TUGAS AKHIR – MO 091336

PERANCANGAN PELAT BERPENEGAR TAHAN LEDAKAN

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JURUSAN TEKNIK KELAUTAN

Fakultas Teknologi Kelautan

Institut Teknologi Sepuluh Nopember

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DEPARTMENT OF OCEAN ENGINEERING

Faculty of Marine Technology

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DESIGN OF BLAST RESISTANT STIFFENED PLATE

FINAL PROJECT

Submitted in Partial Fulfillment of the Requirement
For the Bachelor Degree of Engineering
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Faculty of Marine Technology
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By:
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SURABAYA, AUGUST 2014

PERANCANGAN PELAT BERPENEGAR TAHAN LEDAKAN

Nama : Raditya Danu Riyanto

NRP : 4310 100 097

Dosen Pembimbing : Ir. Handayanu, MSc, PhD

Yoyok Setyo Hadiwidodo, ST, MT, PhD

Perancangan bangunan lepas pantai haruslah memenuhi beberapa kriteria kondisi termasuk kondisi kecelakaan. Ledakan adalah salah satu kecelakaan yang sangat berbahaya untuk operasional bangunan lepas pantai. Tugas akhir ini akan membahas bagaimana cara merancang pelat berpenegar tahan ledakan yang diaplikasikan di bagian-bagian yang potensial terjadi ledakan berdasarkan DNV RP C204 – *Design against accidental loads*. Tujuan tugas akhir ini adalah menginvestigasi respon struktur pelat (*deformation* φ and *stress* σ) yang terkena beban ledakan; menginvestigasi pengaruh variasi konfigurasi penegar, geometri penegar, dan durasi ledakan terhadap respon struktur pelat; serta merancang pelat berpenegar tahan ledakan. Prosedur pelaksanaannya yaitu pemodelan geometri pelat, validasi *meshing* menggunakan *mesh sensitivity* dan perhitungan manual, analisa ledakan dan seluruh analisa menggunakan software ANSYS 14.5. Hasilnya yaitu respon maksimal adalah pelat dengan konfigurasi X dan geometri strip dengan *midpoint displacement* 75.78 mm dan *von mises stress* 347.77 MPa, sedangkan respons minimal terjadi pada pelat dengan konfigurasi sejajar dan geometri strip dengan *midpoint deformation* 59.10 dan *stress* 347.12 MPa. Dan pelat berpenegar tahan ledakan yaitu pelat dengan konfigurasi sejajar dan geometri T yang mampu mereduksi 36.87% deformasi pelat tanpa penegar dengan berat yang lebih ringan dari konfigurasi yang lain. Berdasarkan kriteria perancangan, redesign tidak perlu dilakukan.

Kata kunci: beban ledakan, deformasi, stress, geometri penegar, konfigurasi penegar, perancangan

PREFACE

Assalamu'alaikum Wr. Wb.

Alhamdulillah, praise God Allah SWT for all the mercy and for the entire miracle, the author finally finishes his Final Project successfully. This Final Project, entitled "Design of Blast Resistant Stiffened Plate" is a real hard work from college student and will be the pride for the author to present it for the society. Shalawat and Salam always praised to Prophet Muhammad SAW.

Author wants to say thanks for all the help and guidance from all the person mentioned so that the project is finished and the book is on the hand of the readers:

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3. Yoyok Setyo Hadiwidodo ST, MT, PhD as 2nd Supervisor
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5. All the lecturer at Faculty of Marine Technology, ITS Surabaya
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7. Indria Oktaviani, for the tireless support
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9. All my friends, family, and colleagues for the support

As a human, author will never be a perfect writer and so is this book, which is far from perfect. Critics and suggestions are welcome.

Surabaya, August 2014

Author

Raditya Danu Riyanto

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φ	deformation	(mm)
σ	stress	(MPa)
ρ	density	(kg/m^3)
t	plate thickness	(mm)
L_x	plate width in x direction	(mm)
L_y	plate width in y direction	(mm)
D	plate bending stiffness	($kg.mm^2$)
P(t)	Overpressure at time t	(kg/mm^2)
Ps	Maximum Overpressure	(kg/mm^2)
$m\ddot{u}$	Inertial coefficient	
$b\dot{u}$	Damping coefficient	
ku	Restoring coefficient	
f(t)	Excitation Force	(kg/mm^2)
I	Moment of Inertia (Area)	(mm^4)
S	Section Modulus	(mm^3)
F	Frequency	(Hz)
T	Period	(s)

SECTION I

INTRODUCTION

1.1 Background

The design of offshore structure should satisfy several conditions including the extreme loading condition. Extreme loading condition, also known as Accidental Load, consist of Dropped Object, Ship Collision, Fire Hazard, and Blast Hazard (DNV, 2012). Dropped object is the accident when the shackle or sling of lifted object is broken causing object move freely downward and hit the topside structure. Ship collision is when the platform hit by ship and causing the severe damage to the structure. Fire and blast hazard are mainly caused by the leakage of processing/power component.

