taken to decay the positive pressure to ambient pressure, Positive impulse Io, to at the point, Peak side-on negative pressure (suction), P_{so}-, Negative phase duration t_0. The pressure at that point degrades to the surrounding pressure level over the period of time and degrades at that point additionally degrades underneath the ambient pressure to an under strain, P_{so} before at last coming back to typical pressure conditions over a term, to (TM5-1300 1990). The different form of shock wave is impulse wave that occurs along the positive phase duration I_s, and is given by equation (1)

$I_s = \int t_a + t_d \, P(t)dt$ (1)

In equation (1), P(t) is overpressure as a represented as a function of time. Also, the blast load depends on the charge weight(W) and standoff distance(R). Generally, the weight of charged weight is converted to an equivalent value of TNT equivalency. Also, the TNT is the representation for different types of explosives.

Generally, a detonation occurs in various forms of explosions located separately at some distances, several methods have been introduced to assess the properties of shock waves with respect to charge weight and standoff distance. The most frequently used method for blast loading is Hopkinson Cranz method. It is known as scaled distance represented by a parameter Z, as given below:

$Z=R/W^{1/3}$ (2)

From the equation (2), R is standoff distance from the source, and W is mass of spherical TNT equivalent. This method implies that the equivalent waves are produced at the same scaled distance. The strength of shock waves increases when it undergoes some reflection state. The intensity is non-linear due to the shock wave and angle of incidence.

IV. BEHAVIOUR OF STRUCTURES WHEN SUBJECTED TO BLAST LOADS

When there are very high explosions there will be large deformations in the structure. The main parameters that influence the structure are mode of deformation, transmission of impulse, and energy absorption during deformation. The main characteristic that is primarily influencing all the parameters is mode of deformation and fracture. Usually, different methods are used to evaluate the response of the structure such as experimental, theoretical and numerical simulations.

V. MATERIAL PROPERTIES

A composite sandwich wall panel as shown in figure.2 has been considered for the analysis in the present study. The sizes of the sandwich 3-D walls that are considered are 3mX3m and 2mX2m. Also a masonry wall of size 3mX3m is also modelled using 1:6 cement mortar ratio. The material used in the left and right layers of the panel is concrete of M_{25} grade having σ_c,yield as 12.2MPa and σ_t,yield as 3.5MPa whose density is 25kg/m3 and Poisson's ratio as 0.2 and the core material used is EPS (expanded polystyrene). The thickness of the right and left layers is 35mm and the thickness of core material is 50 mm shown in Figure.2. The layers are bonded by double shear connectors which are embedded through it diagonally to transfer the load applied between the faces. Shear connectors are introduced on either side of the core layer to provide stability to fabricated 3-D sandwich panel walls. The shear connectors are made of steel wires of diameter 2.5 mm and width of 55 mm and of spacing 100 mm is introduced on either side of the core into the structure and is shown in Figure.3. The properties of steel are considered as Young's modulus as 2 $x10^5$ and the density is taken as $7860kg/m^3$ and the poissons's ratio of steel is 0.3. The size of the meshing provided is 2.8m X 2.8 m and 1.8m X1.8m consisting of diagonally placed shear connectors as shown in Figure.4. The properties of Masonry wall of dimensions 3mX3m and thickness 215mm are considered the density as $2000kg/m^3$ and Young's modulus is $118e^8$ and poissons's ratio as 0.15 are assigned to the structure.

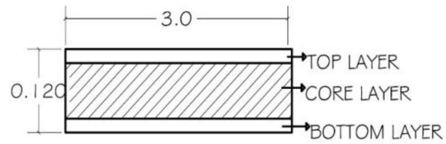

Figure.2: Typical diagram of sandwich 3-D wall

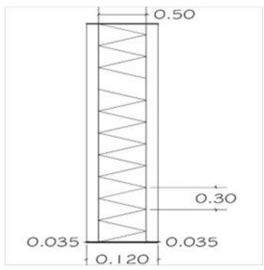

Figure.3: Section view of shear connectors.

