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Simulation of Blast Wall using Ansys

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Abstract: Terrorism is evolving as a major threat to critical infrastructure and personnel throughout the world. A blast wall is a barrier designed to protect vulnerable buildings or other structures and the people inside them from the effects of a nearby explosion, whether caused by industrial accident, military action or terrorism. It is important to study the behaviour of different types of material used for blast wall under blast loading. This study investigates the behaviour of a reinforced concrete blast wall and brick masonry wall coated with polyurethane and CFRP. The thickness of the wall of the wall is 300 mm and height is 2200 mm. Two different explosives TNT and C4 were considered. The weight of explosive charge used was 100 kg at a stand-off distance of 1m from the face of wall. The explicit finite element modelling and analysis were carried out in ANSYS AUTODYN software. The analysis results were obtained in terms of damage displacement and pressure at critical target points on the wall. On comparing the pressure time history of reinforced concrete wall and brick wall covered with CFRP and polyurethane, the peak pressure developed in brick wall covered with CFRP and polyurethane is less than that developed in reinforced concrete wall. Thus an improvement in blast resistance is obtained when brick wall with CFRP and polyurethane is used. Brick wall covered with polyurethane is found to be the better material compared to RC wall and brick wall with CFRP. The pressure and displacement developed in the wall is more when C4 charge is used than TNT.
Keywords: Blast wall, TNT, C4, ANSYS AUTODYN, Polyurethane, CFRP

I. INTRODUCTION

As a result of the antiterrorism and force protection requirements, many government and military facilities must be capable of withstanding a potential explosive detonation. Furthermore, buildings adjacent to areas where munitions are stored or buildings located within refineries can be subjected to accidental detonations. For these facilities, it is imperative to provide a blast-resistant structure to protect the building and lives of the occupants. Explosive events generate a high-pressure dynamic loading on the structure. For the majority of structures, these demands are significantly beyond the conventional lateral design loads (wind and earthquake) which the building system is able to safely resist. An explosive detonation generates an overpressure wave which rapidly radiates out from the source of the detonation. When the overpressure wave meets the structure, it is reflected off the exterior face of the building resulting in a dynamically applied pressure load. Without proper consideration of the design of the exterior walls, the blast demands can result in rapid failure of the exterior envelope of the building. This can result in high velocity debris and high-pressure demands entering the occupied space of the building.

A. Blast wall

A blast wall is a barrier designed to protect vulnerable buildings or other structures and the people inside them from the effects of a nearby explosion, whether caused by industrial accident, military action or terrorism. Concrete is widely used in construction as well as protective structure, due to its good energy absorbing characteristic under high pressures. Concrete has also been used in many constructions as walls, because of the high quality, speedy construction, cost and energy efficiency. In designing of the protective structures, it is important to follow the proper design standards or guidelines, and also to identify the possible threats and their risk of occurrence to enable the characteristic of the design loads. Blast wall is known as barrier wall used to isolate buildings or areas from material containing, highly combustible or explosive materials or to protect a building or an area from blast damage when exposed to explosions. Reinforced concrete blast wall is the type used for blast wall protection.

B. Blast Phenomena

An explosion is the result of a very rapid release of large amount of energy within a limited space and time. The sources of such an action can be different and based on this, the blast event is categorized. With respect to the location of the blast, it is classified as internal or external blast. When it occurs below the ground, it is termed as underground blast and the one above the ground is called air blast. The process by which the blast is created is used to identify whether the explosion is nuclear, chemical or gaseous. When detonation of high explosive occurs, it resulted in high pressure that propagates to the surrounding area and produces a strong shock wave called blast wave. This blast wave increases rapidly from ambient pressure to peak incident pressure.

Here two explosives are considered TNT and C4. Trinitrotoluene is best known as an explosive material with convenient handling properties. The explosive yield of TNT is considered to be the standard measure of bombs and other explosives. TNT has a detonation velocity of 6,940 m/s. Density of TNT is 1.63 g/cm^3. C4 or Composition C4 is a common variety of the plastic explosive family known as Composition C. C4 is composed of explosives, plastic binder, plasticizer to make it malleable, and usually a marker or odorizing taggant chemical. C4 has a texture similar to modelling clay and can be moulded into any desired shape. C4 is stable and an explosion can only be initiated by a shock wave from a detonator. C4 is very stable and insensitive to most physical shocks. Detonation can only be initiated by a shockwave, such as when a detonator inserted into it is fired. It has a detonation velocity of 8040 m/s. Density of C4 explosive is 1.6 g/cm^3.

