NUMERICAL ANALYSIS OF BLAST PRESSURE PARAMETERS FOR THE PLANT AND WALL AS BARRIER

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ABSTRAK

Tumbuhan ditanam secara meluas di banyak kawasan bertujuan untuk menghalang hakisan tanah apabila berlakunya hujan lebat dan ribut. Pada masa kini, penanaman pokok lebih cenderung untuk ditanam untuk tujuan estetik di mana tumbuhan dipotong kepada bentuk untuk mencantikkan tempat. Terdapat kajian yang menyiasat tumbuhan sebagai penghalang apabila dikenakan beban ledakan. Walau bagaimanapun, hanya terdapat beberapa jenis penyelidikan mengenai tumbuhan yang diterbitkan secara akademik mengenai tumbuhan sebagai penghalang. Oleh itu, bacaan akademik secara umum mengenai tumbuhan sebagai penghalang pada dasarnya adalah terhad. Percubaan yang diterbitkan dan boleh diakses untuk rujukan kajian ini ialah kerja menumpukan pada objek yang berbeza yang bereksperimen untuk keupayaannya untuk menyerap atau mengurangkan tekanan letupan. Ia bertujuan untuk mengkaji parameter tekanan letupan sebanyak 30 lbs. (13.61 kg) Trinitrotoluene (TNT). Oleh itu, siasatan lanjut dijalankan untuk dinding RC dan tumbuhan tertakluk kepada beban letupan terutama pada pergantungan mesh tepat terhadap AUTODYN. Experiment ini bertujuan untuk mengkaji parameter tekanan letupan sebanyak 30 lbs. (13.61 kg) Trinitrotoluene (TNT). Analisis elemen terhingga AUTODYN yang tidak linear (FE) adalah perisian komersil yang digunakan untuk membangunkan angka yang disahkan mengikut data tekanan letupan yang direkodkan dari percubaan sebelumnya. Simulasi berangka untuk analisis tekanan letupan dijalankan pada empat kes halangan objek yang berbeza. Kajian numerik kini melibatkan kes-kes di ruang terbuka tanpa sebarang benda yang bertindak sebagai penghalang, RC yang bertindak sebagai penghalang, tumbuhan jenis umum yang bertindak sebagai penghalang dan kedua-dua pokok serta dinding RC bertindak sebagai penghalang. Keempat-empat kes ini dimodelkan dalam ANSYS-workbench dan disimulasikan dalam AUTODYN. Keputusan berangka yang diperolehi diikuti oleh keputusan yang disahkan yang dilaporkan oleh penyelidikan terdahulu untuk pengesahan. Kajian ini membuktikan kes numerik dengan satu-satunya tumbuhan sebagai penghalang menunjukkan pengurangan tekanan ledakan tertinggi sebanyak 9.8% dan 6.7% berbanding dengan kes dengan dinding RC dan kedua-dua tembok dan loji RC. Ini mungkin disebabkan oleh tumbuhan yang menyerap tekanan letupan menyebabkan tekanan letupan berkurangan kepada 290 kPa manakala Case 2 dan Case 4 dikurangkan kepada hanya 490 kPa dan 310 kPa. Keputusan terhadap dinding RC diperolehi menunjukkan pengurangan tekanan terendah apabila tekanan menghasilakn permukaan dinding apabila gelombang itu melanda. Refleksi gelombang letupan telah menyebabkan tekanan ledakan meningkat. Siasatan lanjut disyorkan terutamanya pada ketepatan meshing untuk kedua-dua dinding RC dan tumbuhan sebagai penghalang apabila dikenakan beban ledakan.

ABSTRACT

Plant is widely planted in many areas mainly to prevent soil erosion and as shading purpose from storm and heavy rain. Nowadays, planting plant is more likely to plant for aesthetical purpose in which the plant is cut to shapes to beautify a place. Previously, there was a research carried out that investigated plant as barrier when subjected to blast load. However, there are only few researches on plant academically published regarding plant as barrier. Thus, the academic reading on plant as barrier is basically limited. The published experiment and accessible for reference of this present study is the work focusses on different objects that is experimented for its ability to absorb or reduce blast pressure. It aims to study the blast pressure parameters of 30 lbs. (13.61 kg) Trinitrotoluene (TNT). Thus, further investigation is required for both RC wall and plant subjected to blast load especially on the appropriate and accurate meshing dependency in AUTODYN. Present work aims to study the blast pressure parameter of 30 lbs. (13.61 kg) Trinitrotoluene (TNT). The AUTODYN non-linear finite element (FE) analysis is commercial software used to develop a validated numerical according to the recorded blast pressure data from previous experiment. Numerical simulation for blast pressure analysis is conducted on four cases of different object barrier. The present numerical study involved cases at open space without any objects acting as barrier, only RC wall acting as barrier, only plant of general type acting as barrier and both plant and RC wall acting as barrier. These four cases are modeled in ANSYS-workbench and simulated in AUTODYN. The numerical results obtained are followed by a validated results reported by previous researches for validation. The present study established that, numerical case with only plant as barrier showed the highest blast pressure reduction by 9.8% and 6.7% compared to cases with RC wall and both RC wall and plant respectively. This might due to the plant that absorbs the blast pressure causing the blast pressure to be significantly reduced to 290 kPa whilst Case 2 and Case 4 reduced to only 490 kPa and 310 kPa respectively. Cases with RC wall present showed the lowest pressure reduction as the pressure reflects the wall surface when the wave hits. The reflection of the blast wave had caused the blast pressure to be magnified. Further investigation is recommended especially on meshing precision for both RC wall and plant as barrier when subjected to blast load.

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LIST OF SYMBOLS

$Yc\ (p^*)$	Compressive meridian
$F_{elastic}$	Ratio of the elastic strength to failure surface strength
$F_{cap\ (p)}$	Function that limits the elastic deviatoric stresses
B	The residual failure surface constant
M	Residual failure surface exponent
$D1$ and $D2$	Material constants for effective strain to fracture
$G_{fracture}$	Shear modulus
$G_{elastic}$	Shear modulus
$G_{residual}$	Shear modulus
E_p	Effective plastic strain
T_{room}	Room temperature
T_{melt}	Melting temperature
γ	Ratio of specific heat
ρ	Air density
E_i	Specific internal energy
P	etonation point pressure
D	Damaged scalar

LIST OF ABBREVIATIONS

ALE	Arbitrary Lagrangian Eulerian
FE	Finite Element
Ft.	Feet
JWL	Jones-Wilkins-Lee
JC	Johnson and Cook
Kg	Kilogram
lbs.	Pound weight
m	Meter
mm	Milimeter
msec	Milisecond
MPa	Mega pascal
Psi	Pound per Square Inch
RC	Reinforced Concrete
TNT	Trinitrotoluene

CHAPTER 1

INTRODUCTION

1.1 Research Background

Today's terrorist activities and threats have become massive and on-going problems all over the world. Countries especially in the middle-east are continuously being bombed. These countries that are continuously threated by wars have gone through a huge losses and damages in terms of property and also the people (Remennikov et al, 2005). However, an explosion or a blast load is not only related to bomb. It can also be battery explosion, gas leakage and industrial plants related. Blast load is an overpressure explosive material that results in a large dynamic load that will then cause injuries to the people and catastrophic damages to the buildings both internally and externally. The results may cause the collapsing of buildings, blowing out of windows and debris and breaking down of building safety system due to the dynamic load created by the explosion is higher than the original design loads for which the structures are analysed and designed.

The study of structure to find a blast resistance material has become a significant study due to the blast load case that occurred on December 11, 2005 at the Buncefield Oil Storage Depot. The explosion had caused so much loss such as homes and businesses surrounding the area (Scott G.Davis, 2010). Due to space constraint, development had to be done next to the dynamic loading prone area mentioned earlier. In order to cater this dynamic loading phenomenon towards the safety of the civilians, one of the effective approaches is by investigating the efficiency of tree to reduce or absorb blast wave to prevent the blast wave from harming the civilians and damaging the buildings.

In this study, a presentation of a three-dimensional (3D) model with a specified tree positioned at certain standoff distance from the explosive material is to be designed. This design is modelled to analyse the efficiency of a specified tree to absorb blast wave to reduce the negative impact surrounding the explosion area. Apart from that, a reinforced concrete (RC) wall of several proposed dimensions is also included as model to investigate the blast overpressure parameter at 30 lbs. TNT of blast with the presence and the absence of the RC wall. The RC wall and the specified tree will also be arranged differently to compare the amount of pressure exerted on each of the arrangement to be simulated in the selected software. This 3D modelling will be constructed and designed by using nonlinear finite element analysis software which is AUTODYN. AUTODYN is an integrated explicit tool to model a nonlinear dynamics of solid, fluid and gas that uses finite elements (FE), finite volume (CFD) and mesh-free particle (SPH).

1.2 Problem Statement

There are many life risking explosions that had occurred in our world nowadays. These explosions of different weight and strength had brought a great impact on people and environment. It has caused the death of people living nearby the explosive material such as the explosion of the oil storage terminals, nuclear plant, and rocket fuel containing flammable gas (Zipf et al. 2010). In this case, there have been a lot of towns and residential areas built near to those explosive material plants due to space constraints. The occurrence of an explosion is an instant reaction with dynamic pressure acting on it. The blast waves will propagate around the area and blow away the residential areas, buildings and towns. These damages will cause the repairing and maintaining cost to be higher due to severe damages caused by the explosion (Luccioni et al., 2004).

Other than that, explosion will also bring damages to human health. The blast wave produced by the explosion will cause ruptures to people’s eardrums in about 1% for every 5 psi of blast overpressure and also brings damages to the lungs at about 15 psi of blast overpressure. 1% fatality might occur if 35-45 psi of blast overpressure is subjected to blast load (Glasstone S, 1977). However, most common injuries are due to the flying debris and collapsing structures that strike civilians. Long-term effect of an explosion may cause eye-cataracts to human according to a study of Chernobyl Clean-up workers. These are the dangerous and harmful risks.

Therefore, it has been a significant effort in finding the solution towards saving life and protecting the environment. This research is carried out specifically to investigate plant as blast wave absorbent to reduce the propagation of waves travelling farther and affects the environment and civilians apart from analysing the physical impact of plant with the presence and the absence of RC wall.

1.3 Research Objectives

The objectives of this research are as follow:

- To investigate the blast pressure parameter of 30 lbs. TNT.
- To study either plant is able to reduce or absorb blast pressure.

1.4 Scope of Research

This study is focused on developing a three-dimensional (3D) model to analyse a fully integrated engineering analysis codes specifically designed for non-linear dynamic problems. This 3D model is developed in order to acknowledge the efficiency of plant to absorb shock wave produced by an explosion and able to safe life and buildings. Besides, this 3D model is also done to observe the blast pressure parameter of 30 lbs. Trinitrotoluene (TNT). The Arbitrary Lagrange Euler (ALE) processer is performed in the AUTODYN software to simulate the blast pressure analysis. The blast load is subjected to 30 lbs. TNT that comes from the explosion of various explosive sources. The validation of the blast pressure will also be done by comparing the research work reported by Yan et al. (2011). The result obtained from the simulation will specify the amount of pressure exerted at the back of the plant at 4876.8 mm (16 ft.). Distance from one pressure transducer to another is 1219.2 mm (4ft.).

