Simulation of Annealed Glass Panels Subjected to Air Blast Loading

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Abstract – This paper reports the simulation results for annealed glass subjected to air blast loading. In this research, 8 mm and 12 mm thick annealed glass was subjected to blast with a charge weight of 2 kg and 5 kg of TNT at a standoff distance of 3.0 meter. AUTODYN 3D hydrocode simulation software was used to simulate the behaviour of annealed glass subjected to air blast loading. The simulation result shows that the 8 mm thick annealed glass be able to withstand the blast loading up to 2 kg of TNT explosive only and it’s damaged when subjected to 5 kg of TNT explosive. While the 12 mm thick annealed glass be able to withstand both 2 kg and also 5 kg of TNT explosive.

Keywords – Annealed glass, Air blast loading, AUTODYN simulation, Damage of glass panel.

I. INTRODUCTION

An original glass is called flat glass or also known as annealed glass. It is the origin of all glasses Annealed is derived from the glass manufacturing process. Normally annealed glass used as window in most of the buildings façade.[1] The example of annealed glass is shown in Figure 1.

![Figure 1: Typical annealed glass.][1]

Bombing attack on building has been a very common terrorist tactic since year 1960s. In most of the bombing attacks, the annealed glass which is brittle and offer little resistance to blast wave will break into very sharps fragments and causes injuries to the public.

Historically the majority of injuries from the bomb blast have been from flying glass fragments. This can be seen from the attack on the car bomb attack which happened along the road of the St. Mary Axe, London, which estimated contain 350 kg of trinitrotoluene (TNT) was blown up at St. Mary Axe on April 11, 1992.

This bomb attack has damaged a Bank of European of Reconstruction and Development. This office building was ten storeys in height, which located at an estimated range of 115 m to 160 m away from the car bomb. This bomb caused extensive glass damage, but not many personnel were injured because the explosion occurred at the midnight and there were only a few personnel left. The glass window made of annealed glass panel for first and upper floor of the building were totally blown out, although the glass panel was located at a higher level [2]. Therefore, there is a need to investigate the behaviour of annealed glass subjected to air blast loading. The objective of this study is to simulate the blast effect on different thickness of annealed glass subjected to air blast loading using ANSYS AUTODYN software.

II. AIR BLAST LOADING

The air blast shock wave is the principal damage factor during the blast. The pressures it generates on the structural member may be greater than the loads for which the building is planned. The blast wave front also exert pressure in scenarios that the building may not have been designed for, such as in upward direction on the floor system. As regards order of response, the air blast first strikes the weakest point in the surrounding area of the device closest to the detonation on the exterior surface of the structure. The shock wave thrusts the exterior walls at the lower stories and may result wall failure and window breakage. While the shock wave keeps on progressing, it pierces the structure, pushing both upward and downward on the floors as shown in Figure 2.[3]
When detonation of high explosive occurs, it resulted 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 structure fixed point from the point of detonation, is idealized as shown in Figure 3.[4]

III. METHODOLOGY

The dimension of the glass model used in this project is 1000mm x 800mm. This dimension is based on standard sizing of the glass panel used for testing explosion. According to ISO 16933, Glass in Building Explosion Resistant Security Glazing Test and Classification for Arena Air Blast Loading. [5]. In this research, 8mm thick and 12mm thick annealed glass panel was subjected to blast with a charge weight of 2kg and 5kg of TNT at a standoff distance 3.0 meter for each sample. The model set up for the glass and the explosive were as shown in Table I and II.

