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SIMULATION OF REINFORCED CONCRETE BLAST WALL SUBJECTED TO AIR BLAST LOADING

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ABSTRACT

This research investigates the behavior of reinforced concrete blast wall subjected to air blast loading. In this study a reinforced concrete blast wall was designed to resist a blast load for the capacity of 5 kg of TNT at a distance of 2 meter. The thickness of the blast wall is 250mm and the height is 4500 mm. AUTODYN 3D hydrocode software was used to simulate the behavior of the reinforced concrete blast wall under air blast loading. A total of four different charge weight of TNT, which represents a minimum loading capacity of person or vehicle to carry an explosive was simulated at a stand-off distance of 2 meter from the blast wall. This explosive capacity representative bombs are hand carried bomb by personnel with a loading capacity of 5 kg, Motorcycle 50 kg, car 400kg and also van with the capacity of 1500 kg of TNT explosive. The simulation results show that the blast wall sustained the blast load up to 5kg and had minor damage on the wall when subjected to 50 kg of TNT charge weight, However, the blast wall failed when subjected to 400 kg and 1500kg of TNT charge weight at a stand-off distance of 2 meter. The results show that the simulation results using AUTODYN 3D simulation software is comparable with the design data.

Keywords: Reinforced concrete blast wall, Simulation, Air blast loading, TNT, AUTODYN 3D, Explosive.

1. INTRODUCTION

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. Typical reinforced concrete blast wall is shown in Figure 1.0.

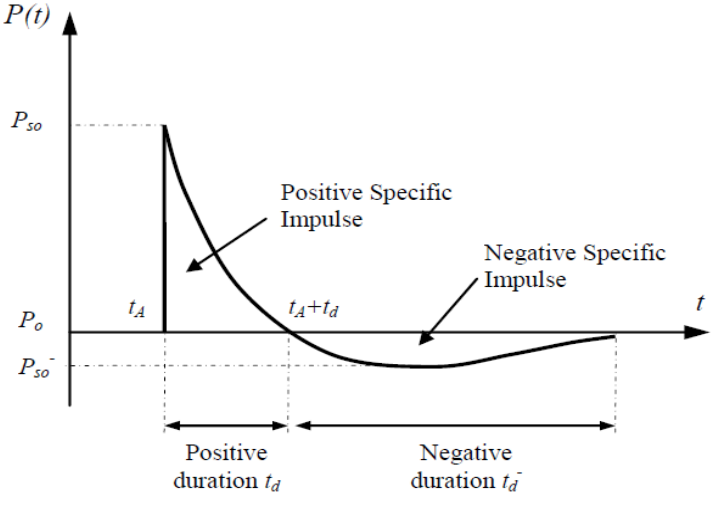
Fig-1. Typical reinforced concrete blast wall [1]

The Oklahoma City Bombing was an assault that involved the bombing on the Alfred P.Murrah Federal Building on April 19, 1995. The blast damaged 324 buildings within 16 blocks and shattered glasses in and around 258 nearby buildings, causing at least an estimated, loss of $652 million worth of damage [2]. Similar terrorist attack occurred in Bali bombing. Bali bombing happened on 12 October 2002 in the tourist region of Kuta on the Indonesian island of Bali. This terrorist attack led to improvements in engineering, especially in civil construction technology. This has allowed buildings to withstand greater forces, in which enhancements were incorporated into the design of new strong buildings. One method to prevent damage to the building is to build a security barrier called concrete blast wall to protect the building from any act of terrorist attack. The objectives of this research are to simulate the blast effect on the reinforced concrete blast wall was subjected to air blast loading using ANSYS AUTODYN software. In this study, a blast load was placed at the distance of 2 meter from the concrete wall, ranging from 5 kg to 1500 kg of TNT which is based on maximum representative bomb size of hand carry bomb and vehicle bomb [3].