Figure 1.1. The Accident of Piper Alpha Explosion (BBC.uk, 2010)

The blast hazard is the one most dangerous accident that could happen on the offshore structure operation. Blast is a pressure disturbance caused by the sudden release of energy. People often think of blasts in terms such as the detonation of an explosive charge. However, there are many other blast sources that have the potential to cause damage. For example, chemicals may undergo a rapid decomposition under certain conditions. Flammable materials mixed with air can form vapor clouds that when ignited can cause very large blasts. Blasts are not always caused by combustion; they can also result from any rapid release of energy that creates a blast wave, such as a bursting pressure vessel from which compressed air expands, or a rapid phase transition of a liquid to a gas (Dusenberry, 2010). There are many case of blast accident that leads a facility to total damage and loss of life, both land-based structures like Fukushima Nuclear Reactor accident or offshore structure like Piper Alpha accident. The accident of Piper Alpha, 1988, an offshore platform at North Sea, collapsed after a series of gas blast. The Piper Alpha Platform was designed without considering the blast load, killing 169 men and total capital loss of US$ 1.7 million (McGinty, 2010). These accidents are strong evidence that a blast resistant structure is important so that would be no casualties regarding to this type of accident in the future.

This project will provide a method to build a panel of stiffened plate that resists to a blast loading based on DNV RP C204 – Design against accidental loads; it can be applied to cover vulnerable area that has a potential blast accident. As stated by Rajendran and Lee (2008), stiffened plate structure is widely used at marine industry such as ship hull or offshore topside structure. This project will vary the stiffener configuration and blast duration to gain the best stiffener configuration and the effect of blast duration to the structure. This may lead us to a safer design of offshore structures, especially the stiffened plate structures.

1.2 Problems

This project will focus on solving the problems:

1. How are the midpoint responses (deformation φ and stress σ) of varied stiffened plate subjected to blast loading?
2. How are the variation of stiffener geometry, stiffener configuration, and blast duration affect the responses?
3. What is the best configuration of the stiffener to be designed based on the responses generated and criteria provided?

1.3 Purpose

This project aims to:

1. Calculate the midpoint responses (deformation φ and stress σ) of plate subjected to blast loading.
2. Investigate the effect of stiffener geometry, stiffener configuration, and blast duration to the responses.
3. Design a blast resistant stiffened plate based on the best stiffener configuration response result.

1.4 Benefit

The motivation for this project arises from primary concern for the design of plate structures against blast loads. Through this project, hopefully there will be a better understanding of blast load characteristic and creates a safer design of stiffened plate against blast load.

1.5 Limitation

This project, in order to focus on the design calculation and for the sake of simplicity, limited by these condition:

1. The material properties of plates are based on ASTM A36 with yield stress at 36 ksi (255 MPa).
2. The geometry used for this analysis is 1000x1000 mm^2 area, with the thickness calculated from DNV OS C101-Design of Offshore Steel Structure, General (LRFD Method):

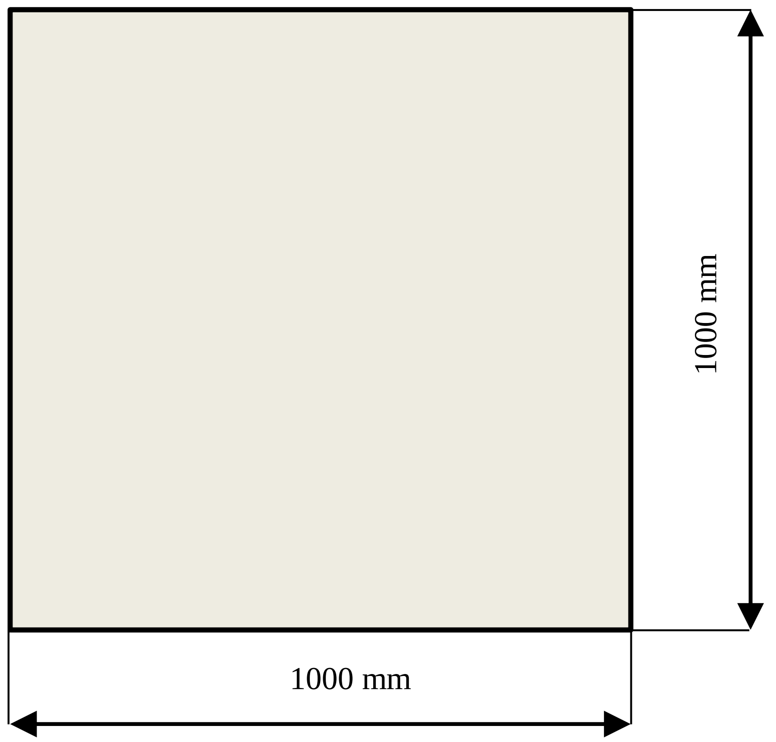


Figure 1.2. Plate Geometry

3. The stiffeners properties are 25 mm thick and 50 mm height as the preliminary design size and limited into 2 pieces, the shape will be varied on “T”, “L” and stripe configuration.
4. The finite element analysis tool used is ANSYS Explicit Dynamic Modules. Each edge of the plate considered as fixed support.
5. The blast loading modeled as simplified time history dynamic pressure. The pressure are fixed at vapor density ρ=1.240 kg/m^3 , that is the vapor density of propane gas explosion (Hall, 1985) and varied at time 50, 100, and 200 ms.
6. The Recommended Practice to be used is DNV RP C204-Design against Accidental Loads.
7. The Design Criteria to be used is DNV OS C101-Design of Offshore Steel Structure, General (LRFD Method)
8. The structural steel resistance curve is an elastic-perfectly plastic curve with strain hardening.
9. The overlapping and weldability of the stiffener configuration crossing is neglected (Kadid, 2008).
10. The critical damping ratio is set at 0.10