The surrounding of the explosion area is modelled with a structural wall sizing 1829 mm x 1219.2 mm. The thickness of the wall is 152 mm with 305 mm of strip footing. The 30 lbs. TNT of the blast load is subjected with a standoff distance of 1219.2 mm from the structural wall. The concrete and steel behaviour used for the structural wall is decided to use from a high strain rate effect. The plant model used in this 3D software system is a general type of plant. The width of the plant is 2000 mm of 550 mm thick and the height of the plant is 1829 mm.

1.5 Significant of Research

The 3D numerical modelling of RC wall and plant subjected to blast load is yet to be developed in AUTODYN commercial software By simulating the behaviour of the RC wall and plant in FE software, the cost of the explosive material and the experimental test area can be saved and cut. Currently, RC wall has been widely used as a fence or barrier from the danger of explosion. However, the effect from the blast wave is still severe when it hits human or environment. Therefore, the investigation between RC wall and plant as potential barrier are compared on their performance when subjected to blast load. Furthermore, the used of the experimental data from previous study to validate the numerical modelling is used for parametric study to determine the blast pressure parameters of 30 lbs. TNT. This reduces the cost of designing and constructing the RC wall, the pricey explosive material as well as saving the plant from being jeopardized.

1.6 Outline of the Thesis

Chapter 1 presents about the general introduction and discussion prior to today's issues as well as research objective, scope of research and significant of research for conducting this study.

Chapter 2 presents about the topic related to this simulation namely blast subjected to RC wall, plant and RC wall and plant as well as the material model used for the objects in AUTODYN. The overviews are also made on the explosion, explosive, detonation, load, TNT equivalent and blast pressure.

Chapter 3 presents about the methodology for the four cases of different objects conducted in AUTODYN to investigate the difference in blast pressure.

Chapter 4 presents about the graphical numerical analysis for the observation of the pressure changes.

Chapter 5 concluded the results obtained from the simulation a well as deciding the best object in reducing the blast pressure. Several recommendations re pointed out for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, it reviews and highlights about this research to further clarify the fundamental of explosion and blast. It concerns about the empirical and numerical methods in order to predict the main objective of this research on investigating the blast overpressure parameter on 4 different cases. This chapter will also involve the numerical work to analyse these 4 cases in which AUTODYN is the exact computational software for this numerical assessment.

2.2 Explosion

Explosion is defined as an abrupt increase in pressure and temperature from oxidation or other exothermic reaction . It is also defined as the rising of temperature and pressure rapidly resulting in the propagation of pressure wave (Keller *et al.*, 2014). When defined by Webster, explosion is a rapid and large scale and spectacular expansion and outbreak (Martin, Reza and Anderson, 2000). The compressed gas or vapour stored energy regardless of temperature can be a source for the occurrence of explosion. The shape of the blast wave depends on the distance from the detonation point. High explosive known as detonation created the supersonic explosions. Explosion may cause destruction on structures and fatality on human. The high temperature from the blast cause the gas to be moving radially outward in a thin, dense shell known as The Hydrodynamic Front propagating the blast wave to the surrounding area. Normally, the effects of explosion damage are based on the charge weight and surrounding factors. Taking natural gas leakage as example, the surrounding factors that increase the ignition of the explosion are the volume of gas, ignition source location, gas diffusion range and the size of a space (Wang et al., 2017). The explosion occurs when the detonation is condensed and generates up to 300 kilo bar with temperature about 3000-4000ºC of hot gases under pressure (Ngo *et al.*, 2007). The hot gases will then expand causing the volume contents to be forcing out from its original space. As a result, the blast wave which is the compressed air forms containing most of the energy released. The blast wave will increase the pressure magnitude across the ambient atmospheric pressure. Within the time of several milliseconds, the pressure started to decrease below the ambient atmospheric pressure. The negative phase indicates that the air is sucked in and partial vacuum is created as shown in Figure 2.1.

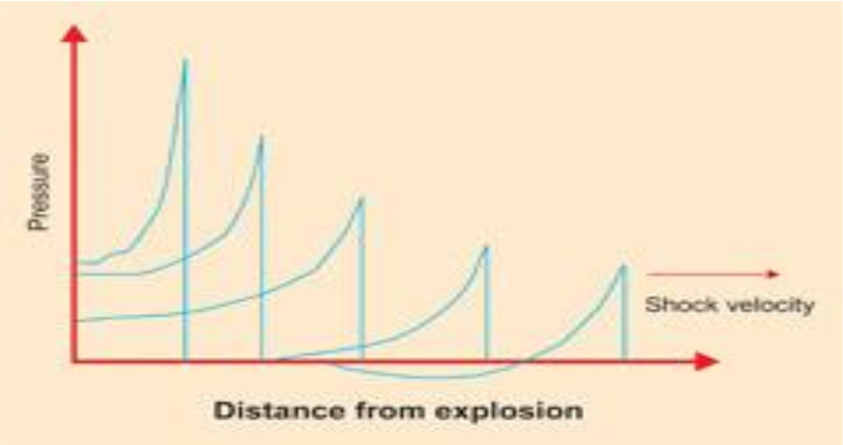

Figure 2.1 Blast wave propagation
Source: (Ngo *et al.*, 2007)

2.3 Explosive

Explosive is a substance that is capable of producing expanding gas that explodes out to the surrounding abruptly. The most common explosive used is chemical explosive. There are also the presences of mechanical explosive and nuclear explosive. A mechanical explosive is the one that produces physical reaction such as loading a container and compressed the air inside. Nuclear explosive is the most powerful explosive ever exist, thus, the usage is restricted to military weapons. The chemical explosive includes nitro-glycerine, black powder, dynamite and trinitrotoluene (TNT). As for this research, the chemical explosive involves is the trinitrotoluene. These kinds of explosives can either be in the states of solids, liquids and gases (Martin et al., 2000).

2.4 Detonation

By every definition, any chemical explosive or detonation of trinitrotoluene (TNT) qualifies as an explosion. It involves all conditions such as gas expansion, shock wave, rapid rising in pressure and rapid releasing in energy. 'Megaton' is used to define millions of metric tons of TNT. Universally, it is applicable for measuring destructive energy release of a huge explosion. A method that is commonly be used widely for comparing different energy from different explosions is through TNT equivalence.

2.5 TNT Equivalent

TNT is also known as Trinitrotoluene is a mass of a conventional charge weight used for chemical explosive. It is a measure for the released of energy for explosion normally used in the detonation of a blast load. It is expressed as the weight of TNT as the amount of energy released is the same as the amount of energy when it explodes. It is one of the most popular explosive compounds. The release of energy of 1 gram of TNT in an explosion has approximately 4000 Joules. The calculation for determining TNT equivalent is based on the comparison between the velocities of detonation by using Eq. 2.1

$$TNTeq = D^2exp\ D^2TNT \qquad 2.1$$

Where D is the velocity of detonation, subscripts *exp* and *TNT* are the studied explosive and TNT explosive respectively.

Another frequently used method of calculating TNT equivalent is to determine it from the heat of detonation. The equation by (Panowicz, Konarzewski and Trypolin, 2017) is shown in Eq. 2.2.

$$TNTeq = Qexp/QTNT \qquad 2.2$$

Where Q is the heat of detonation.

The blast parameters are needed to quantify from an explosive asides from TNT. It must be converted to TNT equivalent weight. In order to convert, the explosive mass is multiplied by a conversion factor based on the energy output of the TNT. The conversion factors are shown in Table 2.1 (May & Smith, 1995).

Table 2.1 Conversion factors for selected explosives

Explosive	TNT Equivalent
TNT (Trinitrotoluene)	1.00
Pentolite	1.42
Compound B (60% RDX, 40% TNT)	1.15
RDX (Cyclonite)	1.19
Semtex	1.25
Dynamite 60%	0.90
C4	1.30
ANFO (Ammonium Nitrate Fuel Oil)	0.82

Source: (May & Smith, 1995)

2.6 Blast Load

Blast loading is defined as a load with short duration of time known as impulsive loading. Blast loading is categorized into three representatives. The representatives are the unconfined free - air explosions, unconfined surface explosions and partially confined explosions. In this study, the blast load is categorized as the unconfined explosion or surface burst. The explosive charge is detonated almost at the ground surface. Surface burst propagates spherically outwards and interact locally with the ground and directly hit the surrounding structures. The interactions between the object and the blast waves creates pressure pattern. The load that is withstood by a structure depends on several parameters. The parameter is the weight of the explosive charge. The heavier the weight, the stronger it is. Distance from the detonation point is also one of the parameters involved. The blast load decreases with the increase in distance from the detonation point. Also, it depends on the structure’s type. If a building is designed to withstand highly from the impacts of explosion, the damages of such building might be lesser when compared to the generally designed buildings. When the blast wave comes to contact with rigid surface such as RC wall, the blast pressure will be reflected and is larger than the incident peak pressure. The reflected pressure can be severally higher up to 8 times than the incident pressure. In determining the blast pressure, there are several factors considered in the computational of blast load. The factors are scaled distance, explosive mass and actual distance from the centre of the spherical explosion.

Based on Unified Facilities Criteria (UFC) (DOD, 2008), there are two divisions that can be made in terms of confinement of the explosive. It can either be unconfined or confined explosion. Apart from that, it can also be subdivided in term of the blast loading produced on the structures or within the structures. The blast loading categories with five possible pressure loads are shown in Table 2.1 below. In this current study, the problem involved is classified as unconfined explosion and categorised as a surface burst. Thus, in this study, the explanation is only done on unconfined explosion. If an explosion occurs adjacent to or above a structure, initial shock wave is produced without wave amplification between structures and the charge weight. The blast load that occurs on the structures is known as the free air burst explosion. When the blast wave arrives on the structures, the ground reflection occurs from the initial wave. The UFC is limited only to explosion. The explosion occurs about two to three times height measuring from a single or double storey building. If the charge weight is located nearer to the ground surface, the amplification of the shock wave occurs at the detonation point due to the ground reflection. Thus, this blast is classified as surface burst. (Remennikov and Rose, 2007, and DOD, 2008).

Table 2.2 Blast loading classification

Charge Confinement	Category	Pressure Loads
Unconfined explosion	1. Free Air Burst 2. Air Burst 3. Surface Burst	a. Unreflected b. Reflected b. Reflected
Confined Explosion	4. Fully Vented	c. Internal Shock d. Leakage
	5. Partially Confined	c. Internal Shock e. Internal Gas d. Leakage
	6. Fully Confined	c. Internal Shock e. Internal Gas

Source: DOD (2008)

When there is no obstruction in the air medium during explosion, the blast wave between the explosive charge and structures will be amplified. This is called free-air explosion. If the explosive charge is located above the ground at the height of about 2 m, it s considered as surface explosion. The blast wave is reflected and amplified by the ground surface producing a reflected blast wave. Thus, the blast wave will produce a hemispherical blast wave propagating to the targets as shown in Figure 2.2. Closer to the ground surface, the shock wave is observed to be vertical, however s goes farther, the shock wave is observed to be horizontal. This sudden and abrupt event of high intensity and short duration, the load produced by the pressures and dynamic pressures are highly critical when compared to wind load. Figure 2.2 illustrates the blast wave from the surface burst.