2. BLAST PHENOMENA

When detonation of high explosive occurs, it resulted in high pressure that propagates to the surrounding area and produce a strong shock wave called blast wave. This blast wave increases rapidly from ambient pressure to peak incident pressure. The blast wave based on pressure versus time history, at the structure fixed point from the point of detonation, is idealised as shown in Figure 2.

Fig-2. Blast wave pressure – time history [4]

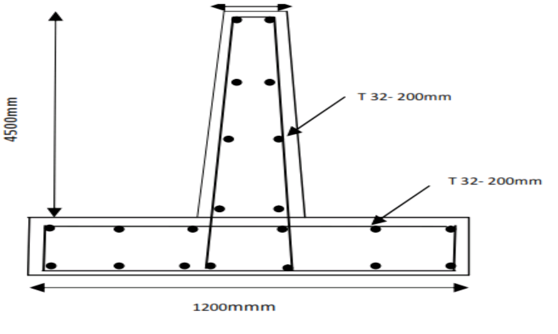


Detonation takes place at time t= 0. After time $t_{A,}$ the blast wave arrives at the point and pressure instantaneously increases from ambient pressure, P_o to peak overpressure, P_{so} caused by the detonation. At time t_A+ td, the pressure returns to ambient pressure, Po which is positive phase, is over and followed by negative phase, P_{so}^-

3. METHODOLOGY

The blast wall was designed based on TM5-1300: Structure to Resist the Accidental Explosion [5]. The blast wall was designed to resist the blast load for the capacity of 5 kg of TNT at a distance of 2 meter.The geometry and reinforcement of the blast wall is shown in Figure 3.

Fig-3. Geometry and detail of the reinforced concrete blast wall.



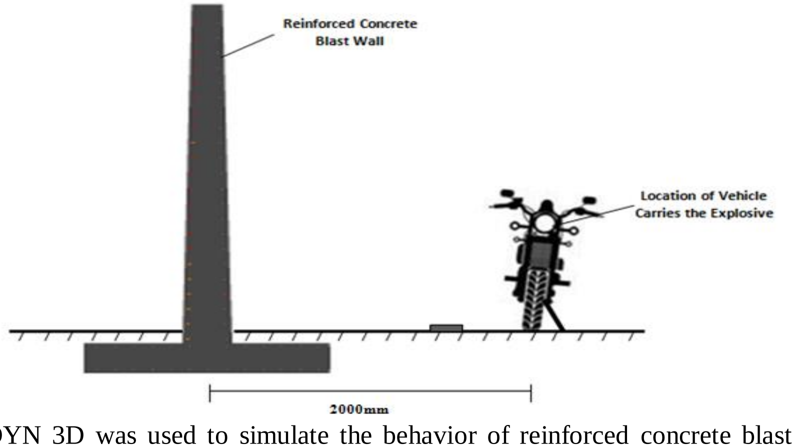
The thickness of the wall is 250 mm and the height is 4500 mm. A total of four different charge weight of TNT which represent a minimum loading capacity of a person or vehicle to carry an explosive was simulated at a *stand-off* distance of 2 meter from the blast wall. These explosive capacity representative bombs are hand carried bomb by a personnel with a loading capacity of 5 kg, Motorcycle - 50kg, Passenger Car - 400kg and also a van with the capacity of 1500 kg of TNT explosive. The explosive capacity of the bombs was calculated on the basis of the loading capacity of a vehicle and is shown in Table 1.0.

Table-1. Bomb size capacity

Bomb	**Explosive Capacity (Kg)**
Hand Carry Bomb	5
Motorcycle	50
Passenger Car	400
Van	1500

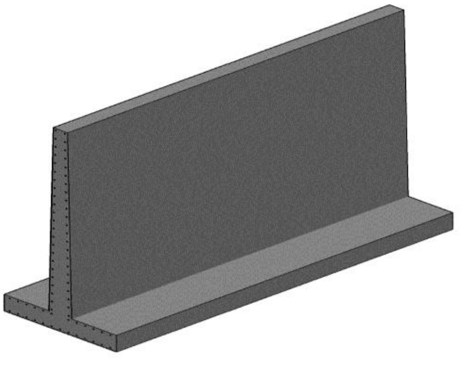
The illustrations for 2D model of blast wall and the vehicle for example a motorcycle, that carries the bomb are shown in Figure 4.