SECTION II

LITERATURE REVIEW & BASIC THEORY

2.1 Literature Study

There has been an increased activity in blast loading research in the last two decades. Most of these were empirical research, but in recent years, modern computers and powerful finite element packages, facilitate the numerical study.

Comparison between experimental and numerical responses of steel plates subjected to air blast loads has been indicated the accuracy of modern calculation methods and computational codes. Modern computational codes can predict the dynamic response of unstiffened plates accurately, specially the forced vibration phase and the first pulses of the response. However, there are differences between different codes because its shell elements definition. These differences could result in different predictions, particularly in free vibration phase and in nonlinear studies (Jacinto, et al., 2001).

A numerical investigation generated by Kadid (2008) and Tavakoli (2013), by modelling some varied stiffened plates subjected to uniform blast loading. In this paper the nonlinear dynamic response of square steel stiffened plates subjected to uniform blast loading was studied. Stiffener configurations and boundary conditions, which maybe affect the dynamic response of the plates subjected to blast loading was considered.

Su (2012) in her thesis, conducted a numerical analysis of pipe rack in shape of hollow steel section (HSS) subjected to uniform blast loading. This paper has been an investigation on the phenomenon of hydrocarbon explosions, the resulting blast load, and the structural response following such an event. Although a hydrocarbon explosion is considered a rare accidental event, effort should be made to reduce the amount of structural damage if an explosion was to occur.

2.2 General Behaviors of Plate Bending

Plates and shells are initially flat and curved structural elements, respectively, for which the thicknesses are much smaller than the other dimensions.

$$t \ll L_x, L_y \qquad (1)$$

Included among the more familiar examples of plates are table tops, street manhole covers, side panels and roofs of buildings, turbine disks, bulkheads and tank bottoms. Many practical engineering problems fall into categories “plates in bending" or “shells in bending." Plates may be classified into three groups: (a) thin plates with small deformations, (b) thin plates with large deformations, and (c) thick plates. According to the criterion often applied to define a thin plate (for purposes of technical calculations) the ratio of the thickness to the smaller span length should be less than 1/20 (Ugural, 1981)

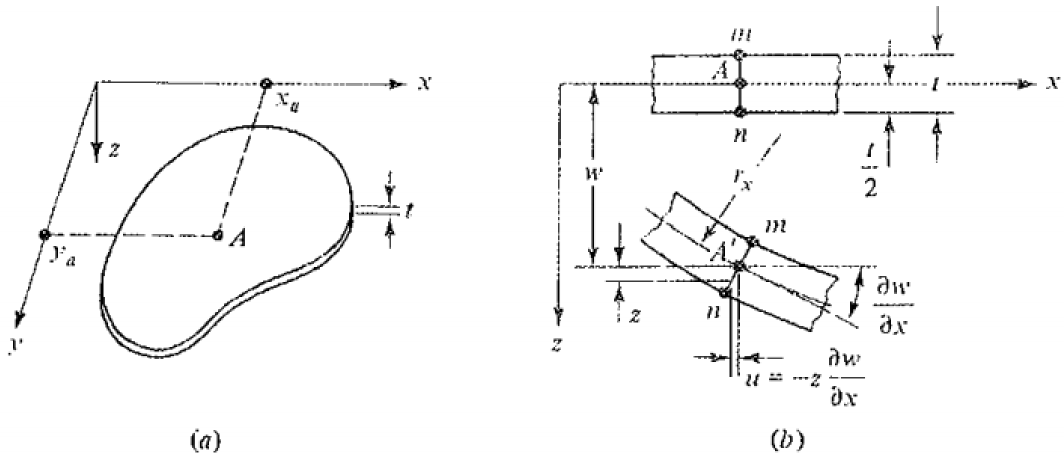


Figure 2.1. Plate Deformation General Assumptions (Ugural, 1981)

Consider a load-free plate, shown in figure above, in which the xy plane coincides with the midplane and hence the z deformation is zero. The components of deformation at A point, occurring in the x, y, and z directions, are denoted by u, v and w respectively. When, due to lateral loading, deformation takes place, the midsurface at any point (x_a, y_a) has deformation w. The fundamental assumptions of the small-deformation theory of bending or so-called classical theory for isotropic, homogeneous, elastic, thin plates are based on the geometry of deformations. They may be stated as follows:

a) The deformation of the midsurface is small compared with the thickness of the plate. The slope of the deflected surface is therefore very small and the square of the slope is a negligible quantity in comparison with unity.
b) The midplane remains unstrained subsequent to bending.
c) Plane sections initially normal to the midsurface remain plane and normal to that surface after the bending. This means that the vertical shear strains γ_{xz} and γ_{yz}, are negligible.
d) The stress normal to the midplane is small compared with the other stress components and may be neglected.