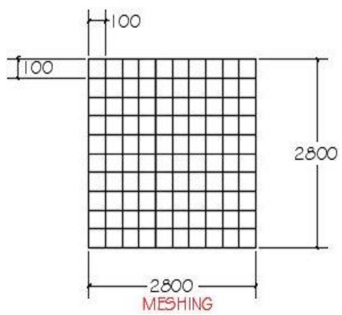

Figure.4: Type of mesh provided in the sandwich 3D wall

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VI. FINITE ELEMENT MODELLING

The numerical modelling of the sandwich 3-D walls is modelled and simulated in ABAQUS/CAE. Finite element (FE) models of sandwich 3-D wall have been developed using the ABAQUS as Explicit models consisting of sizes 3mX3m and 2mX2m having concrete layers with thickness = 35 mm and core with thicknesses c = 50 mm made of Expanded polystyrene (EPS)and is shown in Figure.5 and Figure.7. The properties of the EPS are assigned to the model. The shear connectors are assembled to the structure to increase the stability of structure and it acts as a bonding between these layers. These layers are thus assembled and they are hooked up with the help of tie constraints and are converted into dependent elements. The finite element meshing of seeds for each layer is given as 50 mm. The sandwich 3-D wall is assigned the fixed boundary conditions on all the sides. A masonry wall of 3mX3m is also modelled in the ABAQUS and the material properties are assigned and provided fixed condition on all sides and the Response of this structure is shown in Figure.6. The Blast load is applied as a uniformly distributed pressure on right layer surface of the sandwich 3-D wall and masonry wall. The dynamic response of sandwich 3-D wall is carried out to study the simulations for pressure, velocity and displacement vs time as well as the energy absorption and is compared with the Masonry wall.

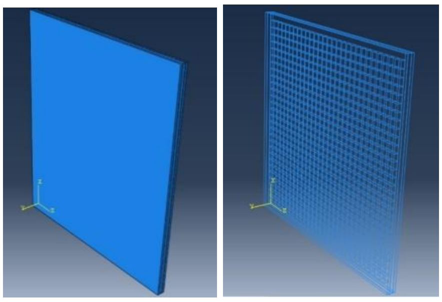

Figure.5: Mesh model of sandwich 3-D wall.

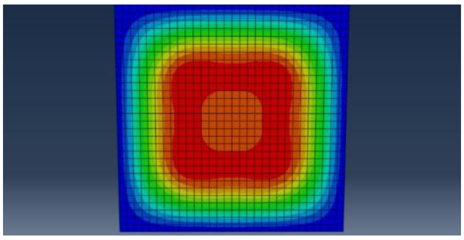

Figure.6: Deformation of Masonry wall under blast loading.

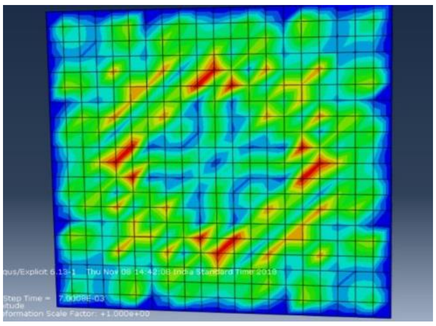

Figure.7: Response of 2m Sandwich 3-D wall under Blast loading.

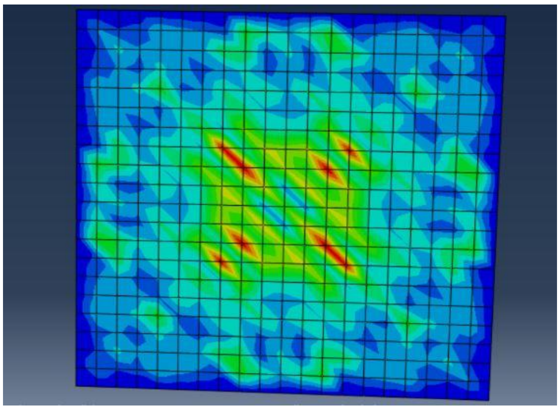

Figure.8: Typical diagram of response of the of 3m 3-D Sandwich wall under Blast loading.

VII.BLAST LOAD CALCULATIONS

The Blast load is calculated from the pressure time history curve as shown in Figure 1 and is applied to the panels. The analysis is performed for the peak positive overpressure of 2.41N/mm^2 which is applied for 0.0116ms. These calculations are done by using Hopkinson-cranz rule which is present in the TM5-1300 US army manual. The overpressure time history curve is shown in Figure.1. in Hopkinson-cranz rule t_a is arrival time of the blast wave, P_{so} is the peak pressure and P_o is ambient air pressure, t_0 is decay time of the positive pressure to ambient pressure.