Fig-4. Illustration of the location of the motorcycle to the blast wall



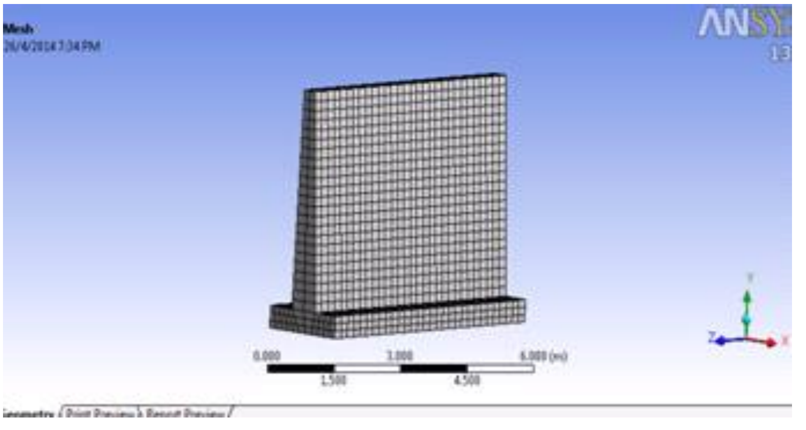
AUTODYN 3D was used to simulate the behavior of reinforced concrete blast wall that is subjected to air blast loading. Firstly, ANSYS Workbench used to create the reinforced concrete blast wall of 3D model. The 3D model of reinforced concrete wall is shown in Figure 5.

Fig-5. 3D model of Reinforced Concrete blast wall



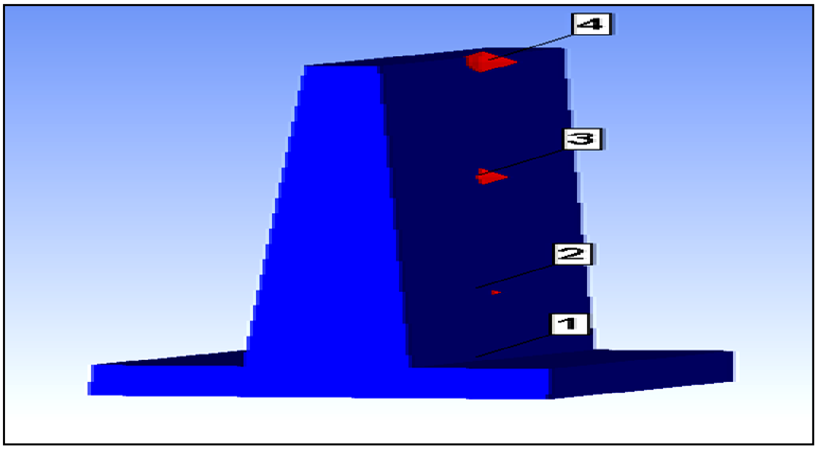
Reinforced concrete blast wall was modeled using Lagrange sub grid, while the air and the explosive were modeled using Euler sub grid solid element with an element length of 5 mm. A mesh size of 0.1mm was selected for the model. The element number is 80 x70 x 80, resulting the optimum element number of 488,000. This was obtained after several trial runs of the simulation works, until the results converged. The 3D model of reinforced concrete blast wall after the meshing is shown in Figure 6.

Fig-6. Meshing for the 3D blast wall model.