II. NEED FOR THE STUDY

It is important to provide a blast resistant structure to protect the structures and the lives of the occupants. Strategies to protect against the blast are divided into two major categories: strengthening of members and protection/mitigation strategies. The protection/mitigation strategies includes mainly increasing the standoff distance from the threat, because the blast pressure decays very rapidly and even a small distance is important. Furthermore, these mitigation measures are less expensive than the strengthening strategies. It can further be noted that the standoff distance can be increased only where sufficient space is available; however, in a city environment, many times it is not possible to adopt the strategies that require space. In such situations, the sacrificial blast wall provides a better solution and can be adopted or designed against an explosive induced threat. The blast wall effectively reduces the pressure from a reflected pulse to an incident pulse, permitting reduced safe standoff distances. Additionally, a properly designed perimeter blast walls will stop the effects of fragmentation. Therefore it is important to know the effectiveness of materials that can be used for the blast wall. In this study different materials are considered and their behaviour under blast loading is studied.

III. SCOPE AND OBJECTIVES

The scope of the present study is to compare the behaviour of a reinforced concrete wall and a brick masonry wall coated with CFRP under air blast loading with TNT and C4 using ANSYS. The blast analysis of the wall is carried out with the following objectives;

A. To conduct the finite element analysis of reinforced concrete wall for two different explosives.
B. To conduct the finite element analysis of CFRP covered brick masonry wall for two different explosive.
C. To conduct the finite element analysis of polyurethane coated brick masonry wall for two different explosive.
D. To determine the peak pressure developed in the wall and variation of peak pressure with respect to the material of wall and explosives.

IV. METHODOLOGY

In this study a reinforced concrete wall and brick masonry wall coated with CFRP is considered. The two walls are subjected to air blast loading with TNT and C4. The peak pressures developed in the two walls are then compared. The geometry and reinforcement detail of the wall considered is shown in Fig. 1.

A. Blast on Reinforced Concrete Wall

In this paper the numerical investigation is carried out for obtaining the response of a reinforced concrete wall against explosion. For this purpose initially a wall panel fixed with ground is subjected to equivalent blast pressure using ANSYS AUTODYN software. This is basically done to understand behaviour of reinforced concrete wall when subjected blast. The blast pressures on the face are determined and obtained in terms of pressure-time histories. In this study two explosives are considered TNT and C4. The net charge is taken 100 kg and a stand-off distance of 1m is considered. The wall considered in the study has a thickness of 300 mm at top and 400 at the base with a height 2200mm. The width of wall is 1000mm. The wall is reinforced with 12 mm and 10 mm diameter steel bars at spacing 175 mm center to center in the stem portion and with 12 mm bars at 250 mm center to center in the base portion. The wall had a cover of 25 mm and the compressive strength and shear modulus of concrete are 35 MPa and 16.7 GPa, respectively. The steel reinforcement had a yield strength of 415 MPa, whereas, the Young's modulus is 230 GPa. The 3D model of reinforced concrete wall after meshing is shown in Fig. 2. The next step is to place the gauge used to measure the pressure and damage at certain specific location. A total of four 3 gauges were located. Gauge 1 was placed at wall to define the pressure at bottom support of the wall. Gauge 2 defines the pressure at the wall which is same height as charge weight. Gauge 3 is used to define the pressure at the upper wall. The location of gauges in the reinforced concrete wall is shown in Fig. 3.