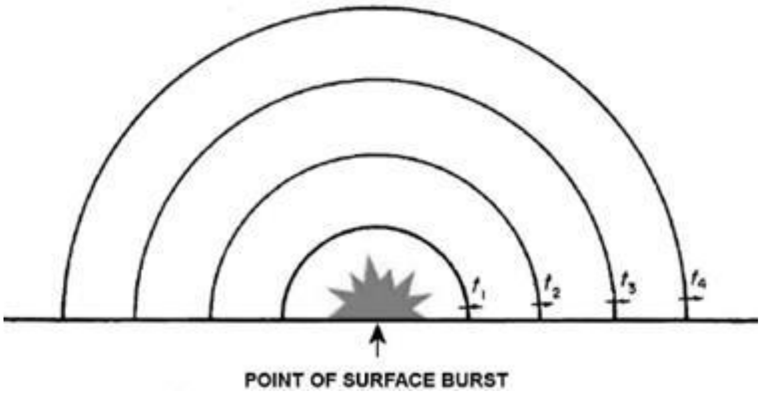

Figure 2.2 Blast wave from surface burst
Source: (Remennikov, 2007)

2.6.1 Blast Pressure

Blast pressure is the pressure that is caused by the shock wave across the atmospheric pressure. The blast pressure from explosion decreased with the increased of scaled distance (Taniguchi *et al.*, 2004). Scaled distance is the distance from the source of explosion at which the blast effect is caused by the charge weight. This ideal relation is also agreed by (Rasbash, 2003). It means here that the energy from the explosion is converted to the blast energy resulting in blast pressure coming from the detonation point. High blast pressure may cause many negative impacts to the surrounding and the civilians. It causes numerous numbers of damages that consumes high cost for repairing purpose. In this assessment, the blast pressure is supposed to be decreasing when there is barrier at the point of detonation. The barrier such as reinforced concrete (RC) wall will help in minimizing the pressure at the back of the RC wall causing the impacts to be minimizing. This study also assess if plant is able to reduce the blast wave in which it results in decreasing the blast pressure.

The Friedlander's equation for Conventional Weapons Effect (ConWep) which is the automated computer program is used in this simulation study. Friedlander suggested that the classic pressure time-history could be described by Eq. 2.2.

$$P = P_S e^{-\frac{t}{t^+}}\left(1-\frac{t}{t^+}\right) \qquad 2.3$$

When an explosion occurs, a sudden released of energy to the atmosphere caused the transient pressure or blast wave. The blast wave propagates radially in all directions from the source at a supersonic speed. The magnitude and shape of the blast wave depend on the nature of the energy released and the distance from the source of explosion. A high explosive detonation generally produces a characteristic shape known as ideal blast wave. It is symmetrical. The generated pressure profile by an ideal blast wave at a point at some fixed distance R removed from the centre of explosion is shown in Figure 2.3.

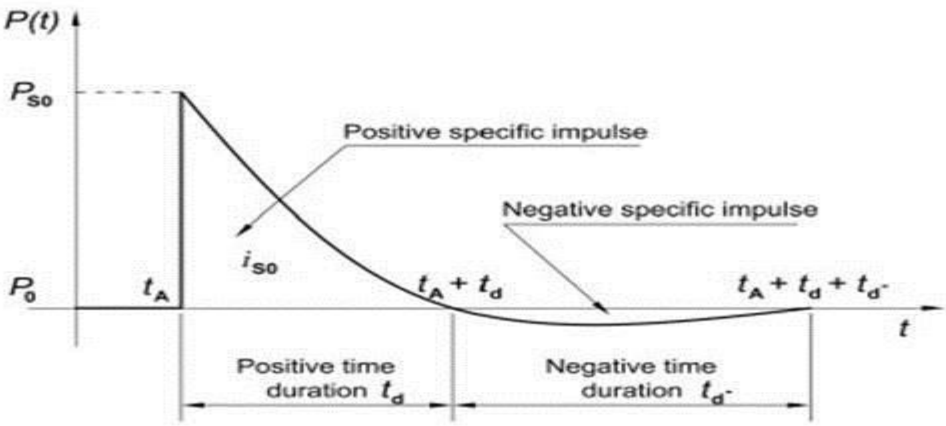

Figure 2.3 Blast wave pressure time - history
Source: (Abd-alrazaq, 2018)

Minimum pressure can be described by the equation 2.4 and 2.5 below. t_{min} is the minimum time taken whilst P_{min} is the minimum pressure.

$$t_{min} = 2t^+ \qquad 2.4$$

$$P_{min} = -P_s e^{-2} = -0.135P_s \qquad 2.5$$

The total impulse from the properties of Friedlander's equation is described by Eq. 2.6.

$$I_{Tot} = \int_0^{\infty} P_S e^{-\frac{t}{t^+}} \left(1 - \frac{t}{t^+}\right) = 0 \qquad 2.6$$

2.7 Scaling Law

The amount of energy released by a detonation has caused the establishment of scaling law. The blast energy is released in the form of blast wave. This can be described by the equation below where R is the standoff distance from the explosive and W_{TNT} is the equivalent weight of TNT. It is said that scaling law can be used to predict the properties of blast wave at high altitude (Baker et al., 1983).

$$Scaled\ distance, Z = R / {W_{TNT}}^{1/3} \qquad 2.7$$

2.8 Numerical Method

AUTODYN was developed in the back days by Century Dynamics (Robertson et al., 1994) Today, it is a part of the ANSYS Workbench Platform and has been used since the year 1977. AUTODYN is an explicit hydrocode containing several different solvers. The solvers include Euler, Lagrange, Arbitrary Lagrange Euler, Smoothed Particle Hydrodynamics, Beam and Shell. Every solver has its own characteristics, strengths and weaknesses. Each solver is designed and created to solve different range of problems. Euler solver is usually used when modelling shock waves. Euler solver has two types which are Godunov and Flux-Corrected-Transport (FCT). These two types of Euler solver are able to reach different solutions. Godunov is used for local Riemann cell interfaces while the FCT method is the combination of convective step and anti-diffusive step (Trulsen, 1984). Table 2.3 shows the applications for AUTODYN.

Table 2.3 Applications for AUTODYN

APPLICATION	2D	3D	PROCESSORS
Hypervelocity Impacts	/	/	Euler, Lagrange and SPH
Ceramic Armor Impact,		/	Lagrange
Oblique Penetration and Ricochet		/	Lagrange
Oil well shaped charge and perforation	/		Euler
Impact and crush of a steel girder		/	Shell

2.8.1 Material Model for Concrete

It is crucial to find a proper model in order to describe the behaviour of the concrete under blast load. This concrete model is first developed by Reidel, Hiermayer and Thoma (RHT) and is available in AUTODYN since 2000 (Tu et.al, 2010) Besides it is used for the description of concrete, it is also used in dynamic loading situations and implemented in AUTODYN. RHT is an advanced plasticity model specifically used for brittle materials to model dynamic loading. This model involved the equation of state of ρ - α to present the concrete behaviour at high stress. There are three pressure-dependent surfaces. Those are failure surface, elastic limit surface and residual surface for describing the concrete behaviour. Figure 2.4 shows all the strength surfaces.

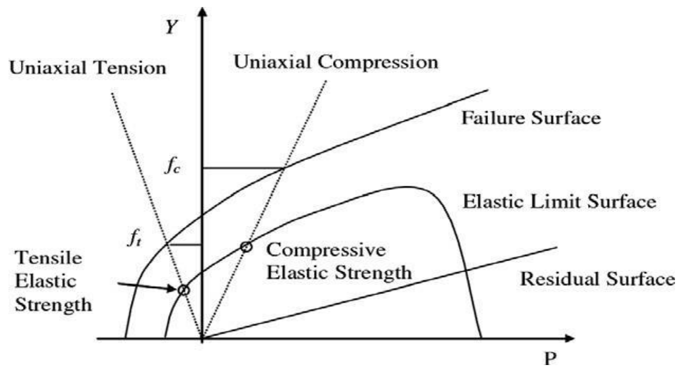

Figure 2.4 Maximum strength, yield strength and residual surfaces
Source: ANSYS (2011)

The failure surface Y_{fail} is the function of the normalized pressure $\mathcal{P}^*$, load angle ɵ and strain rate έ;

$$Y_{fail}(p^*, \theta, \dot{\varepsilon}) = Y_c(p^*) \cdot\ r_3(\theta) \cdot\ F_{rate}(\dot{\varepsilon}) \qquad 2.8$$

Yc ($\mathcal{P}^*$) is the comprehensive meridian and it is represents by

$$Y_c(p^*) = \ f_c \left[A \cdot \left(p^* - \ p^*{}_{spall} F_{rate}(\dot{\varepsilon}) \right)^N \right] \qquad 2.9$$

The tensile and comprehensive meridian on the stress Π plane is illustrated in Figure 2.6.

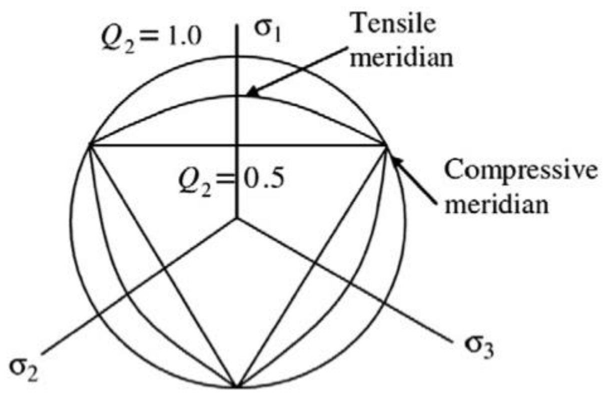

Figure 2.5 Third invariant depend on stress plane

Source: ANSYS (2011)

The elastic limit scaled from the failure surface,

$$Y_{elastic} = Y_{fail} \cdot F_{elastic} \cdot F_{cap}(p) \qquad 2.10$$

Where $F_{elastic}$ is the ratio of the elastic to failure surface strength. F_{cap} limits the elastic deviatoric stresses under hydrostatic compression, varying within the range of (0,1) for pressure between initial compaction and solid compaction pressure.

The residual failure surface is defined as

$$Y^*_{residual} = B \cdot (p^*)^M \qquad 2.11$$

Where B is the residual failure surface constant, and M is the residual surface exponent.

After the phase of hardening, the plastic straining is damaged and the strength is reduced. The damage is assumed to be using the relationship

$$D = \sum \frac{\Delta \varepsilon_p}{\varepsilon_p^{failure}} = \sum \frac{\Delta \varepsilon_p}{D_1\left(p^* - p_{spall}^*\right)^{D_2}} \quad 2.12$$

where D1 and D2 are material constants for effective strains to fracture.

There are two damage effects which is reduction in strength and reduction in shear stiffness as below

$$Y_{fracture}^* = (1-D)Y_{failure}^* + DY_{residual}^* \quad 2.13$$

$$G_{fracture} = (1-D)G_{elastic} + DG_{residual} \quad 2.14$$

Where $G_{elastic}$, $G_{residual}$ and $G_{fracture}$ are the shear modulus.