2.2.1 Governing Equation of Plate Deformation

The components of stress generally vary from point to point in a loaded plate. These variations are governed by the conditions of equilibrium of statics. Fulfillment of these conditions establishes certain relationships known as the equations of equilibrium.

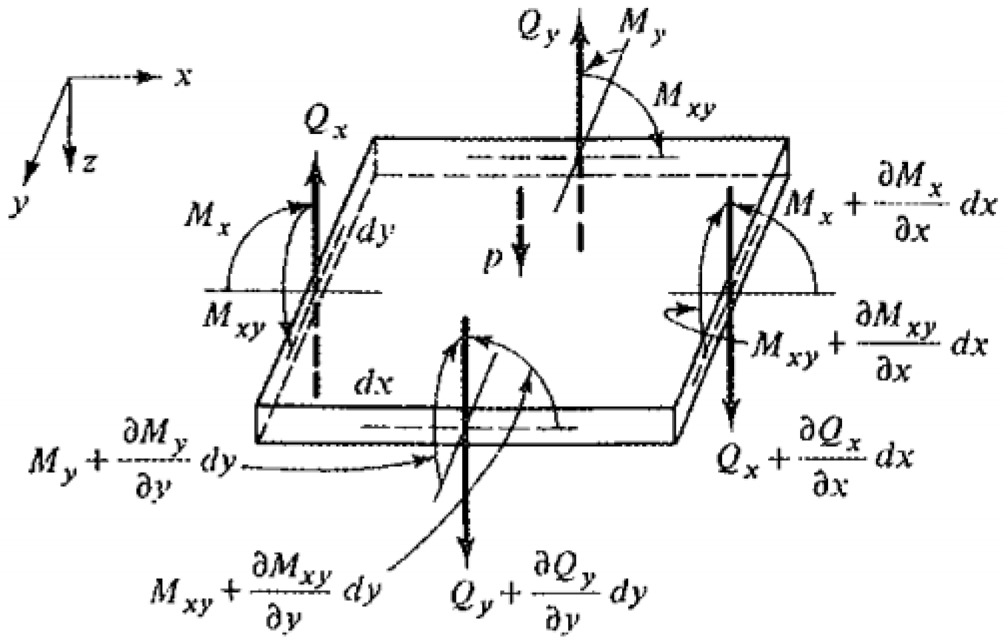


Figure 2.2. Forces and Moments acting on Plate (Ugural, 1981)

Consider an element dx dy of the plate subject to a uniformly distributed load per unit area as stated by Figure 2.2. The element is very small, for the sake of simplicity the force and moment components may be considered to be distributed uniformly over each face, in the figure they are shown by a single vector, representing the mean values applied at the center of each face. With change of location, as for example, from upper left corner to the lower right corner, one of the moment components, say Mx acting on the negative x face, varies in value relative to the positive x face. This variation with position may be expressed by a truncated Taylor's expansion in general form:

$$M_i + \frac{\partial M_i}{\partial i} di \qquad (2)$$

And moment at x, y, and xy plane direction, symbolized Mx, My, and Mxy respectively, defined by:

$$M_x = -D(\frac{\partial^2 w}{\partial x^2} + v\frac{\partial^2 w}{\partial y^2})$$

$$M_y = -D(\frac{\partial^2 w}{\partial y^2} + v\frac{\partial^2 w}{\partial x^2})$$

$$M_{xy} = -D(1-v)\frac{\partial^2 w}{\partial x \partial y}) \qquad (3)$$

From the state above we can build the plate deformation governing equation:

$$\frac{\partial^4 w}{\partial x^4} + \frac{\partial^4 w}{\partial x^2 y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{p}{D} \qquad (4)$$

The equation above is firstly stated by Lagrange in 1811 (Ugural, 1981), can also be written in concise form:

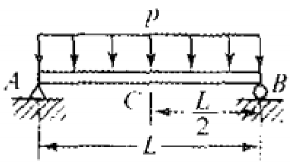
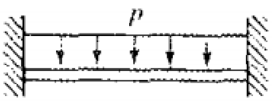
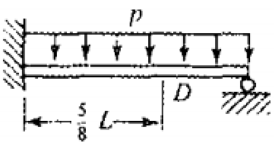
$$\nabla^4 w = \frac{p}{D} \qquad (5)$$

2.2.2 Strip Method to Solve Rectangular Plate with Arbitrary Boundary Condition under Various Loading

H. Grashof stated an efficient way for computing deformation and moment in a rectangular plate with arbitrary boundary conditions (Ugural, 1981). This so-called *strip method* that is the plate is assumed to be divided into systems of strips, each strip regarded as functioned as a beam. The method permits qualitative analysis of the plate behavior with ease but is less adequate, in general, in obtaining accurate quantitative results.