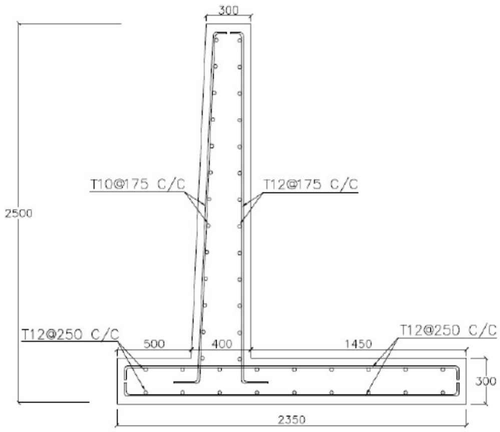

Fig.1 Geometry and details of RC blast wall

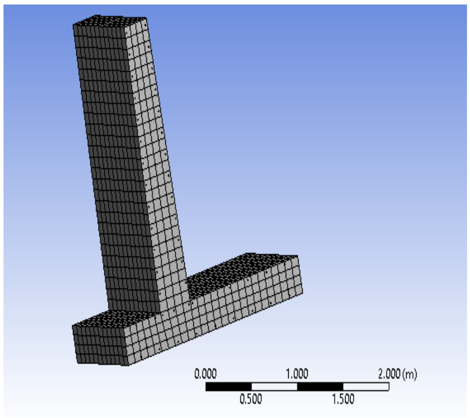

Fig.2 3D Model of wall after meshing

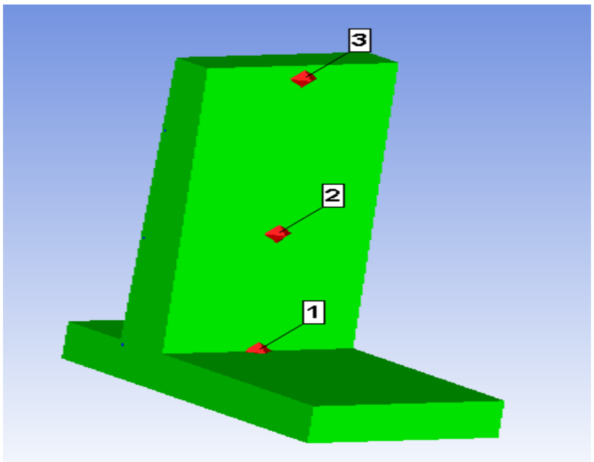

Fig. 3 Location of gauges on the wall

B. Blast on Brick Wall with CFRP and polyurethane

In this case, a brick wall with the same dimension as that of the reinforced concrete wall is modelled and covered with CFRP on both faces. The thickness of the coating is taken as 6mm. In the next case it is covered with polyurethane on both faces with a thickness of 6 mm. The net charge is taken 100 kg and a stand-off distance of 1m is considered.

For numerical simulation certain material parameters are used to represent the behaviour of structural elements. The material strength parameters are considered for practical brick masonry used in Indian context. The typical strength of bricks and mortar are provided in table 1.

For other materials like air and TNT and C4 default values are used from the material library of the AUTODYN software. For modelling brick wall standard size of brick was taken ie., 20x20x10 cm. The thickness of mortar was taken as 10 mm.

So as to provide the space needed for the blast wave to propagate and interact with the wall, air was modeled around the reinforced concrete wall. The modeled air should extend beyond a distance equal to the stand-off distance so as to simulate the blast process. 20 mm cell division is provided for zoning air model. The flow out boundary conditions are provided on all the faces of air medium except at the bottom face due to fixed support at the base/ground. Appropriate equation of state is adopted for simulating the volume change under high pressure. The incident blast pressure applied at the mid height of the wall. The start time of the 3D analysis was set equal to the end time of the 1D analysis which was found to be 0.2 ms for TNT charge and 0.17 ms for C4 and the output of the 1D analysis was transformed into the 3D domain. The output of the 1D domain was remapped to the mid height of the wall and at a stand-off distance of 1000 mm from the face of the wall.

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TABLE 1
Material Properties Of Masonry Bricks And Mortar

Material (homogeneous)	Strength (MPa)	Failure criteria	Erosion criteria
Bricks	Compressive=10.5 Tensile=0.84 Shear=1.89	RHT concrete D1=0.04, D2=1.0 Minimum strain to failure=0.01	Instantaneous Geometric strain 1.0
Mortar	Compressive = 5.17 Tensile = 0.52 Shear = 0.93	RHT concrete D1=0.04, D2=1.0 Minimum strain to failure=0.001	Instantaneous Geometric strain 1.0

V. RESULTS AND DISCUSSION

Blast on reinforced concrete wall and brick wall with CFRP and polyurethane coating is done using TNT and C4 at a standoff distance of 1m. The peak pressure and displacement developed in each case is obtained.

A. Blast on Reinforced Concrete Wall

Blast using TNT and is done on the reinforced concrete wall with charge weights 100 kg at a stand-off distance of 1m. The termination time for 1D wedge model is 0.2 ms for TNT and 0.17 ms for C4. These values are used for the further analysis in 3D domain.