2.8.2 Material Model for Steel Reinforcement

Johnson-Cook (JC) material model is used to describe the behaviour of the steel reinforcement (Johnson and Cook, 1983). It represents the strength for large strain, high strain rates and high temperature materials. The yield stress is defined as

$$Y = [A + B\varepsilon_p^n]\left[1 + C\ln\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_0}\right][1 - T_H^m] \quad 2.15$$

Where the $\acute{\varepsilon}_p$ is defined as effective plastic strain; $\acute{\varepsilon}_p = \acute{\varepsilon} / \acute{\varepsilon}_0$ is normalized effective plastic strain rate.

2.8.3 Material Model for Plant

The material model used for plant in this present study is WATER2. WATER2 can be used for Smoothed Particle Hydrodynamics (SPH) in simulating plant. It uses SPH techniques as it is a gridless technique and thus removes the problem of grid tangling. When the blast wave hits the plant, the plant will disperse into particles allowing us to see how the plant loses from each other and break.

Regularized Smooth Particle Hydrodynamics (RSPH) was developed as method and also code. It is an extension a SPH solver. RSPH is more flexible in which the resolution can be adaptively made. The regularization is also introduced as it prevents the particle distribution from becoming too irregular. RSPH can withstand a high resolution near the shock wave structure and low resolution at other regions (Trulsen, 1984). In this current research, SPH is chosen to be used in AUTODYN as it will be simulating the plant as one of the barriers involved in this study. Plant is using SPH solver as the plant is to be observed the dispersion of the plant under blast. This is because, the validated SPH solver can display the dispersion pattern of the plant particle in AUTODYN. The solutions by using SPH solver show a good result although the particle resolution is increased. Overall, SPH solver can be qualitatively and quantitatively be used to determine the blast induced to dispersion or even fracture to be suitable and accurate for modelling plant in this study (Gharehdash *et al.*, 2019).

The final basic SPH equation by (Lecture, 1977) requied for the evolution of a fluid system is the energy equation. We start from the first law of thermodynamics. Taking these rates as a function of time and using D/Dt for Langrangian dynamics,

$$\frac{DU_a}{Dt} = \frac{P_a}{\rho_a^2}\frac{D\rho_a}{Dt}. \quad 2.16$$

2.8.4 Material Model for Air and High Explosive

There is interaction in between the structure and the air. The numerical approach involved is the Arbitrary Lagrange Euler (ALE). By applying this approach, the interactions between different solvers such as structures, liquids and gases can be simultaneously modelled y using Lagrange and Euler.

Air is modelled by an ideal gas EOS equation in numerical model. The pressure related to energy is given in Eq. 2.16.

$$p = (\gamma - 1)\rho E_i \qquad 2.17$$

Where ɣ is the ratio of specific heat and ρ is the density of air. E_i is the specific internal energy. The standard constant of air density is ρ = 1.255 kg/m³. ɣ is 1.4 and air initial internal energy E_i = 2.068 x 10^5 kJ/kg.

TNT is modelled by using the Jones-Wilkins-Lee (JWL) EOS. It models the pressure generated by chemical energy by using Eq. 2.17.

$$P = A\left(1- \frac{\omega}{R_1}\right) e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right) e^{-R_2 V} + \frac{\omega E_i}{V} \qquad 2.18$$

2.9 Summary

This chapter explains about RC structures and plant related to blast load. It explains about the details of the material models used in AUTODYN for all the materials provided in the material library. General clarification on explosive, detonation, blast load, TNT equivalent blast pressure and numerical software used (AUTODYN) are also stated in this chapter for a better understanding. This clarification provides more inputs in further chapters.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains more about the methodology on how the simulation is done in the numerical software mentioned in previous chapter. In the first part, this chapter explains the method of designing and simulating the blast wedge in which it will be remapped and used for other simulation cases. Besides, the designation of the materials used for RC wall and plant will also be stated and assured in this chapter apart from the materials and material models used in AUTODYN to clarify more about the simulation in the second part of this chapter. The third part will be the clarification on the four cases involved which are simulation in open space, simulation with RC wall as barrier, simulation with plant as barrier and simulation with both RC wall and plant as barrier. These cases are subjected blast loading of 30 lbs. TNT.

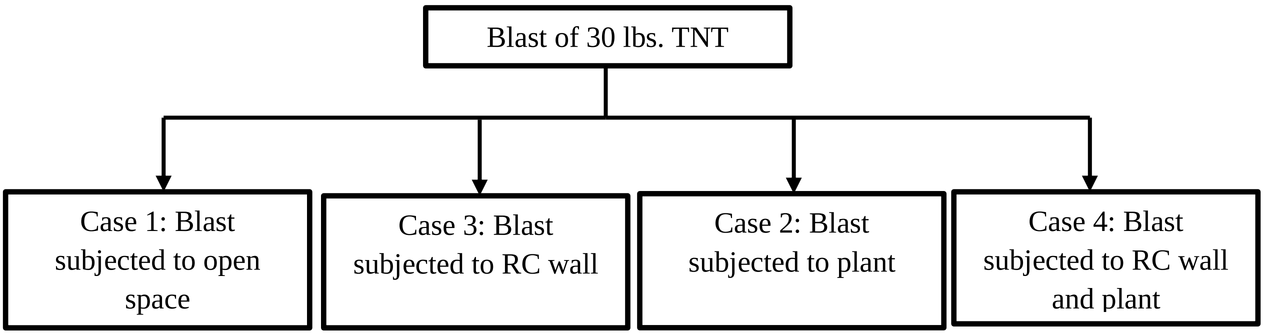

Figure 3.1 Flowchart for the methodology

3.2 Numerical Modelling in AUTODYN 3D RC Wall and Plant Subjected to Blast Load

In this present study, AUTODYN is used for numerical analysis. AUTODYN is one of the most convenient numerical software today that capable in assessing the blast pressure and solid RC wall for the integration between two techniques which are Langrangian and Euler. Besides the two techniques, ALE in which it stands for Arbitrary Langrange and Euler is another solver applicable for this blast study as it acts as a mesh-based hybrid for Lagrangian and Euler method. Figure 3.2 illustrates the ALE solver techniques in AUTODYN.

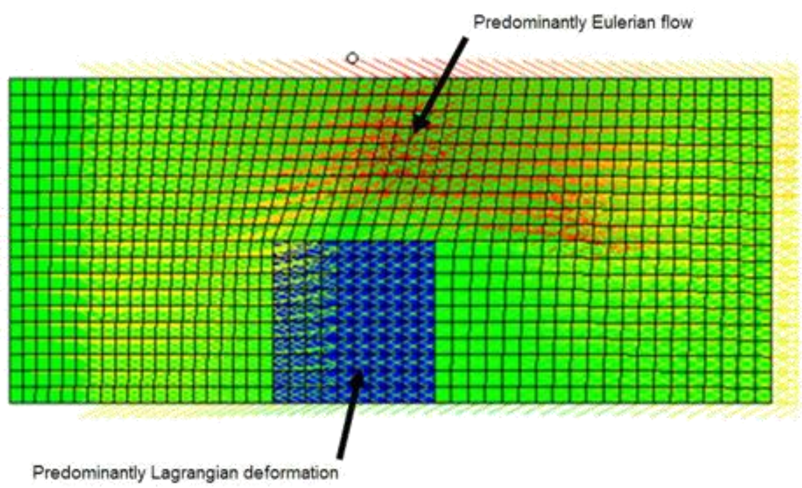

Figure 3.2 ALE solver techniques in AUTODYN
Source: ANSYS 2011

Before the RC wall and plant can be transported to the AUTODYN solver for blast pressure analysis, the solid elements must be primarily performed in ANSYS-Workbench. The steel reinforcement is treated as a perfect and compatible bonding between the steel reinforcement and concrete analysis. For steel reinforcement, meshing is assigned to an eight-noded hexahedral element as shown in Figure 3.3. This element is used as it is best suited to the transient dynamic applications such as large strains and complex contact conditions. This formulation is based on an exact volume calculation by Wilkins, Blum, Cronshagen and Grantham (1974) for distorted elements

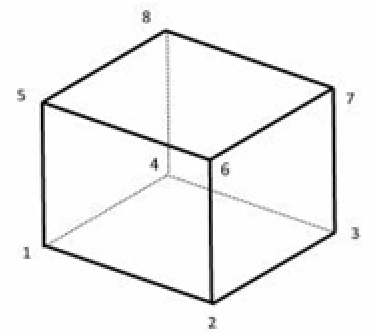

Figure 3.3 Eight noded hexahedral element

Source: ANSYS 2011

Figure 3.4 illustrates the details of the RC wall in this current study. The steel is designed to be vertically 16 mm in diameter and horizontally 10 mm diameter. Its spacing is set to be 152 mm. concrete cover which covers all the steels is 25 mm thickness. For the cylinder, the compressive strength of concrete is 44 MPa with standard deviation of 1.38 MPa. Its modulus elasticity is 31.5 GPa with 827 MPa standard deviation. The yield strength and Young's modulus of the reinforcement is 619 MPa and 200 GPa respectively. The size of the RC wall is measured to be 1219.1 mm in length, 1219.2 mm in width, 152 mm wall thickness and 305 mm of wall footing. Figure 3.5 shows the coarse hexahedral element of steel.

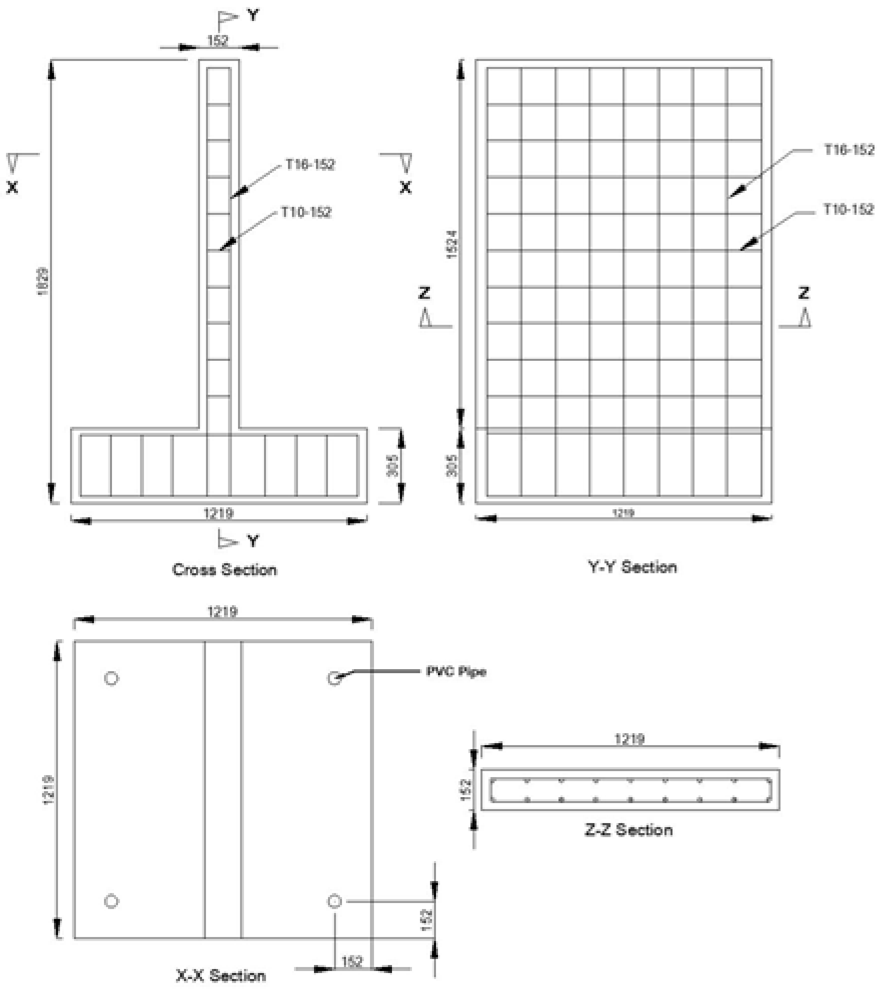

Figure 3.4 Details of RC wall (Unit: mm)