Note, however, that because this method always gives conservative values for both deformation and moment, it is often employed in practice. A very efficient engineering approach to design of the rectangular floor slabs is also based upon the strip method. Before proceeding to a description of the method, it will prove useful to introduce maximum deformation and moments of a beam with various end conditions. Expressions for such quantities for a beam of length L subjected to a uniform load p, derived from the mechanics of materials, are given in table below:

Table 2.1. Beam with Various Boundary Condition under Uniform Load P (Ugural, 1981)

	$w_c = \frac{5}{384}\frac{pL^4}{EI}$	$M_c = \frac{1}{8}pL^2$	$M_a = M_b = 0$
	$w_c = \frac{1}{384}\frac{pL^4}{EI}$	$M_c = \frac{1}{24}pL^2$	$M_a = M_b = \frac{1}{12}pL^2$
	$w_c = \frac{1}{192}\frac{pL^4}{EI}$	$M_d = M_{max} = \frac{9}{128}pL^2$	$M_a = \frac{1}{8}pL^2$ $M_b = 0$

With this guidance of configuration of beams under uniform loading with various boundary conditions, it is convenient to calculate a rectangular plate under deformation and bending moments with this method. Note that each strip should satisfy the whole system. Taking an example of rectangular plate with simply supporting system subjected by uniform pressure:

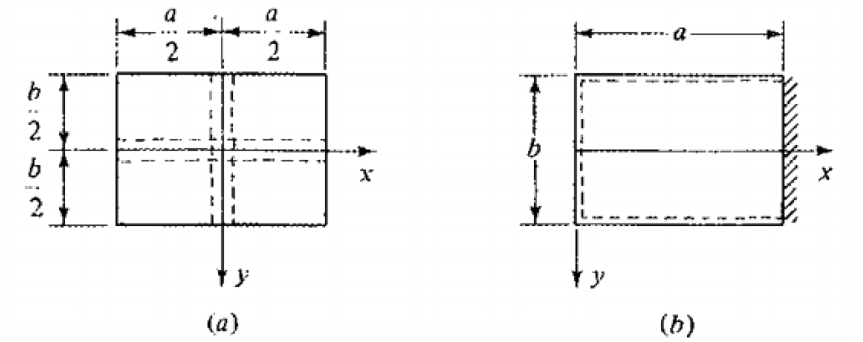


Figure 2.3. Plate Stripping (Ugural, 1981)

System (a) is the stripped plate and each fraction threatened as beam and (b) is the original state condition. Note that these following conditions should be applied to obtain the bending moments and the deformation:

$$W_a = w_b \text{ and } P_0 = P_a + P_b \text{ at } (x = y = 0)$$

DNV RP-C204 gives more accurate calculations rigid plastic theory combined with elastic theory that may be used. In the elastic range the stiffness and fundamental period of vibration of a fixed plate under uniform lateral pressure can be expressed as:

$r = k_1 w$ = resistance-displacement relationship for plate centre

$k_1 = \psi \frac{D}{s^4}$ = plate stiffness

$T = \frac{2\pi}{\eta}\sqrt{\frac{\rho t s^4}{D}}$ = natural period of vibration

$D = E\frac{t^3}{12(1-v^2)}$ = plate bending stiffness

..................*(6)*

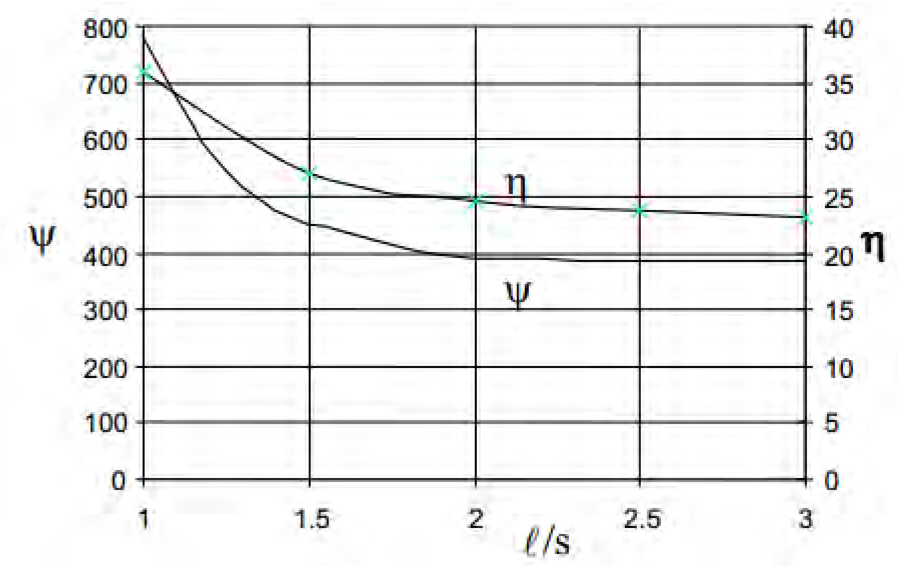


Figure 2.4. Coefficient ψ and η

2.3 Blast Phenomena and Loading

Blast is a pressure disturbance caused by the sudden release of energy. People often think of blasts in terms of explosions such as the detonation of an explosive charge. However, there are many other blast sources that have the potential to cause damage. For example, chemicals may undergo a rapid decomposition under certain conditions. These events are often referred to as runaway reactions. Flammable materials mixed with air can form vapor clouds that when ignited can cause very large blasts. Blasts are not always caused by combustion; they can also result from any rapid release of energy that creates a blast wave, such as a bursting pressure vessel from which compressed air expands, or a rapid phase transition of a liquid to a gas. (Dusenberry, 2010)