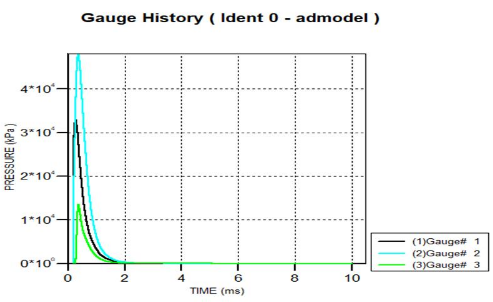

Fig. 4 Pressure time history for TNT explosive

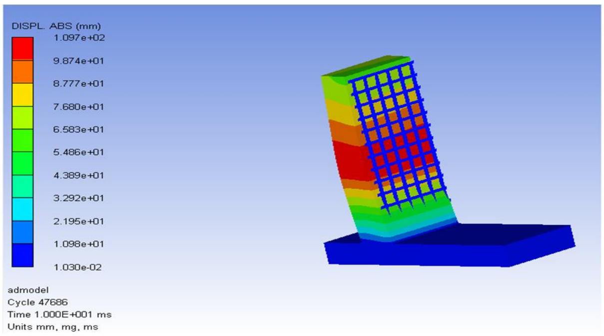

Fig. 5 Displacement contour for TNT at the end of 10 ms

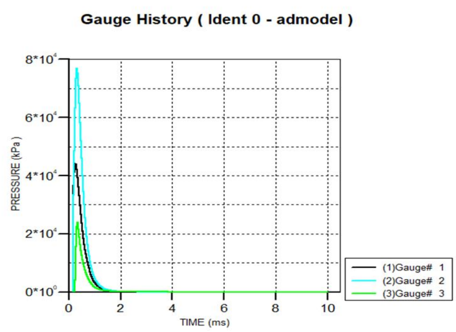

Fig. 6 Pressure time history for C4 explosive

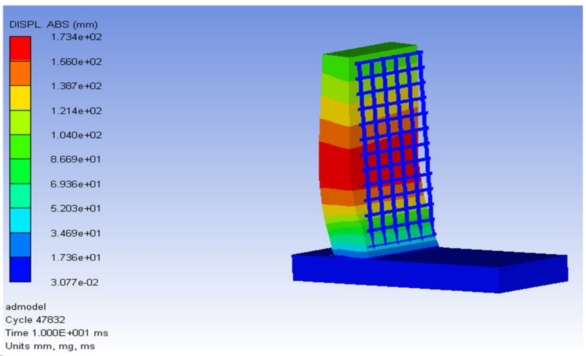

Fig. 7 Displacement contour for C4 at the end of 10 ms

Fig. 4 shows the pressure time history graph results from 100 kg TNT placed at a stand-off distance of 1m from the reinforced concrete wall. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of 4.8 $x10^4$ kPa. Fig. 5 shows the displacement contour of reinforced concrete wall for TNT explosive at the end of 10ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 109.7 mm.

Fig. 6 shows the pressure time history graph results from 100 kg C4 placed at a stand-off distance of 1m from the reinforced concrete wall. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of 7.6 x10^4kPa while the second peak pressure was at gauge 1 with 4.4 x 10^4kPa. Fig. 7 shows the displacement contour of reinforced concrete wall for C4 explosive at the end of 10ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 173.4 mm.