VIII. ANALYSIS OF RESULTS

From the Figure.9 it is observed that the sandwich 3-D wall has the ability to absorb the energy due to the presence of core material (i.e EPS) while the shock wave is transferring through the faces of the structure. Hence it has good resistance to Blast pressure than the masonry wall. As the length of the sandwich 3-D wall is decreasing the amount of energy absorption is decreased. The Figure.10 represents Acceleration of the shock waves inside the layers of the structure and it is clear that the masonry wall is highly affected by the intensity of the shock wave and it is failed earlier than sandwich 3-D wall because there are no core layer or shear connectors present in it. The displacement in the structures is due to Blast pressure applied on the surface and it is noticed that sandwich 3-D wall has lesser displacement with respect to time than the masonry wall since it has shear connectors which enhance the resistance to the loads transferred throughout the structure. Masonry wall is deteriorated highly than 2m and 3m sandwich 3-D wall structures and is shown in Figure.11. The Figure.12 illustrates the velocity of the shock wave propagating through the structure and it is found that the intensity of the wave is higher in masonry wall and it failed prior to the sandwich 3-D wall, where as in sandwich 3-D wall there are less fluctuations and with the increase in the size of the structure the resistance of the structure increases. The 2m Sandwich 3-D wall decreased initially and increased with the time, although the velocity in the 3m sandwich wall rises at 0.08 ms and again falls prior to the 0.01 ms. Figure.13

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represents The energy stored in the structures during the transmission of the Blast wave is more in the Sandwich 3-D wall than the masonry wall. Due to the existence of core material (i.e EPS) in sandwich 3-D walls has good insulation and the capacity to absorb some quantity of energy which is released gradually may not affect the structure much. But in case of masonry wall, bricks do not possess any insulation capacity and the energy absorption is very less. The Blast pressure is observed to decrease linearly with the time and is constant throughout the time period where as the masonry wall is highly affected by the Blast pressure. At the time of the pressure wave moving away from the explosion, the amplitude decreases and the duration of the shock wave increases and is shown in Figure.14.

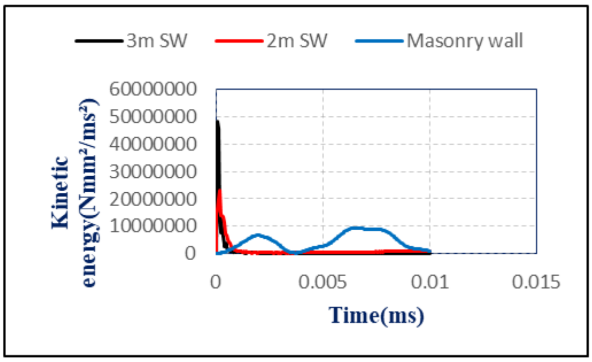

Figure.9: Kinetic energy vs Time graph for 3m and 2m Sandwich 3-D wall and 3m Masonry wall.

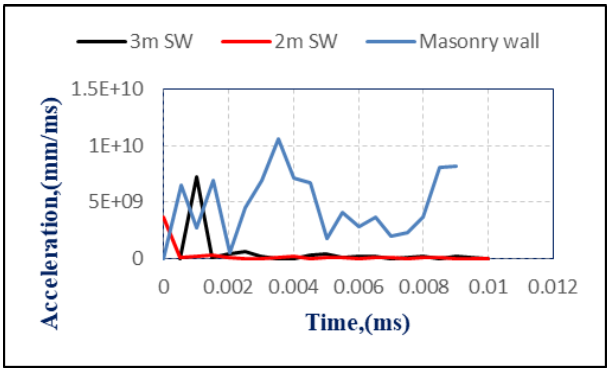

Figure. 10: comparison of Acceleration vs Time graph for 2m, 3m sandwich 3-D wall and 3m Masonry wall.