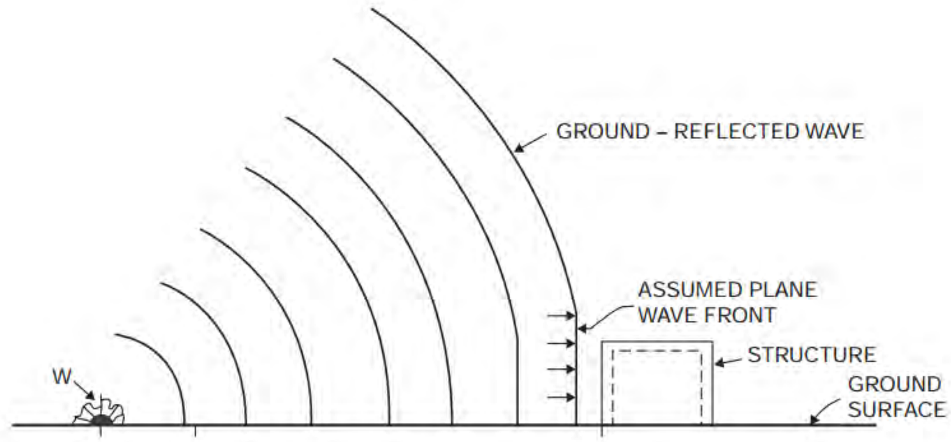


Figure2.5. Blast Wave Propagation (Dusenberry, 2010)

Blasts are separated into two types; (a) detonations and (b) deflagrations. A typical gas explosion is of the deflagration type, while an explosion of condensed explosives (or a very powerful gas explosion) is in the detonation range.

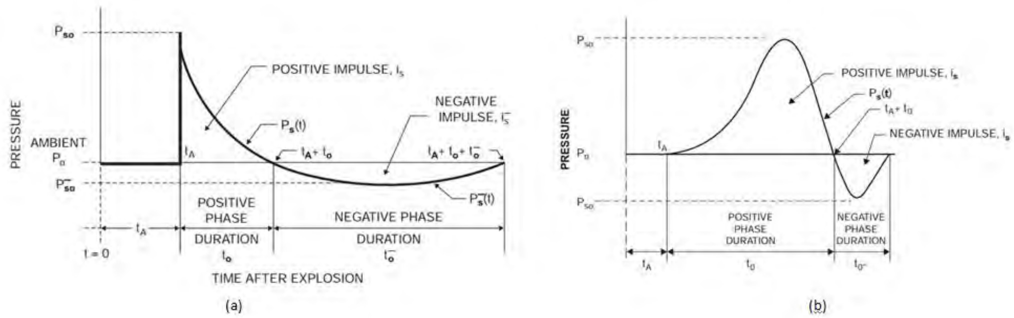


Figure2.6. The Typical Load Diagram for (a) Detonation or Shock Wave and (b) Deflagration or Pressure Wave (Dusenberry, 2010)

As stated by Su (2012), a detonation is characterized by an instantaneous pressure rise (no rise time), and often a negative pressure after Tp (positive phase duration). As a shock wave travels away from the source, the pressure amplitude decreases, and the duration of the blast load increases. Overexpansion at the center of the blast creates a vacuum in the source region and a latter creates a reversal of gas motion. This negative pressure region expands outward, causing a negative pressure (below ambient), which trails the positive phase. The negative phase pressure is generally lower in magnitude (absolute value) but longer in duration than the positive phase.

The detonation empirical function as provided by Bangash (2012) is widely accepted, this equation also used by Spranghers (2012) and Vantomme (2012) for measuring aluminum plates under blast load:

$$P(t) = P_0 + P_s\left(1 - \frac{T}{t_p}\right)e^{\left(-\frac{at}{t_p}\right)} \quad \text{.......................}(7)$$

Where:

P(t)	= Overpressure at time t	*(kg/m²)*
Ps	= Maximum Overpressure	*(kg/m²)*
t	= Time	*(s)*
t_p	= Blast duration	*(s)*
a	= Negative time constant	

The maximum value of this negative pressure does not normally play any important role, since this pressure is of a magnitude much smaller than the positive peak overpressure. A deflagration is characterized by a rise time, and a slower decrease to zero within the positive phase duration time. A common simplification of the shape of the pressure diagrams is to linearize the variation, as shown in figure below, as provided by Merx (1992):