B. Blast on Brick Wall with CFRP and polyurethane

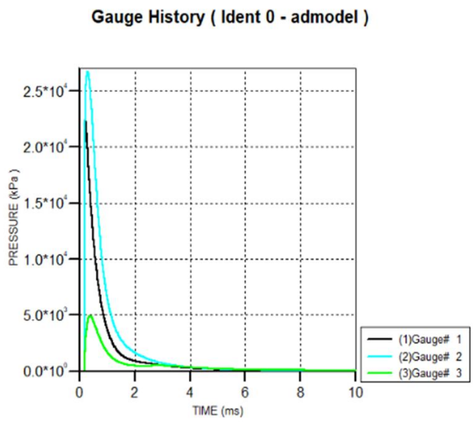

Fig. 8 Pressure time history for TNT explosive

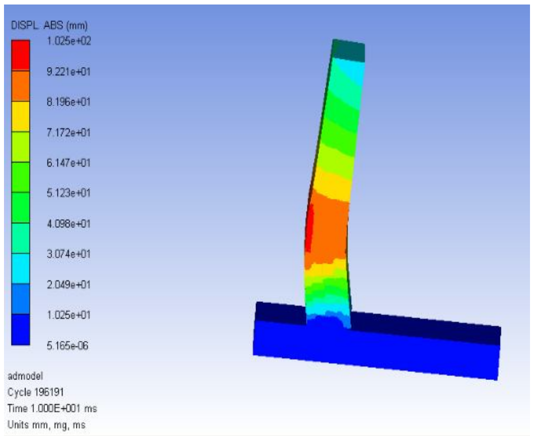

Fig. 9 Displacement contour for TNT at the end of 10 ms

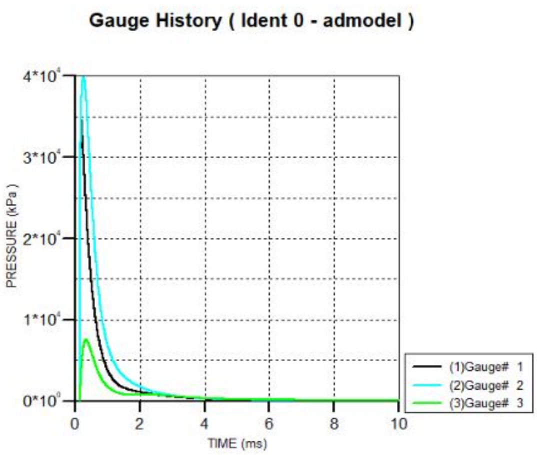

Fig. 10 Pressure time history for C4 explosive

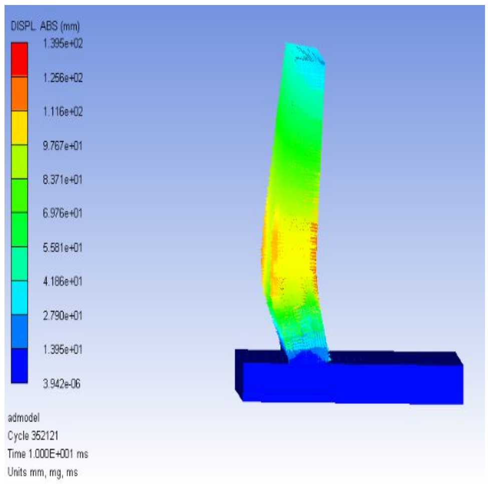

Fig. 11 Displacement contour for C4 at the end of 10 ms

Fig. 8 shows the pressure time history graph results from 100 kg TNT placed at a stand-off distance of 1m from brick wall covered with CFRP. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of 2.9 x10^4kPa while the second peak pressure was at gauge 1 with 2.3x 10^4kPa. Fig. 9 shows the displacement contour of brick wall covered with CFRP for TNT explosive at the end of 10 ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 102.5 mm at the end of 10ms.

Fig. 10 shows the pressure time history graph results from 100 kg C4 placed at a stand-off distance of 1m from brick wall covered with CFRP.

From the graph, the maximum peak pressures occurred at gauge 2 with pressure of 4x10^4 kPa while the second peak pressure was at gauge 1 with 3.5x10^4kPa. Fig. 11 shows the displacement contour of brick wall covered with CFRP for C4 explosive at the end of 10 ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 139.5 mm at the end of 10ms.

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C. Blast On Brick Wall With Polyurethane