The next step is to place the gauge used to measure, the pressure, and damage at certain specific location. A total of four (4) gauges were located at an equal distance of 1500 mm from each wall of the reinforced concrete blast wall. Gauge 1 was placed at wall to define the pressure at bottom support of the wall. While, gauge 2 define the pressure at the wall which is same height as charge weight and gauge 3 was located at the centre between charge weight and upper wall. Last gauge, the gauge 4 to define the pressure at the upper wall. The increment of 2.5 milliseconds was set for the output to see the differences of pressure in 5 milliseconds of simulation. The location of gauges is shown in Figure 7.

Fig-7. Location of Gauges at the Blast Wall Panel



In order to develop a robust nonlinear finite element model of the reinforced concrete blast wall in computer simulation, it is important to select proper material constitutive formulation for structural components. Each component of the reinforced concrete structure is given an appropriate material constitutive model as shown in Table 2.

Table-2. Material model used in the simulation

Material	Equation of State	Strength Model	Reference Density ($g.cm^{-3}$)	Shear Modulus (kPa)
Concrete 35Mpa	P-alpha	RHT (Riedel-Hiermaier-Thoma)	2.75	$1.67x10^7$
Steel	Linear	Johnson Cook	7.90	$8.00x10^7$
TNT	JWL	None	1.63	None
Air	Ideal Gas	None	$1.225x10^{-3}$	None

The concrete was modeled with RHT material model. This material model was developed by Riedel [6]. This is the standard material model for concrete in the material library of AUTODYN that describes the behavior of concrete. The equation for this model is as in Eqn. 1.

$$Y_{fail} = f_c\left(A\left(\frac{p}{f_c} - \frac{p_{HTL}}{f_c}.F_{Rate}\right)^{N}\right) R_3\,(\Theta) F_{Rate}(\varepsilon) \qquad (1)$$

Where;

f_c = Compressive Strength

P_{HTL} = Tensile Strength

A and N = Constant value

P = Hydrostatic Pressure

F_{Rate} = Strain Rate Factor

$R_3(\Theta)$ = Internal Resistance Force for the concrete

Johnson Cook material model was used to describe the behavior of the steel reinforcement inside the concrete [7]. This material model is usually used for steel reinforcement, that describes the behavior of steel reinforcement, subjected to explosion. The yield strength is 460 MPa based on the high strength steel bar materials strength properties obtained from BS 8110 [8]. The following in Eqn. 2 defines the yield stress of steel reinforcement.

$$\sigma_y = (A + B\varepsilon^n)\left(1 + C\ln\frac{\varepsilon^{p}_{eq}}{\varepsilon_0}\right)\left(1 - \left(\frac{T-T_r}{T_m-T_r}\right)^{m}\right) \qquad (2)$$

Where;

A = constant value, basic yield stress of the steel at low strain

B = constant value, represent effect of hardening

T_r = reference temperature

T_m = melting temperature of the materials

Air was modeled as an ideal gas. Air was modeled using Equation of State of known as EOS which is the equation for this model as used in Eqn. 3. The air density used is ρ=1.225 kg/m3 and air initial internal energy used is 2.068 x 105kJ/kg which is obtained from AUTODYN material library.

$$P = (\gamma - 1)\, \rho\, e \qquad (3)$$

Where;

γ = Constant value

p = Air Density

e = Specific internal energy

Jones–Wilkens–Lee (JWL) equation of state was used to model the rapid expansion of high explosive detonation of TNT which is obtained from AUTODYN material library. The equation for this model is written in the Eqn. 4.

$$P = A\left(1 - \frac{\omega}{R_1 V}\right) e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right) e^{-R_2 V} + \frac{\omega E}{V} \qquad (4)$$

Where;

E = Internal specific energy

V = Volume of the material at pressure divided by the initial volume of unreact explosive.