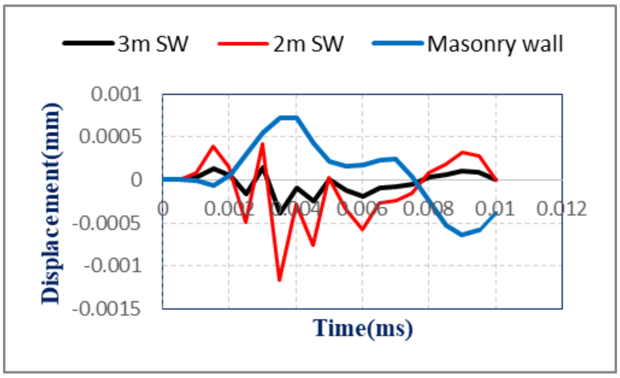

Figure. 11: Displacement vs Time graph.

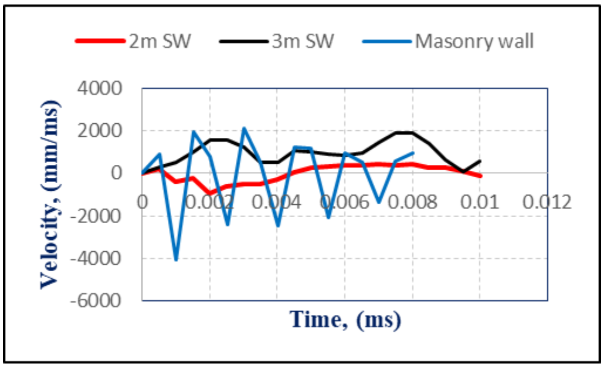

Figure. 12: Comparison of Velocity attenuation in the 2m, 3m 3-D Sandwich wall 3m and Masonry wall.

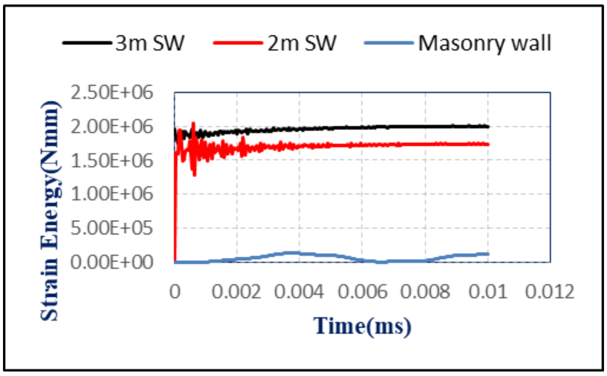

Figure. 13: Energy absorption of core material i.e EPS in 2m ,3m 3-D Sandwich wall and 3m Masonry wall.

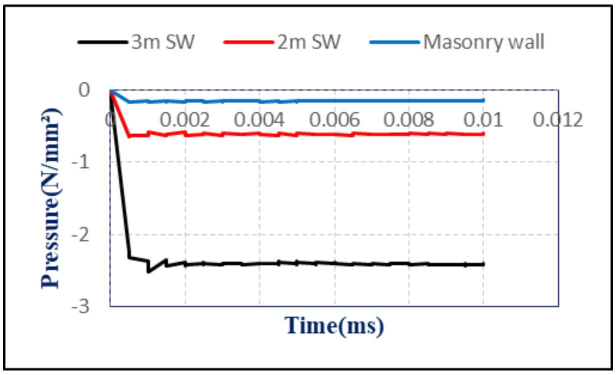

Figure 14: Blast wave pressure vs Time graph of 3-D Sandwich wall of 2m, 3m and Masonry wall.

IX. CONCLUSIONS

In this research, the study of sandwich structures subjected to blast loads and the corresponding response is studied. From the numerical analysis carried out on sandwich 3-D wall, the energy absorption and the velocity, pressure and time graphs were determined during the propagation of blast wave.

1. Energy absorption is dependent on the core material, which is more for the sandwich 3-D wall and negligible for the masonry wall.
2. 3-D Sandwich walls have more resistance to Blast pressure and the amplitude decreases with the increase in the duration of the shock wave.

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3. The displacement in the 3-D sandwich walls is less compared with the masonry wall and is determined by the attenuation of velocity of shock wave with respect to Time.
4. The effect of acceleration and velocity of the shock wave is more in the masonry wall than in the3-D sandwich wall.
5. The characteristics of the 3-D Sandwich wall increases with the decrease of size of the wall.

To enhance the resistance of sandwich structures against extreme explosions, high impact design criteria is very important. Hence, further simulations of structure with varying thickness of outer layers and introducing different core materials are to be studied under Blast loadings.

X. ACKNOWLEDGMENT

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