The thickness of the glass model chosen was based on the availability in the market and its popularity. The thickness of the annealed glass chosen was based on the production from glass manufacture in Malaysia. The standoff distance used in this research was 3m. It is because the distance from the vehicle parked at the road side to the building might have a distance of only 3m. Assuming there is a walkway outside the building which is 1.5m and the road side of 1.5m. Therefore in this case, the shortest distance from the vehicle to the building consist of glass panel is around 3m. This distance is also known as standoff distance. The layout of the building and the vehicle was as shown in Figure 4.
Air was modeled as an ideal gas. Air was modeled using Equation of State known as EOS which the equation for this model were as in Equation 2. The air density used is \( \rho = 1.225 \text{ kg/m}^3 \) and air initial internal energy used is \( 2.068 \times 10^5 \text{kJ/kg} \), which is obtained from AUTODYN material library.

\[
P = (\gamma - 1) \rho e \tag{2}
\]

Where:
- \( \gamma \) = Constant value
- \( \rho \) = 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 obtained from AUTODYN material library. The equation for this model is written in the Eqn. 3.

\[
P = A \left(1 - \frac{\omega}{R_1 V}\right) e^{-\frac{R_1 V}{\omega}} + B \left(1 - \frac{\omega}{R_2 V}\right) e^{-\frac{R_2 V}{\omega}} + \omega E \tag{3}
\]

Where:
- \( E \) = Internal specific energy
- \( V \) = Volume of the material at pressure divided by the initial volume of unreact explosive.
- \( A, B, \omega, R_1 \) and \( R_2 \) = Empirically derived constants.
The simulation results for the damage on the annealed glass panel are shown in Figure 6. It was observed that there is no sign of damage to the annealed glass panel. This is because the pressure exerted on the glass panel is not high enough to damage and break the glass panel.

**B. 8mm thick annealed glass with 5 kg of TNT**

Figure 7 shows the pressure time history graph for the 8 mm thick of annealed glass model subjected to 5 kg of TNT at a stand of distance of 3 meter. From the graph, the range of the pressures in between 81.07 kPa to \(-3.374 \times 10^3\) kPa and the highest peak pressure is 391.3 kPa occur at 0.5 ms.

The simulation results for the damage on the annealed glass panel are shown in Figure 8. It was observed that there is no sign of damage to the annealed glass panel. This is because of the pressure exerted on the glass panel is not high enough for damaged and break the glass panel.

**C. 12mm thick annealed glass with 2 kg of TNT**

Figure 9 shows the pressure time history graph for the 12 mm thick of annealed glass model subjected to 2 kg of TNT at a stand of distance of 3 meter. From the graph, the highest pressure of the simulation of 12 mm thick glass model with 2 kg TNT was 240 kPa at 0.7 ms.

The simulation results for the damage on the annealed glass panel are shown in Figure 10. It was observed that there is no sign of damage to the annealed glass panel. This is because of the pressure exerted on the glass panel is not high enough for damaged and break the glass panel.
D. 12mm thick annealed glass with 5 kg of TNT

Figure 11 shows the pressure time history graph for the 12mm thick of annealed glass model subjected to 5 kg of TNT at stand of distance of 3 meter. The range of the pressure when the highest pressure occurred at 0.4 ms was $1.37 \times 10^2$ kPa to $-3.32 \times 10^3$ kPa. The highest pressure of the simulation of 12 mm thick glass model with 5 kg TNT was 399 kPa at 0.6 ms.

Figure 11: Pressure time history for 12 mm thick annealed glass panel subjected to 5kg of TNT

The simulation results for the damage on the annealed glass panel are shown in Figure 12. It was observed that there is no sign of damage to the annealed glass panel. This is because of the pressure exerted on the glass panel is not high enough for damaged and break the glass panel.

Figure 12: Damaged results for 8mm thick of glass panel subjected to 5 kg of TNT

V. CONCLUSION

From the results obtained, it can be conclude that the 8 mm thick annealed glass is capable to withstand the blast load up to 2 kg only and it’s damaged when subjected to 5 kg of TNT explosive. While the 12 mm thick annealed glass be able to withstand both 2 kg and also 5 kg of TNT explosive. In addition to this, it was observed, that the AUTODYN simulation software can help the researchers to simulate the blast loading effect on the glass panel.

REFERENCES