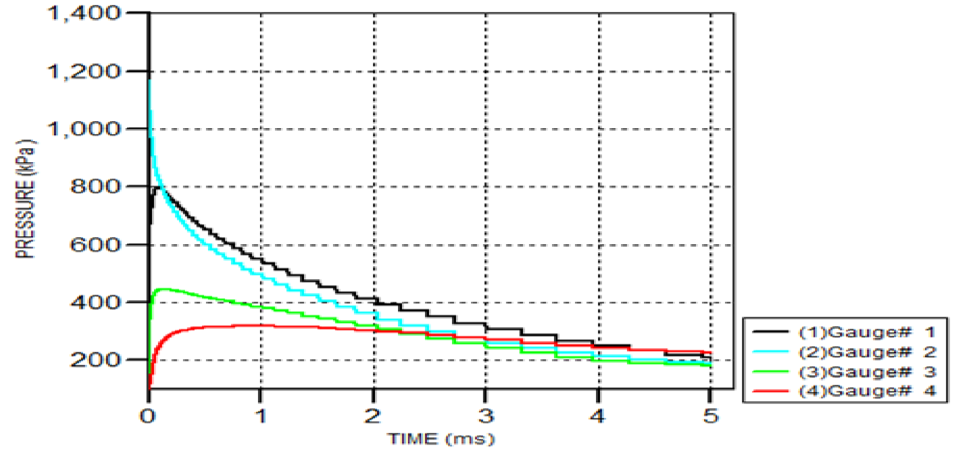
A, B, ω, R1 and R2 = Empirically derived constants.

4. RESULTS AND DISCUSSION

4.1. Hand Carry Bomb

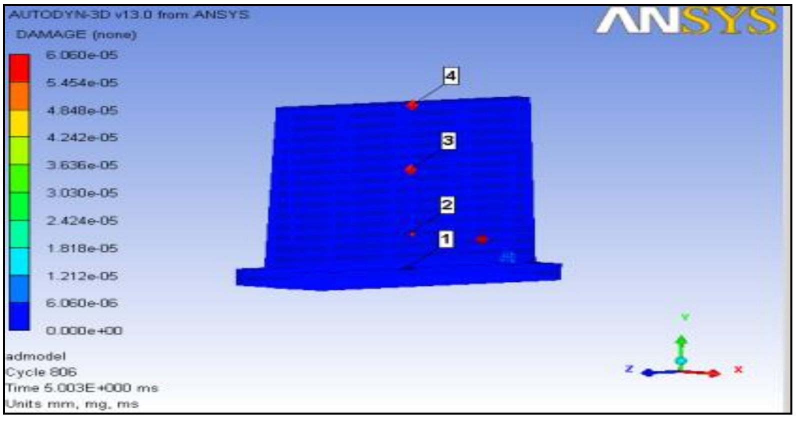
Figure 8 shows the pressure time history graph for the explosion of 5 kg of hand carry bomb at a *stand-off* distance of 2 meter which was recorded until 5 milliseconds of blast detonation. From the graph, it was found that highest pressure resulted from the detonation occurred at gauge no 2 with the peak pressure of 1.17 x 10^3 kPa, while the second peak pressure is at gauge 1 with 7.9 4x10^2 kPa. Both pressures occurred at the same time which was at zero millisecond. The presence of pressure at gauge 3 begun at 0.01 milliseconds with pressure of 4.4340x10^2kPa.

Fig-8. Pressure time history for 5kg of explosive at 2 meter *stand- off* distance from the wall for Hand Carry Bomb



The simulation results for the damage on the blast wall are shown in Figure 9. It was observed that there is no sign of damage to the reinforced concrete wall. This is because of the reinforced concrete wall was designed to sustain the required blast load up to 2.0 x 10^3 kPa Therefore, the concrete wall was able to absorb the energy from the detonation. Thus, this simulation results have validated the design of reinforced concrete wall.