Source: Chan et al. (2018) and Yan et al. (2011)

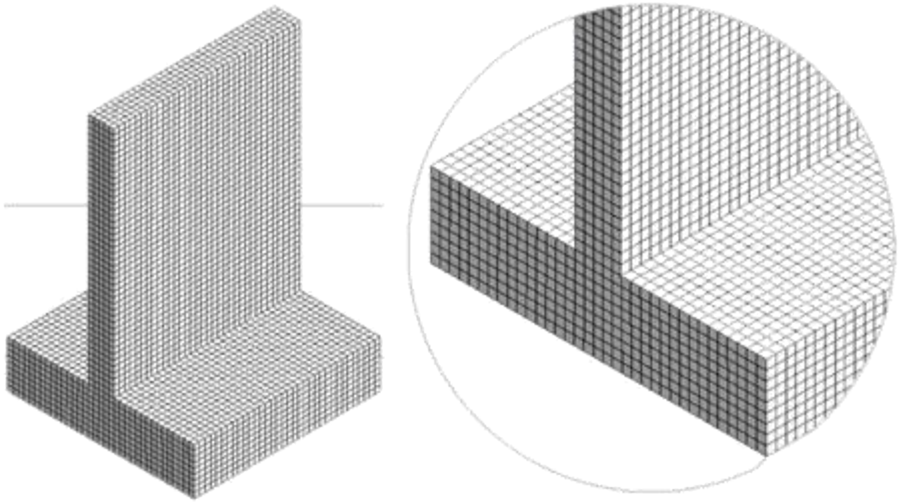

Figure 3.5 Coarse hexahedra meshing of RC wall

The material model used in AUTODYN's material library for the RC wall is CONC-35 MPA. This material model developed by Riedel, Hiermayer and Thom (RHT), is used to describe the behaviour of concrete (Nyström et al., 2009). As for the reinforcement, the behaviour of the reinforcement is describes by a standard model of STEEL-4340. This material model obtained in material AUTODYN library was developed by Johnson and Cook (JC) (Johnson and Cook, 1983). These material models are further specified in Table 3.3, Table 3.4 and Table 3.5.

Table 3.1 CONC-35 MPA material model input in AUTODYN

Equation of State	***P* Alpha**
Reference density, ρ	2.75000E+00 (g/cm³)
Porous density	2.31400E+00 (g/cm³)
Porous sound speed	2.92000E+03 (m/s)
Initial compaction pressure	2.33000E+04 (kPa)
Solid compaction pressure	6.00000E+06 (kPa)
Compaction exponent	3.00000E+00 (none)
Solid EOS	Polynomial
Bulk modulus A1	3.52700E+07 (kPa)
Parameter A2	3.95800E+07 (kPa)
Parameter A3	9.04000E+06 (kPa)
Parameter B0	1.22000E+ (none)
Parameter B1	1.22000E+ (none)
Parameter T1	3.52700E+07 (kPa)
Parameter T2	0.00000E+00 (kPa)
Reference temperature	2.95150E+02 (K)
Specific heat	6.54000E+02 (Jkg/K)
Compaction curve	Standard
Strength	RHT concrete

Table 3.1 Continued

Shear modulus	1.67000E+07 (kPa)
Compressive strength (fc)	3.50000E+04 (kPa)
Tensile strength (ft/fc)	1.00000E-01 (-)
Shear strength (fs/fc)	1.80000E-01 (-)
Intact failure surface constant A	1.60000E+00 (-)
Intact failure surface exponent N	6.10000E-01 (-)
Tens./ Comp. meridian ratio (Q)	6.80500E-01(-)
Brittle to ductile transition	1.05000E-02 (-)
G (elastic)/(elastic-plastic)	2.00000E+00 (-)
Elastic strength/(ft)	7.00000E-00 (-)
Elastic strength/(fc)	5.30000E-01 (-)
Fractured strength constant B	1.60000E+00 (-)
Fractured strength exponent M	6.10000E-01(-)
Compressive strain-rate exponent α	3.20000E-02 (-)
Tensile strain-rate exponent δ	3.60000E-02 (-)
Max. fracture strength ratio	1.00000+20 (-)
Use *CAP* on elastic surface?	Yes
Failure	RHT Concrete
Damage constant $D1$	4.00000E-02 (-)
Damage constant $D2$	1.00000E+00 (-)
Minimum strain to failure	1.00000E-02(-)
Residual shear modulus fraction	1.30000E-01 (-)
Tensile failure	Principle stress
Principle tensile failure stress	3.50000E+03 (kPa)
Max. principle stress difference/2	1.01000E+20 (kPa)
Crack softening	Yes
Fracture energy, Gf	1.20000E+02 (J/m²)
Flow rule	Bulking (Associative)
Stochastic failure	No
Erosion	Geometric strain
Erosion strain	2.00000E+00 (-)
Type of geometric strain	Instantaneous

Source: ANSYS (2017)

Table 3.2 STEEL - 4340 material model input in AUTODYN

Equation of State	Linear
Reference density	7.83000E+00 (g/cm³)
Bulk modulus	1.59000E+08 (kPa)
Reference temperature	3.00000E+02 (K)
Specific heat	4.77000E+00 (J/kgK)
Thermal conductivity	0.00000E+00 (J/mKs)

Table 3.2 Continued

Strength	Johnson Cook
Shear modulus, G	8.18000E+07 (kPa)
Yield stress, fy	7.92000E+05 (kPa)
Hardening constant, Ɓ	5.10000E+05 (kPa)
Hardening exponent, η	2.36000E-01(none)
Thermal softening exponent, m	1.03000E+00 (none)
Melting temperature, T_{melt}	1.79300E+03 (none)
Ref. strain-rate(1/s)	1.00000E+00 (none)
Failure	None
Erosion	None

Source: ANSY (2017)

Figure 3.6 shows the dimensions of plant modelled in AUTODYN. The plant is modelled to a rectangular shape measuring 1219.2 mm length and 1829 mm height while the width of the plant is measured to be 550 mm. the plant uses WATER2 as material model in AUTODYN. The material model used in AUTODYN for plant is Water2. Water is just the material but it will be changed its density to the average of density of plant. Based on Blast Protection in Urban Areas using Protective Plants journal, it says that the estimate densities for leaves and woods of a plant is about 400-700 kg/m³ (Gebbeken, Warnstedt and Rüdiger, 2017). Thus, the density of the Water2 material is changed to 700 kg/m³ in order to ensure the compatibility with plant properties. The plant material model input in AUTODYN is shown in Table 3.4

In AUTODYN, the solver used for the plant is different from the other material models. For plant, Smooth Particle Hydrodynamics (SPH) is used to solve the simulation. Different solver technologies are allowed to choose to ensure the solver to effectively working at an optimum level for a given part of model. In this part, the SPH is applied to the plant for displaying and observing the dispersion of the SPH nodes when blast wave hits the plant. AUTODYN's interaction allows the communications between many different solvers coexisting in the same model.

Table 3.3 PLANT material model input in AUTODYN

Equation of State	**Value**
Reference Density, ρ	700 (kg/m³)
Shear modulus	0 (Pa)
Gruneisen Coefficient	0.28
Parameter C1	1483 (m/s)
Parameter S1	1.75
Parameter Quadratic S2	0 (m/s)
Maximum Tensile Pressure	0 (pa)

Source: ANSY (2017)

Primarily before starting any blast simulations on objects such as RC wall and plant, numerical modelling of blast wedge is first to be done. This is because, the blast wedge is further used in all simulation for exploding purpose. The blast model is designed to be an axially symmetric wedge shape. The wedge is 1 m in length with charged circle filled in. The filled charged circle weighs for 30 lbs. of TNT which is equal to 13.61 kg. The outside of the circle is the air surrounding the charged circle. After designing the model, it is then initiated and ran in AUTODYN until it reaches 1 m of the wedge length from the centre of detonation point. The model of the air is shown in Figure 3.8. This accomplished blast simulation will be next used for further analysis. As for the material model used for air, a standard constant of air is selected in the AUTODYN's material library. It is modelled through ideal gas to describe the behaviour of the air. As for the explosive, the material model selected in the previously mentioned solver is trinitrotoluene (TNT) which is modelled by Jones-Wilkins-Lee. The material model for blast wedge is shown in Figure 3.7 while the characteristic for the two material models are shown in Table 3.1 and Table 3.2

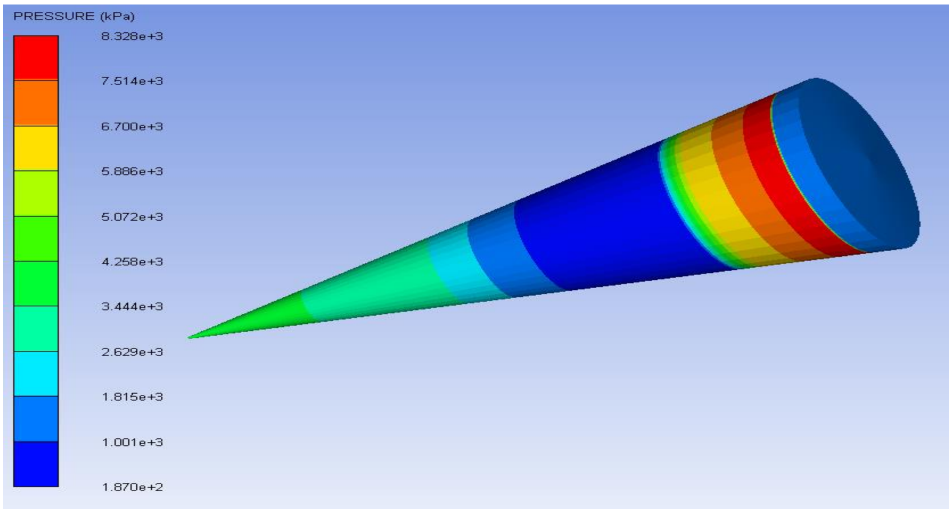

Figure 3.7 Blast wedge model of 30 lbs. TNT

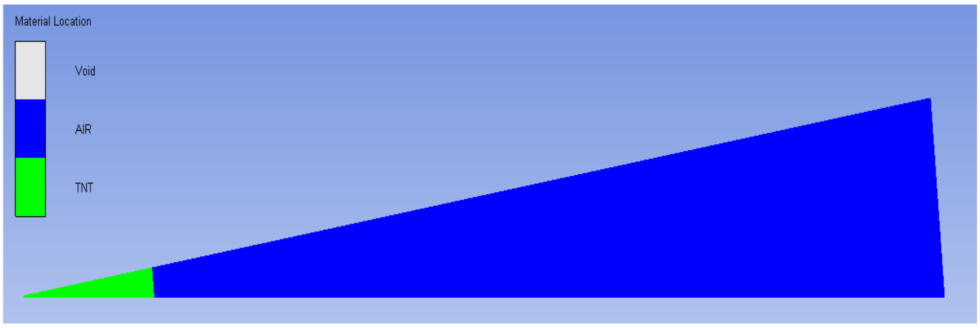

Figure 3.8 Blast wedge model of 30 lbs. TNT

Table 3.4 Employed material data for air, input to the ideal gas EOS

Equation of State	Ideal Gas
Reference density	1.22500E+00 (kg/m³)
Specific heat	7.17600E+02 (J/kgC)
Adiabatic exponent, ɣ	(none)
Reference temperature	(C)
Specific internal energy	(J/kg)