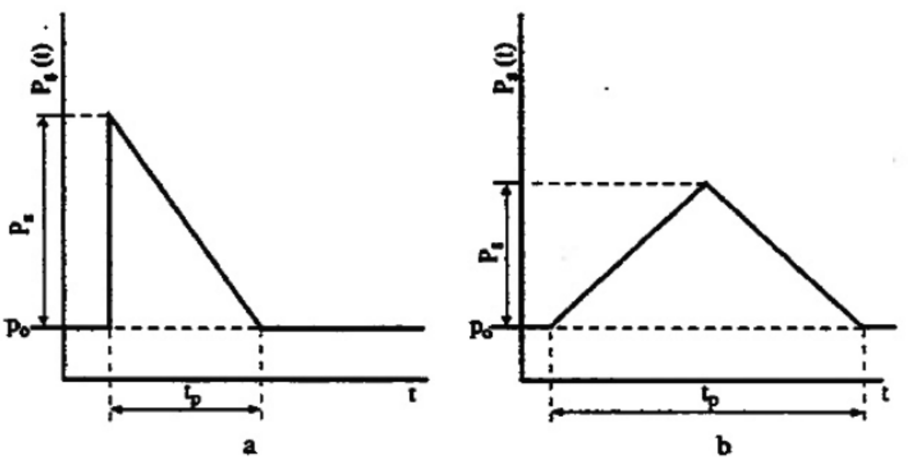


Figure 2.7. Simplified (a) Detonation and (b) Deflagration (Merx, 1992)

These simplifications are easier to produce because it neglects the presence of curvature and forms a rectangle shape instead. This simplification is still valid because the maximum overpressure and blast positive duration has the same value as the empirical ones. The simplified blast load (triangular load) is stated as follow:

$$P(t) = Ps(1 - \frac{t}{t_p}) \quad \text{...(8)}$$

Where:

P(t)	= Overpressure at time t	*(kg/m²)*
Ps	= Maximum Overpressure	*(kg/m²)*
t	= Time	*(s)*
t_p	= Blast duration	*(s)*

The equation above is the simplified equation for detonation blast, while the deflagration is stated as follow:

$$P(t) = \begin{cases} Ps\left(\frac{t}{t_p}\right) & 0 < t_p < \frac{t}{2} \\ Ps\left(1 - \frac{t}{t_p}\right) & \frac{t}{2} < t_p < t \end{cases} \quad \text{..............(9)}$$

Where:

P(t)	= Overpressure at time t	*(kg/m²)*
Ps	= Maximum Overpressure	*(kg/m²)*
t	= Time	*(s)*
t_p	= Blast duration	*(s)*

2.4 Interaction between Blast and Structure

A blast, when meeting a structure or an obstacle creates a dynamic load on the structure. This is caused by air displacement in the direction of the blast-wave. The air displacement from a blast is referred to as an *explosion wind*, and causes a dynamic overpressure given by the following formula:

$$P_s = \frac{1}{2} \times C_D \times \rho_s \times v_s^2 \quad \text{........................(10)}$$

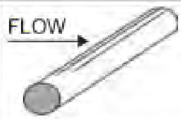
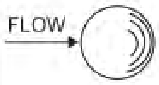
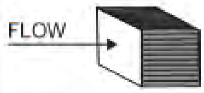
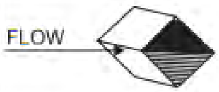
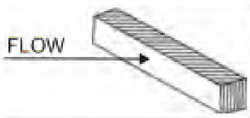
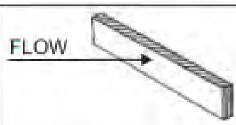
Where:

Ps	= Dynamic Overpressure	(Pa)
C_D	= Drag Coefficient	
ρ_s	= Air Density within a blast	(kg/m³)

v_s = Blast wave propagating velocity (m/s)

C_D is drag coefficient which is dependent on the shape of the structure (projected area) and its orientation relative to the blast front.

Table 2.2. Drag Coefficient on Various Shapes (Dusenberry, 2010)

Shape	Sketch	C_D
Circular cylinder (Long rod), side-on		1.20
Sphere		0.47
Rod, end-on		0.82
Disc, face-on		1.17
Cube, face-on		1.05
Cube, edge-on		0.80
Long rectangular member, face-on		2.05
Long rectangular member, edge-on		1.55
Narrow strip, face-on		1.98

It is often common to differentiate between three types of extreme conditions when dealing with blast wave interactions on a structure. Situation (A) in figure below represents a case where the blast wave runs over a large surface without hindrance. The load on the surface will for this case be taken equal to the overpressure PS of the incident wave. In case (B), the blast wave is on a path perpendicular to a surface of very large dimensions. There will be minimal rarefaction effects from the edges, and the load on the surface can be taken as the overpressure from the reflected blast wave Pr. For case (C) we are dealing with an object of small dimensions, the rarefaction progresses so quickly that any reflection can be neglected. Furthermore, one can assume that the pressure difference between the front and back part of the part is so small that only the dynamic pressure PD is considered. It should be noted that in most structures, a combination of these three cases must be considered.