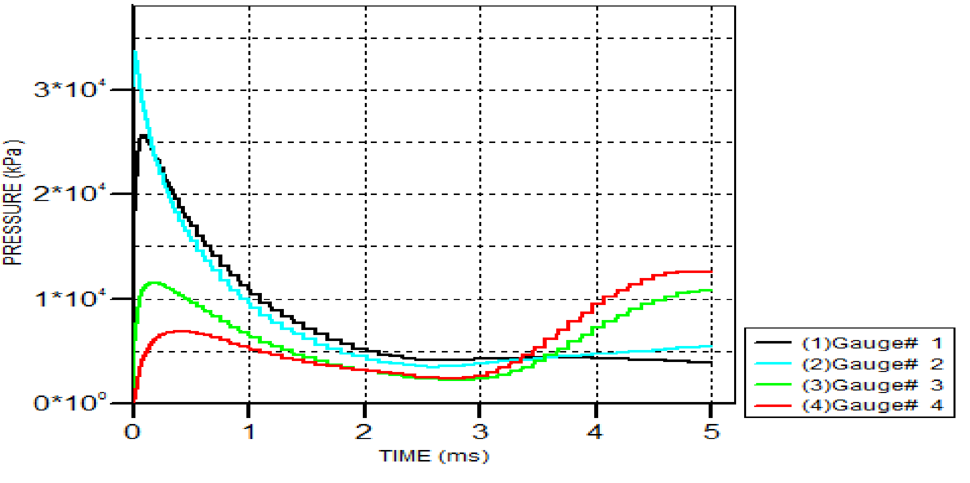
Fig-9. Damaged results for hand carry bomb attack on the blast wall



4.2. Motorcycle Bomb Attack

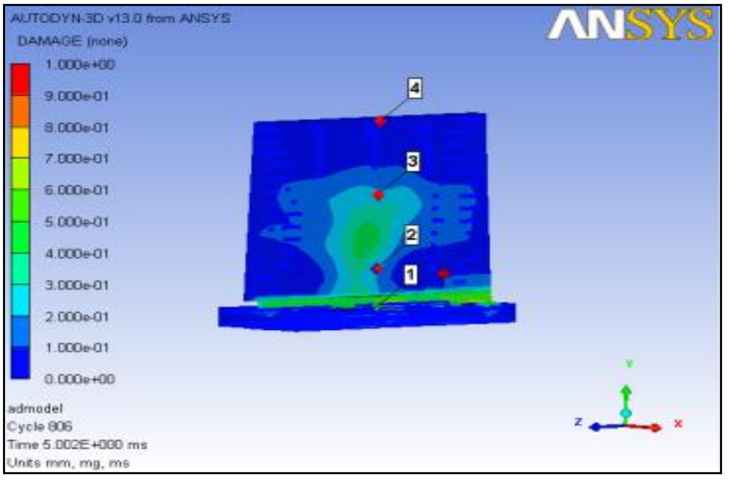
Figure 10 shows the pressure time history graph results from 50kg of TNT placed on a motorcycle with *stand-off* distance of 2m from the blast wall. The results showed that detonation took place at zero millisecond, after certain time, the blast wave arrived at the point and pressure instantaneously increased from ambient pressure to peak pressure caused by the detonation. From the graph, the maximum peak pressures occurred at gauge 2 with pressure of 3.38 x10^4kPa while the second peak pressure was at gauge with 2.56 x 10^4kPa which happened at 0.06ms and 0.08ms respectively.

Fig-10. Pressure time history for 50 kg of explosive at 2 meter stand of distance from the wall for Hand Carry Bomb attack.



The simulation results for the damage on the blast wall are shown in Figure 11. From the simulation it was found that the blast pressure have caused only minor damage at the centre and also at the bottom support of the wall, however, the wall was still intact and no sign of collapse for the wall.

Fig-11. Damaged results for motorcycle bomb attack on the wall.