Source: ANSYS (2017)

Table 3.5 Employed material data for TNT, input to the JWL EOS

Equation of State	JWL
Reference density	1.63000E+00 (g/cm³)
Parameter A	3.73770E+08 (kPa)
Parameter B	3.74710E+06 (kPa)
Parameter R1	4.15000E+00 (none)
Parameter R2	9.00000E-01 (none)
Parameter ɷ	3.50000E-01 (none)
C-J detonation velocity\	6.93000E+03 (m/s)
C-J Energy / unit volume	6.00000E+00 (kJ/m³)
C-J pressure	2.10000E+00 (kPa)
Strength	None
Failure	None
Erosion	None

Source: ANSYS (2017)

3.2.1 Blast in open space

Figure 3.9 shows that a simulation being performed in open space without any barriers standing 4 feet from the detonation point. In the first case, 18 feet to the right side from the detonation point is simulated and analysed its results. At the 18^{th} feet, a pressure transducer is located in order to determine the amount of pressure obtained from the 30 lbs. TNT blast load. When simulated, the blast is numerically exploded while AUTODYN records the amount of pressure induced at the selected transducer. 18 feet standoff distance is chosen as the 18 feet has been conducted its blast simulation test by one of the previous researchers. This has to be first simulated as equal as the one done by Yan as this current simulation will be validated based on his numerical experiment. Thus, the amount of pressure induced at the 18th feet of pressure transducer should be equal to the numerical experiment results done Yan. When numerical simulation has been validated by the paper written by Yan, this validated condition can be applied in Case 1, Case 2, Case 3 and Case 4 in which these cases will be performing their numerical simulations in AUTODYN.

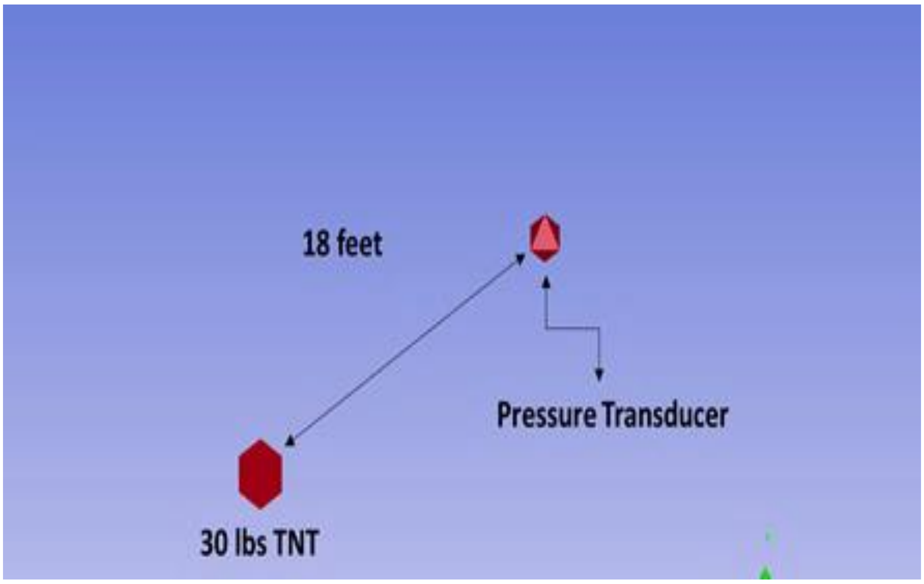

Figure 3.9 Blast test at 18th feet standoff distance.

3.2.2 Blast Subjected to RC wall

In this present study, AUTODYN is used for numerical analysis. AUTODYN is one of the most convenient numerical software today that capable in assessing the blast pressure and solid RC wall for the integration between two techniques which are Langrangian and Euler. Besides the two techniques, ALE in which it stands for Arbitrary Langrange and Euler is another solver applicable for this blast study as it acts as a mesh-based hybrid for Lagrangian and Euler method.

Before starting the simulation assessment in AUTODYN, the RC wall is first to be designed in ANSYS-Workbench. ANSYS-Workbench is software that serves a designing platform. The designs perform in ANYS-Workbench can be directly exported to the AUTODYN for blast pressure analysis. Thus, the RC wall with 1219.2 mm length, 1829 mm height and 1219.2 mm width dimensions are specifically designed and fixed in the platform mentioned. Besides, the detonation point without blast primarily remapped is also designed to be at the centre of the wall with 1219.2 mm standoff distance from the RC wall. The material model used in AUTODYN's material library for the RC wall is CONC-35 MPA. This material model developed by Riedel, Hiermayer and Thom (RHT), is used to describe the behaviour of concrete. This material model is further specified in Table 3.2

As the designs completed, it is then exported to the AUTODYN for blast pressure analysis. Before running the simulation in AUTODYN, several settings are fixed in order to check the compatibility between RC wall and AUTODYN settings. Besides, for the accuracy of the upcoming results, the flow-out and mirror boundary are assigned for the whole area with contented air volume. The I, J, K element is set to be 18, 22, 72 respectively. In this case, the positions of the charge weight, RC wall and pressure transducers are determined and arranged. The charge weight of 30 lbs. TNT with the size of about a regular ball is positioned to be at the centre of the RC wall measured 914.5 mm from the ground level. The RC wall measured from the surface of the wall is then positioned to a distance of 1219.2 mm from the charge weight facing one. Taking the nearest transducer as reference, another 4 transducers are assigned at the back of the wall as the pattern of the blast pressure reduction will be graphically observed until it reaches the last pressure transducer assigned. The distance between them is 1219.2 mm from each other. Thus, the graphical result will definitely show the difference pressure at every 1219.2 mm.

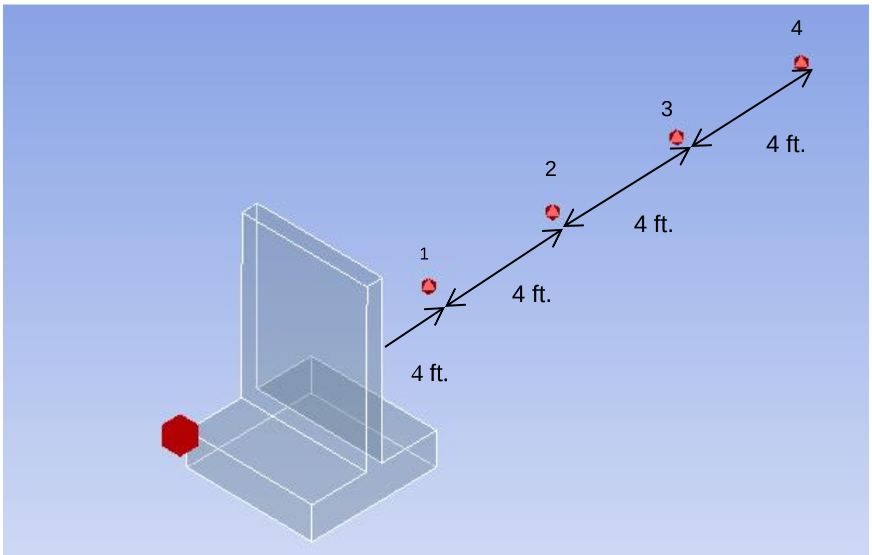

Figure 3.10 RC wall modelling in AUTODYN

3.2.3 Blast Subjected to Plant

In the third case, the material model involved in this numerical simulation is plant. This plant is a general type of plant. No specific type of plant is considered in this numerical model. Before simulation starts, the plant is drawn in the designing platform which is ANSYS-workbench. In ANSYS-workbench, the plant is drawn to a specific size of 1829 mm height, 2000 mm length and 550 mm width. The height of the plant is equal to the height of the RC wall in Case 1. Once the plant is designed, the detonation point with no blast is first replaced is set to be at the centre of the plant as shown in Figure 3.11. Both plant and the detonation point are separated at a distance of 1219.2 mm from each other. Before the two drawn objects are exported to AUTODYN and set in Explicit Dynamics, the base of the plant is fixed. It is fixed as plant is not set to be moving or thrown out from its first place. The material model used in AUTODYN for plant is Water2. However, water is just the material but it will be changed its density to the average of density of plant. Based on Blast Protection in Urban Areas using Protective Plants journal, it says that the estimate densities for leaves and woods of a plant is about 400-700 kg/m³ (Gebbeken, Warnstedt and Rüdiger, 2017) Thus, the density of the Water2 material is changed to 700 kg/m³ in order to ensure the compatibility with plant properties. The plant material model input in AUTODYN is shown in Table 3.4.

In AUTODYN, the solver used for the plant is different from the other material models. For plant, Smooth Particle Hydrodynamics (SPH) is used to solve the simulation. Different solver technologies are allowed to choose to ensure the solver to effectively working at an optimum level for a given part of model. In this part, the SPH is applied to the plant for displaying and observing the dispersion of the SPH nodes when blast wave hits the plant. AUTODYN's interaction allows the communications between many different solvers coexisting in the same model.