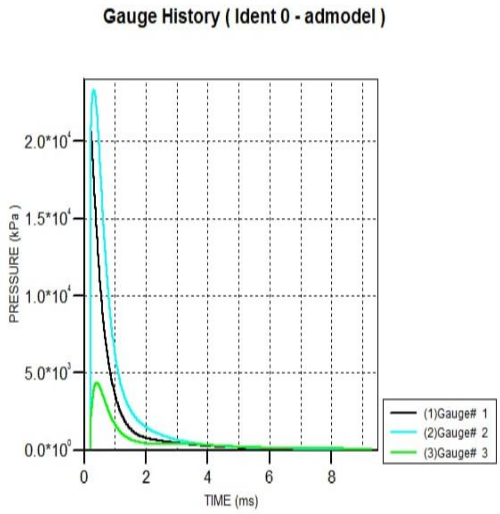

Fig. 12 Pressure time history for TNT explosive

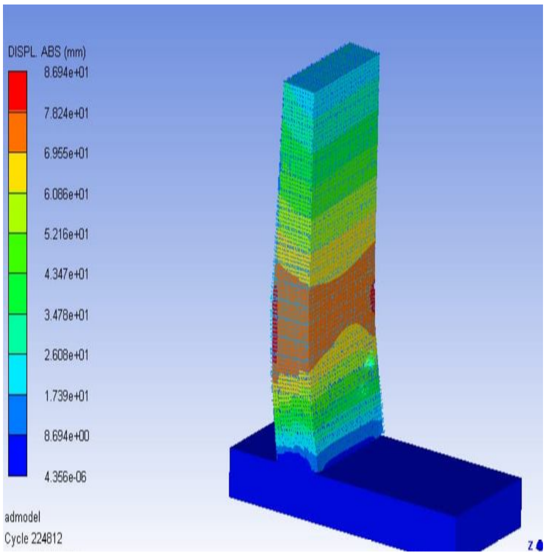

Fig. 13 Displacement contour for TNT at the end of 10 ms

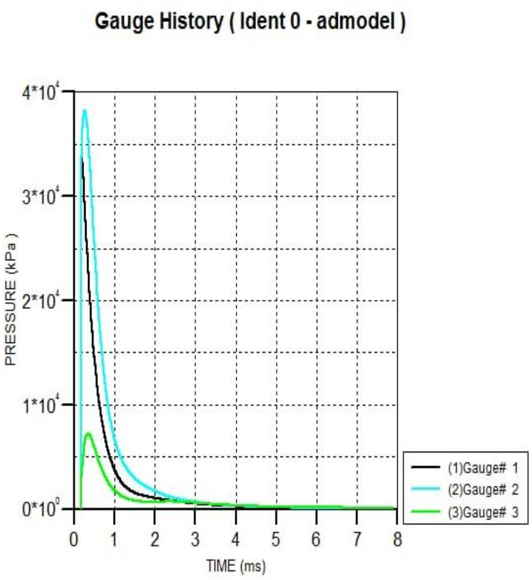

Fig. 14 Pressure time history for C4 explosive

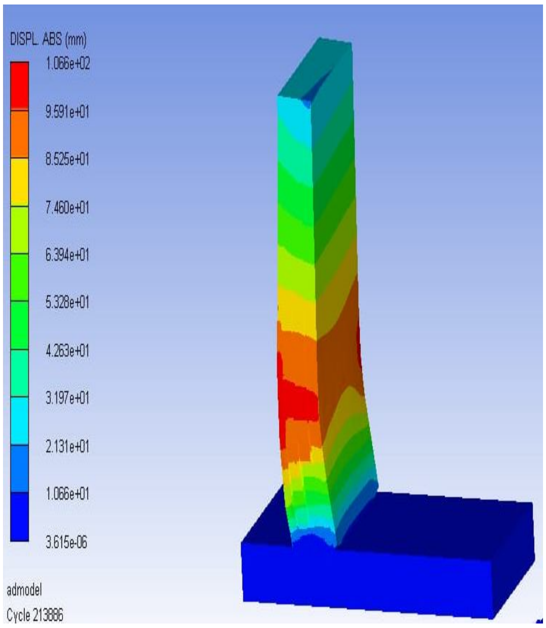

Fig. 15 Displacement contour for C4 at the end of 10 ms

Fig. 12 shows the pressure time history graph results from 100 kg TNT placed at a stand-off distance of 1m from brick wall covered with polyurethane. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of $2.4x10^4$kPa while the second peak pressure was at gauge 1 with $2.0x10^4$kPa. Fig. 13 shows the displacement contour of brick masonry wall coated with polyurethane for TNT explosive at the end of 10 ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 86.94 mm.

Fig. 14 shows the pressure time history graph results from 100 kg C4 placed at a stand-off distance of 1m from brick wall covered with polyurethane. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of $3.8x10^4$kPa while the second peak pressure was at gauge 1 with $3.4x10^4$kPa. Fig. 15 shows the displacement contour of brick masonry wall coated with polyurethane for C4 explosive at the end of 10 ms. The maximum displacement occurs at the mid height of the wall. The maximum displacement is found to be 106.6 mm.

The variation of peak pressure developed and displacement is shown in Fig. 16 and Fig. 17 respectively.