4.3. Car Bomb Attack

Figure 12 shows the results of peak pressure results from a detonation of a car which had the maximum capacity charge weight of 400kg of TNT detonated at a *stand-off* distance of 2 meter, from the blast wall. The results show that the detonation took place at zero millisecond, and the pressure instantaneously increased from ambient pressure to peak pressure caused by the detonation. From the graph, the peak pressures occurred at gauge 2 with pressure of 8.9 $x10^4$kPa while the second peak pressure was at gauge 1 with $5.6x10^4$kPa at 0.025 milliseconds and 0.13 milliseconds respectively.

Fig-11. Blast wave pressure time history for 400kg of explosive at 2 meter *stand-off* distance from the wall for car bomb attack.

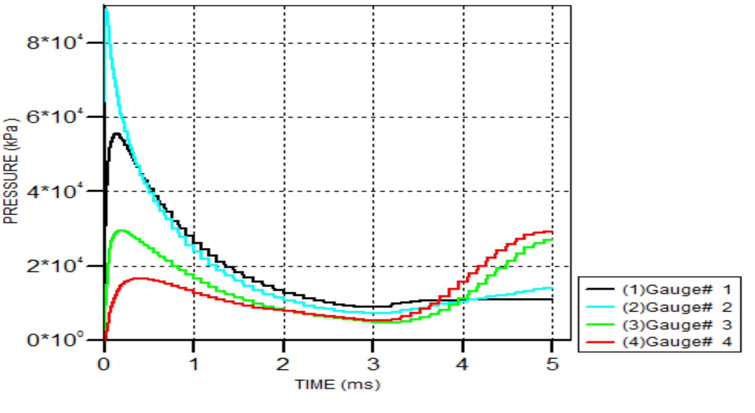
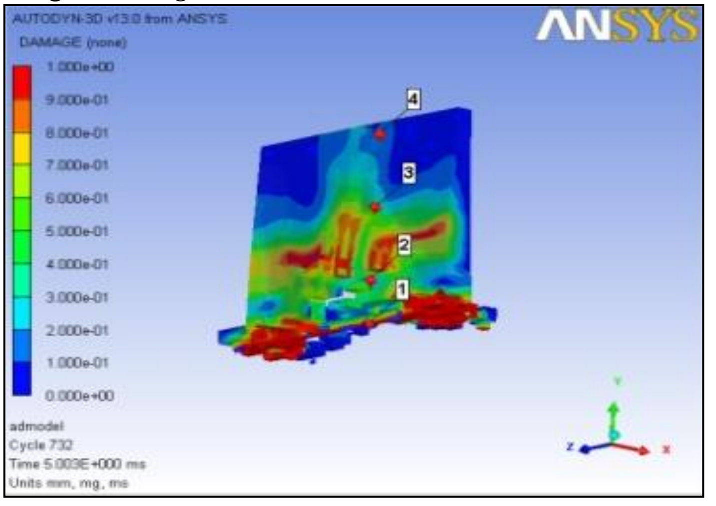


Figure 12 shows the damage at the centre and also at the bottom support of the wall, and part of the wall failed due to high pressure resulting from the detonation. Since the blast wall had serious damage, the buildings that were protected by the wall may be affected by serious damage from the blast wall. In addition, the debris produced by the damaged blast wall may cause injury to the people in the surrounding area.

Fig-12. Damage results for car bomb attack on the blast wall.



4.4 Van Bomb Attack

Figure 13 shows the results of the peak pressure result from a detonation by a bomb placed in a van with maximum charge weight of 1500kg planted on a van with a *stand-off* distance of 2m from the blast wall. It was noticed that the blast wall damaged immediately, due to high pressure. From the graph, the peak pressures occurred at gauge 2 with pressure of $3.24x10^5$kPa which immediately started at 0.0 milliseconds, while the second peak pressure at gauge 1 with 1.53 $x10^5$kPa at time of 0.28 milliseconds.