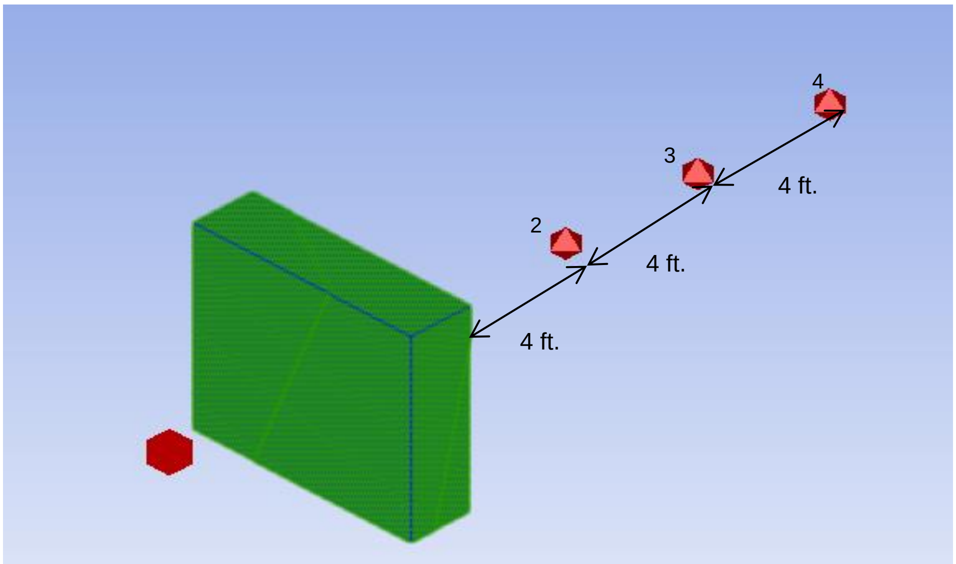

Figure 3.11 Plant modelling in AUTODYN

3.2.4 Blast Subjected to RC Wall and Plant

In the fourth case, both RC wall and plant are included in the simulation. Pressures behind the two objects will be analysed in order to compare the difference in results between Case 1, Case 2, Case 3 and Case 4. As mentioned previously, the RC wall must first be designed in ANSYS-workbench through explicit dynamics with equal dimensions of RC wall in the previous cases (1219.2 mm length, 1829 mm height and 1829.2 mm width). There are two plants positioned in this case. In ANSYS-workbench, the RC wall is set to be in the middle between the two plants of 1829 mm height, 1219.2 mm length and 550 mm while the detonation point is set to be at the centre of the RC wall of about 609.6 mm from the ground. The RC wall is then fixed to the ground. The model is displayed in Figure 3.12. Transferring the design to the AUTODYN, there are four pressure transducers placed at the back of the wall with 1219.2 mm distance from one another in order to observe the change in pressure. The air volume is set to all objects for the blast wave to propagate surrounding the area and the boundary is set to ‘all equal’. The I, J, K element used in this case are also equal to all cases which are 18, 22, 72 respectively. The blast wedge that has been designed and simulated earlier will be remapped in the detonation point that has been set in ANSYS-workbench. Once everything is set, the simulation will be started and ran until pressures assigned at the back of the RC wall are obtained. The numerical results are then analysed.

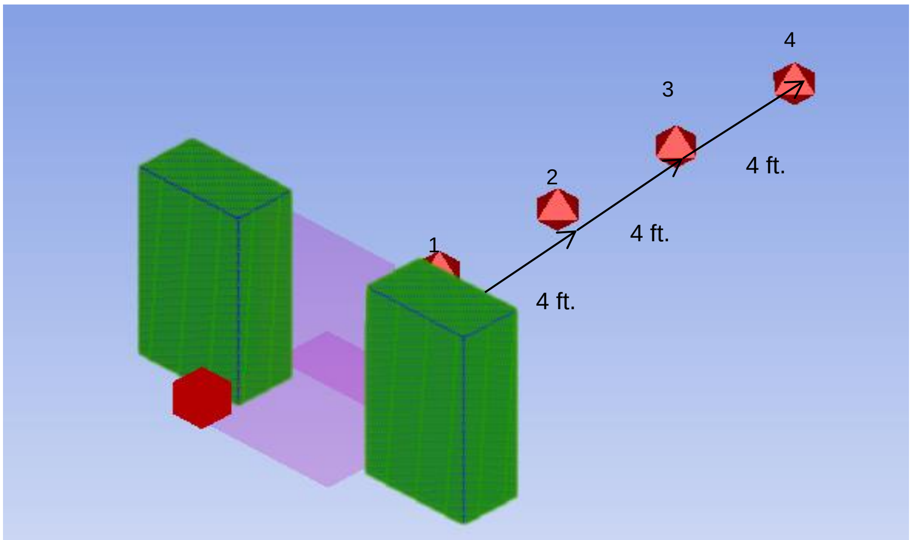

Figure 3.12 RC Wall and plants modelling in AUTODYN

3.3 Summary

This chapter explains about the methodology on this numerical simulation. The numerical blast pressure assessment is carried out in four different cases. All cases will be applied a box-sized of air volume for the propagation of blast wave and flow-out boundaries. Initially, a blast wedge is designed and simulated. The blast wedge is then remapped into all the four cases for the blast to explode numerically in the AUTODYN. The findings will be analysed and clarified in the next chapter.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter explains about the results and analysis on blast pressure parameters for the plant and RC wall on this present numerical simulation study. There are four parts of analysis presented. The first part is Case 1 and then followed by Case 2, Case 3 and Case 4. This different cases with different objects are compared its different in blast pressure parameters 4876.8 mm (16 ft.) behind the objects obtained from numerical modelling by previous researcher. This study is validated by previous research by (Yan et al., 2016) by comparing the numerical modelling in this study.

4.2 Blast pressure analysis in AUTODYN

4.2.1 Blast in Open Space

Figure 4.1 shows the graphical simulation result of blast pressure at 5486.4 mm (18 ft.) to the right side of the blast load. Pressure transducer located is exactly the same position as the investigation by (Yan et al., 2016). Based on the graph, the numerical simulation on a plain area at 5486.4 mm distance from the blast load has achieved the peak blast pressure close to the recorded peak blast pressure by Yan which is 490 kPa at 4.64 msec. This indicates that the numerical simulation can be further relied for next simulation cases as the blast pressure obtained at exactly the same position is validated when compared to previous research. The duration for the blast pressure to drop to the ambient pressure is observed to be longer than the blast test with 14.7 msec compared to 6.6 msec which is about 8.1 msec difference in time taken. Figure 4.1 Comparison of blast pressure at open space and blast test conducted by (Yan et al., 2016).

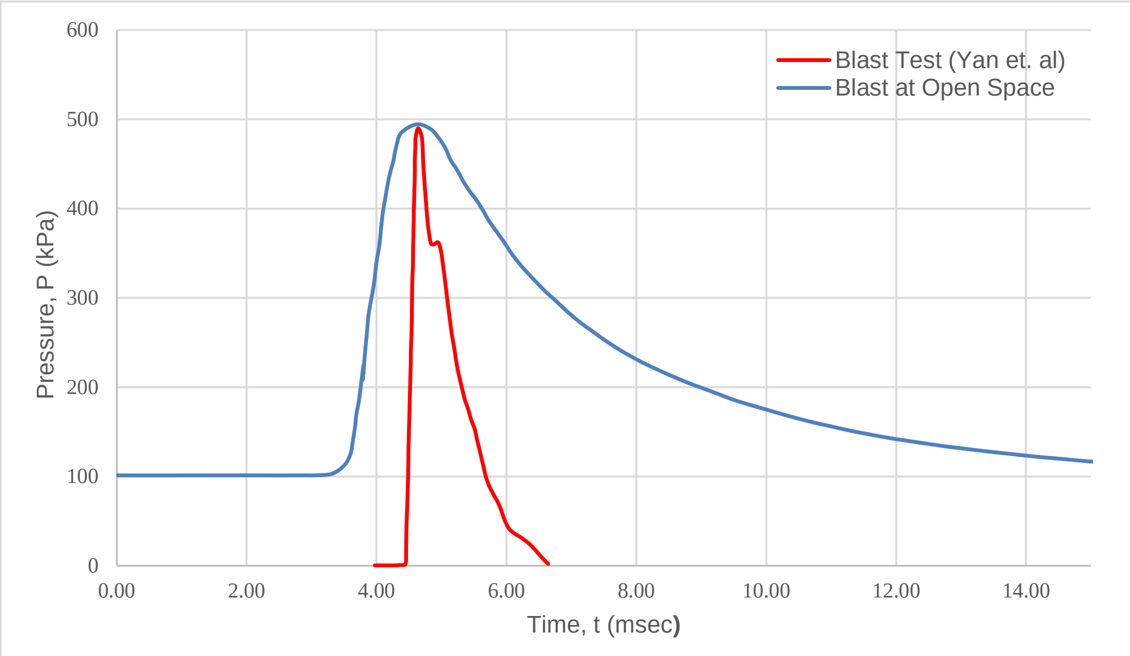

Figure 4.1 Comparison of blast pressure at open space with Yan et al. (2011)

4.2.2 Blast Subjected to RC wall

Figure 4.2 shows the graphical simulation result of blast pressure at 1219.2 mm (4ft.), 2438.4 mm (8ft.), 3657.6 mm (16ft.) and 4876.8 mm (16 ft.) from behind the RC wall. The blast pressures and the time taken obtained from every pressure transducers assigned in AUTODYN are 1250 kPa (0.25), 440 kPa (1.25), 340 kPa (2.90) and 320 kPa (4.00) respectively. It is clearly shows that the simulated peak pressure from exactly 1219.2 mm (4ft.) from behind the wall until the last pressure transducer is decreasing gradually until 4.00 msec. The recorded highest blast pressure is at a distance of 1219.2 mm (4 ft.) with 1250 kPa (0.25 msec) away from the wall. This explains that the nearer the distance, the higher the blast pressure. This is because a rigid object or material will reflect the blast wave as it hits the wall. This reflected blast wave has caused the pressure at nearer distance to be magnified when compared to farther distance. At 2438.4 mm (8 ft.) distance, the blast pressure has reduced to 440 kPa. Table 4.1 shows the recorded pressures and the time of arrival of the blast wave.

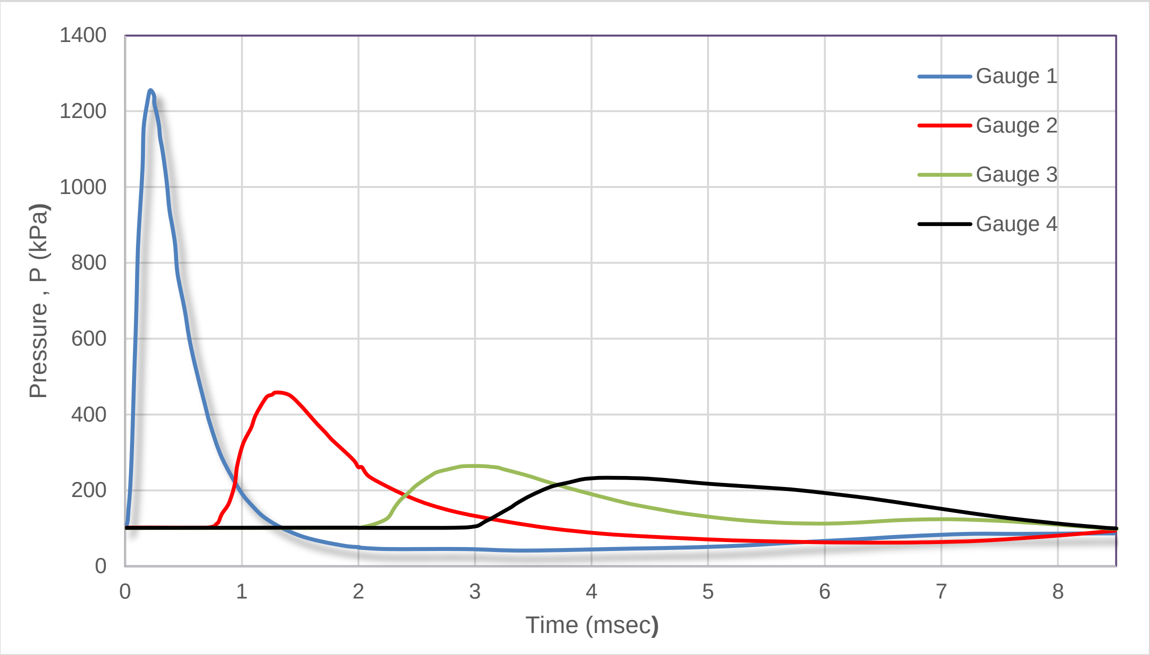

Figure 4.2 Change in blast pressure with RC wall subjected to blast load

Table 4.1 Recorded pressures and time of arrival for Case 2

Pressure Transducer	Pressure Parameters	
	Peak Pressure (kPa)	Time of Arrival (msec)
1	1250	0.25
2	490	1.25
3	340	2.90
4	320	4.00