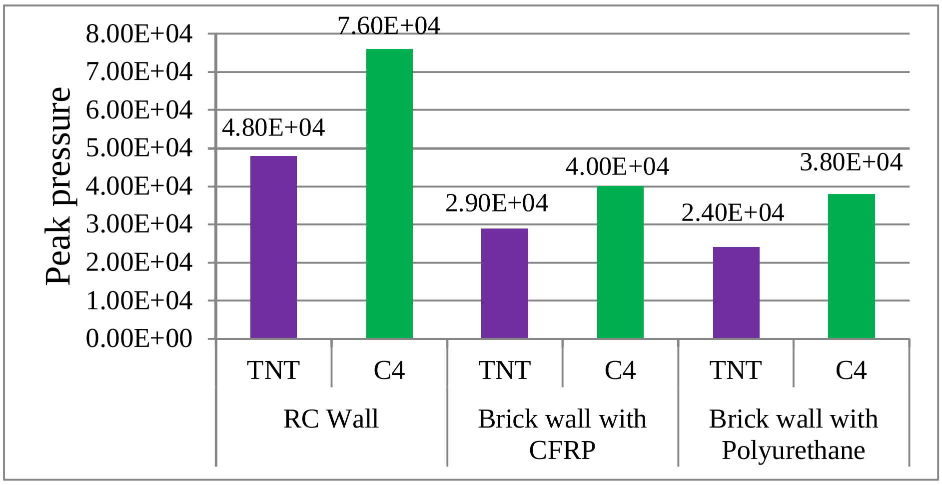

Fig. 14 Variation of pressure

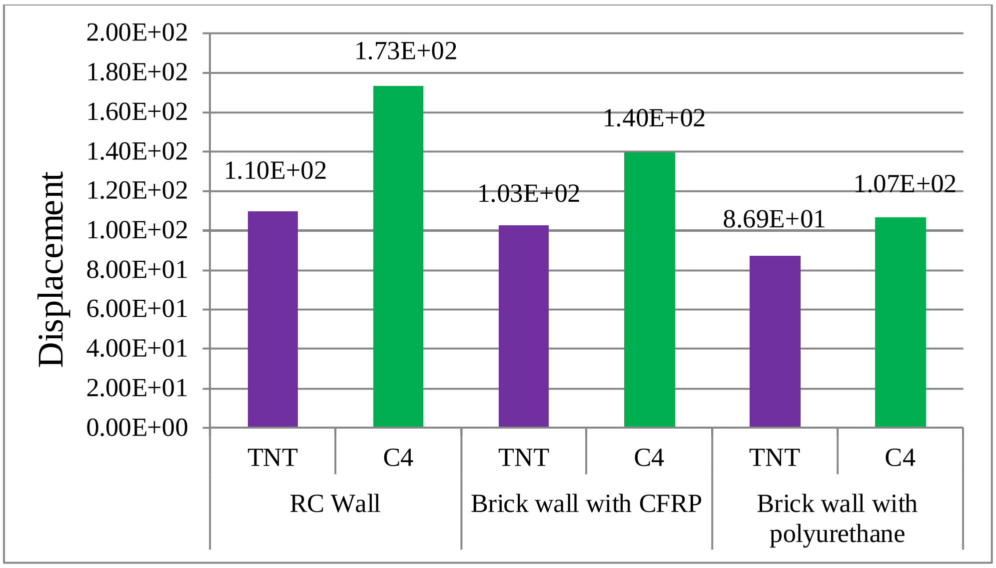

Fig. 14 Variation of displacement

VI. CONCLUSIONS

The finite element analysis of three types of walls under blast loading is conducted which includes an RC wall, brick masonry wall covered with CFRP and brick masonry wall coated with polyurethane. The walls were analysed under blast loading using TNT and C4. The parameters like peak pressure, displacement and damage contour is obtained. The following conclusions can be made:

A. While comparing the peak pressure developed in walls it is found that the brick wall with CFRP reduces the peak pressure by 39.58% when using TNT and 47.36% when using C4 compared to RC wall.

B. The brick wall coated with polyurethane could reduce the peak pressure developed by 50% when both TNT and C4 is used compared to RC wall.

C. It is found that brick wall coated with CFRP reduces displacement by 7% is obtained when using TNT and 19.55% when using C4.

D. The brick wall coated with polyurethane could reduce the displacement developed by 20.77% when using TNT and 38.52% when using C4 compared to RC wall.

E. Brick wall covered with polyurethane is found to be better material when compared with RC wall and brick wall with CFRP.

VII. ACKNOWLEDGEMENT

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