Figure-13. Blast wave pressure time history for 1500 kg of explosive at 2 meter *stand-off* distance from the wall for Van Bomb attack.

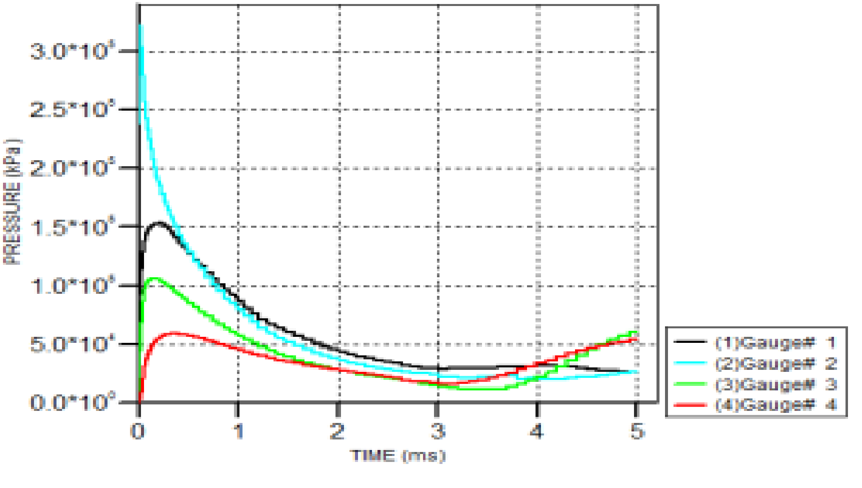
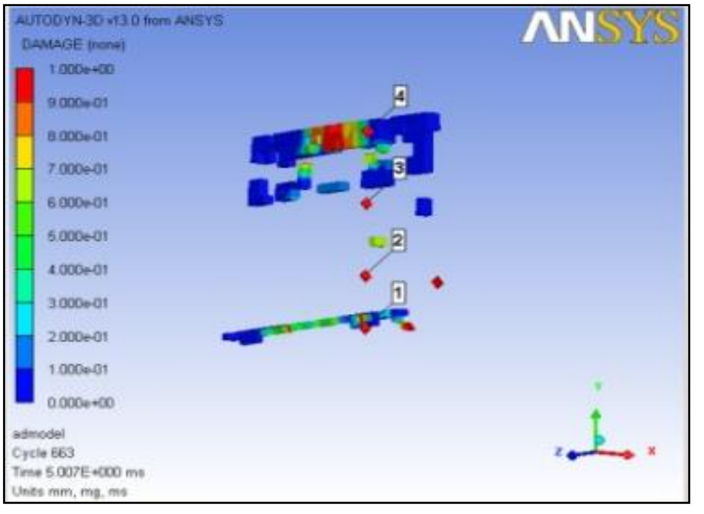


Figure 14 shows that the blast wall was heavily damaged due to the blast attack on the wall. The wall scattered into debris which can harm and cause injuries to the people at the surrounding area. Besides that, the blast effect can cause deaths, and also damage to the structure of the building.

Fig-14. Damaged results for van bomb attack on the blast wall



5. CONCLUSIONS

From the results obtained, it can be concluded that 50 kg and below of the TNT bomb cannot blow down the blast wall, thus the building protected by blast wall are safe from the blast effect. However, for 400kg of TNT and above, the blast wall will be damaged or completely blown off , thus the building protected by blast wall may experience minor or major damages. Blast wall is constructed not to protect the building structure perfectly from any damage due to explosion, but to prevent heavy damages, minimizing injuries and loss of life. If the detonation occurred because of the explosive carried by trucks or trailers, the buildings at close proximity will also be affected by the blast effect. In addition to this, it was observed, that ANYSY AUTODYN can help experts to simulate the effect to the structure or body for such an impact or blast. It is also used to properly evaluate threats, in future conflicts for reasonable cost, without having any experimental test, since it's very dangerous and expensive.

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