Figure 4.2 Change in blast pressure with RC wall subjected to

4.2.3 Blast Subjected to Plant

Figure 4.3 shows the graphical simulation result of blast pressure at an equal location with previous case. This location is equal and applicable to all cases applied in this study. The analysis also shows the different in blast pressure with decreasing peak pressure pattern. The pressures obtained from the first transducer until the last transducer is 520 kPa, 290 kPa, 220 kPa and 180 kPa while the time taken is 1.20 msec, 3.00 msec, 5.20 msec and 7.60 msec respectively. The recorded highest blast pressure is exactly 1219.2 mm (4ft.) from behind the wall with pressure value of 520 kPa at 1.20 msec. This indicates that the wall reflects the propagating blast wave causing the pressure at that location to be the most amplified as the standoff distance is the nearest when compared to the other pressure transducers. The amplified pressure transducer is then reduced to the second pressure transducer by 250 kPa which is quite a huge amount of pressure reduction. This explains that, the plant may have reduced or absorb the blast wave causing the reduction of blast pressure in high amount. From the second until the fourth pressure transducer is then gradually decreasing as increased in standoff distance. Table 4.2 shows the recorded pressures and the time of arrival of blast wave for Case 3.

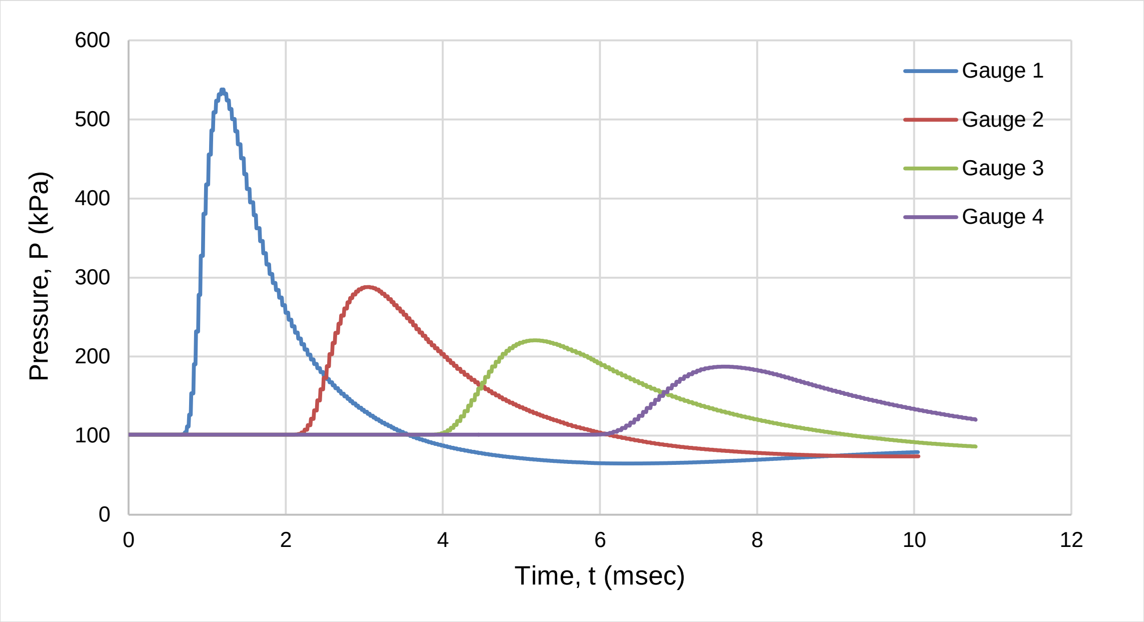

Figure 4.3 Change in blast pressure with plant subjected to blast load

Table 4.2 Recorded pressures and time of arrival for Case 3

Pressure Transducer	**Pressure Parameters**	
	Peak Pressure (kPa)	Time of Arrival (msec)
1	540	1.20
2	290	3.00
3	220	5.20
4	180	7.60

4.2.4 Blast subjected to RC wall and plant

Figure 4.4 shows the graphical simulation result from the same pressure transducer being located in AUTODYN. The analysis also presents various blast pressures from different transducers. From the graph obtained, the pattern of the graph is significantly decreasing as well as the other graphical results from other cases. The result from this case is 620 kPa, 310 kPa, 230 kPa and 190 kPa at the time of arrival of 1.20 msec, 2.75 msec, 4.60 msec and 7.25 msec respectively. The recorded of the highest blast pressure is from the first pressure transducer which is 1219.2 mm (4ft.) distance at 1.20 msec from the surface of the plant. Its difference in blast pressure from the second pressure transducer is 310 kPa which is greater than the amount of pressure reduction in Case 3 (with plant as barrier) in which it might be due to the presence of both plants and RC wall to act as barrier. The highly amplified pressure may indicate that the wall reflects the propagating blast wave causing the pressure at the first transducer to be highly amplified. As the distance goes further away from the charge weight, the pattern of the graph shows a gradually decreasing amount of pressure.

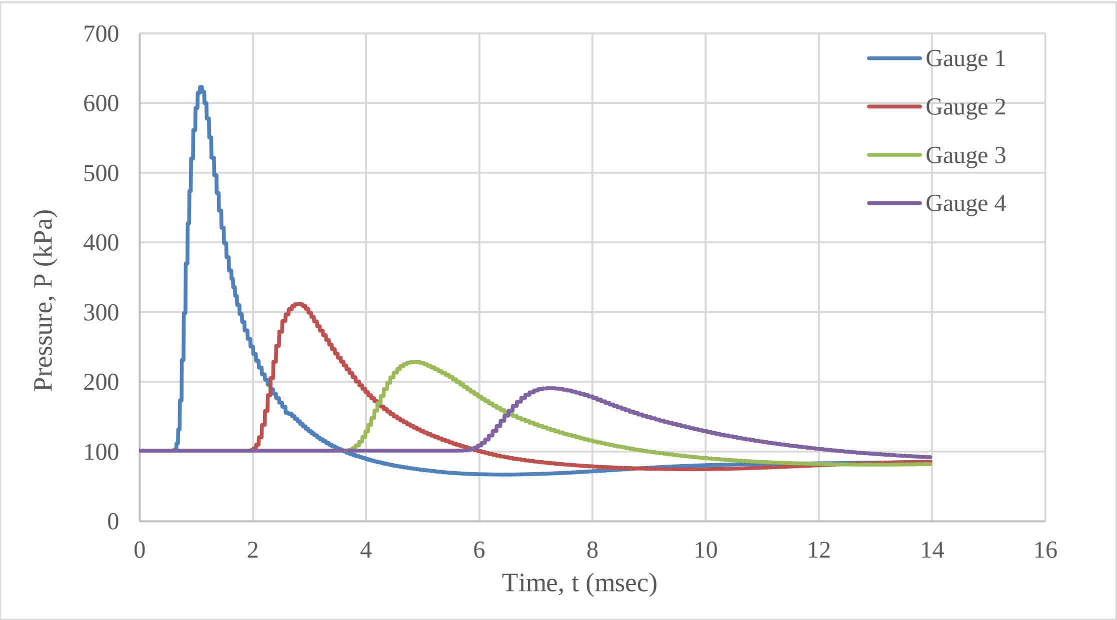

Figure 4.4 Change in blast pressure with plant subjected to blast load

Table 4.3 Recorded pressures and time of arrival for Case 4

Pressure Transducer	Pressure Parameters	
	Peak Pressure (kPa)	Time of Arrival (msec)
1	620	1.20
2	310	2.75
3	230	4.60
4	190	7.25

Table 4.4 shows the comparison of blast pressure at 2438.4 mm (8 ft.) from the charge weight. From the result obtained, it can be compared and stated that Case 3 with only plant as barrier showed the highest pressure reduction (290 kPa) when compared to other cases. This might be due to the reason that the plant is able to reduce or absorb blast pressure. Case 2 with only RC wall as barrier showed the least pressure reduction (1250 kPa). This can be said that the blast wave is reflected as it hits a hard surface (RC wall). The reflected blast wave had caused the blast pressure to be magnified. Case 4 which pressure reduction is in between (310 kPa) might be due to the presence of both RC wall and plant (hard and smooth surface) that provides both pressure magnification and reduction.

Table 4.4 Comparison of blast pressure at 2438.4 mm (ft.) from the charge weight

Case	Pressure (kPa)
2 (RC wall)	1250
3 (Plant)	290
4 (RC wall and plant)	310

4.3 Summary

From the simulation analysis conducted, all pressures for all cases with different barriers demonstrated the decrease in pressure as the distance increase. The comparison between the numerical simulation and research done by Yan has shown a comparative validation for this current study as the numerical simulation is able to achieve approximately close. It can also be observed that, among all the graphical results obtained, Case 3 with only plant as barrier has shown the greatest pressure reduction by taking gauge 2 as reference. The pressure recorded is 290 kPa at 3.00 msec.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This chapter concludes the results from the numerical investigation of RC wall and plant subjected to 30 lbs. TNT (13.61 kg) blast load. The following are the conclusions:

1. The validation of this numerical analysis between the peak blast pressure obtained in Case 1 (open space) and the blast pressure investigation reported by Yan has shown a closed result which is 490 kPa, both at a distance of 1219.2 mm (4ft.) to the right side of the charge weight.

2. The peak blast pressure impacted by 30 lbs. TNT blast load on plant alone (Case 3) has shown a substantial lower than the RC wall (Case 2) or with both RC wall and plant (Case 4) barrier. This is because, the plant might have reduce or absorb the blast wave while the RC wall might reflects the blast pressure causing it to be magnified.

3. The peak blast pressure obtained for RC wall (Case 3) is higher than both with RC wall and plant (Case 4) barrier. Case 3 has no plant modelled in it. Thus, it might be due to the absence of the plant that caused the blast pressure in Case 3 to be magnified higher than Case 4 in which the plant is present.

5.2 Recommendations for Future Research

Recommendations for future numerical research are as follows:

1. Plant can be further research whether it is applicable to replace the wall barrier.

2. Further investigations are needed to adjust the gridline used for the simulation and applied to all cases for an exact result.

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