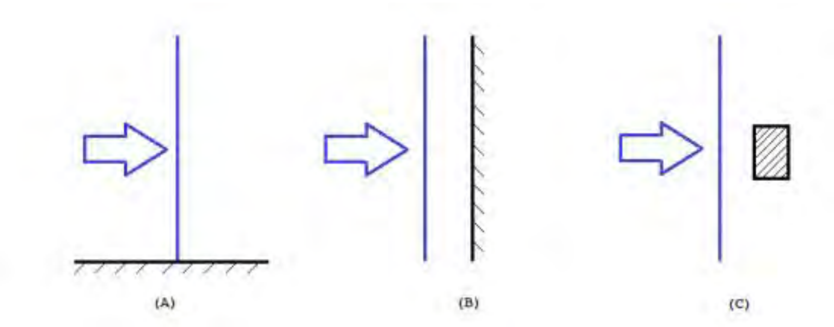


Figure 2.8. A schematic representation of the pressure variation (Dusenberry, 2010)

2.5 Properties of Various Explosive Gases

The blast wave is mainly influenced by gas density and deflagration velocity. Hall et. al. (1985) studied the behavior of hydrocarbon explosion in free air.

Table 2.3. Properties of Explosive Gases (Hall, 1985)

Gas		Density (kg/m^3)	Energy Release per Unit Volume (MJ/m^3)	Blast Velocity (m/s)
Acetylene	C_2H_2	1.223	1.503	1,830
Ethylene	C_2H_4	1.225	1.348	1,705
Propane	C_3H_8	1.240	1.238	1,660
Methane	CH_4	1.198	1.204	1,590
Ammonia	NH_3	1.151	1.063	1,095
Hydrogen	H_2	1.180	1.179	1,830

The typical vapor gas blast duration at petrochemical facilities is at 50 up to 200 ms (Su, 2012). The effect of duration variation is the most important to be accounted for, due to the short-and-heavy load characteristic of blast load, and it is implies the magnitude of impulse generated from the loads.

2.6 Response of Blast Loaded Structures

The response of structural components can conveniently be classified into three categories according to the duration of the explosion pressure pulse, td, relative to the natural period of vibration of the component, T (DNV, 2012):

Impulsive domain *td/T < 0.3*

Dynamic domain *0.3 < td/T < 3*

Quasi-static domain *td/T > 3*

- Impulsive domain:

The response is governed by the impulse defined by:

$$I = \int_0^{t_d} F(t)dt \quad \text{.........................} (11)$$

Hence, the structure may resist a very high peak pressure provided that the duration is sufficiently small. The maximum deformation, w_{max}, of the component can be calculated iteratively from the equation:

$$I = \sqrt{2m_{eq} \int_0^{w_{max}} R(w)dw} \quad \text{.............} (12)$$

Where:

R(w) = Force-deformation relationship for the component

m_{eq} = Equivalent mass for the component

- Quasi-static domain:

The response is governed by the peak pressure and the rise time of the pressure relative to the fundamental period of vibration. If the rise time is small the maximum deformation of the component can be solved iteratively from the equation:

$$w_{max} = \frac{1}{F_{max}} \int_0^{w_{max}} R(w)dw \quad \text{.........................} (13)$$

If the rise time is large, the maximum deformation can be solved from the static condition:

$$F_{max} = R(w_{max}) \quad (14)$$

- Dynamic analysis:

The response has to be solved from numerical integration of the dynamic equation of equilibrium. In most cases, the domain of blast duration is at dynamic region.

2.6.1 Dynamic Analysis of Blast Loaded Structure

Dynamic analysis is characterized by the time variant change of both loading and response. The solution of dynamic response should account for all time variant response and form it as a time history result. In general, dynamic equilibrium equation is stated as follow:

$$m\ddot{u}(t) + b\dot{u}(t) + ku(t) = f(t) \quad (15)$$

Where:

$m\ddot{u}(t)$ = Inertial force, the product of mass and acceleration

$b\dot{u}(t)$ = Damping force, the product of viscous damping

$ku(t)$ = Restoring force, the product of stiffness constant K and displacement

$f(t)$ = Excitation Force

An object subjected to the blast loading could be modelled as SDOF or MDOF system (DNV, 2012).

a. SDOF System – Continuous System

The SDOF system used in analyzing the blast loading to the structures is the continuous system with assumed shape function (φ) also known as Biggs' method. The Biggs' method considers the system component as a generalized form (Clough, 1993):

$m = \int_0^l m\varphi^2 dx + \sum_i^n M_i \varphi_i^2$ = *generalized mass* *(16)*

$b = \int_0^l b\varphi^2 dx + \sum_i^n b_i \varphi_i^2$ = *generalized damping* *(17)*

$k \quad = \int_0^l EI(\varphi'')^2 dx + \int_0^l k(x\varphi^2)dx + \sum_i^n K_i \varphi_i$ *= generalized stiffness (18)*

$p(t) = \int_0^l q(x,t)\varphi dx + \sum_i^n F_i \varphi_i$ *= generalized excitation force (19)*

Where φ is the assumed shape function, the integral parts show the continuous form of the system while the Σ shows the several discrete elements or forces may be present.

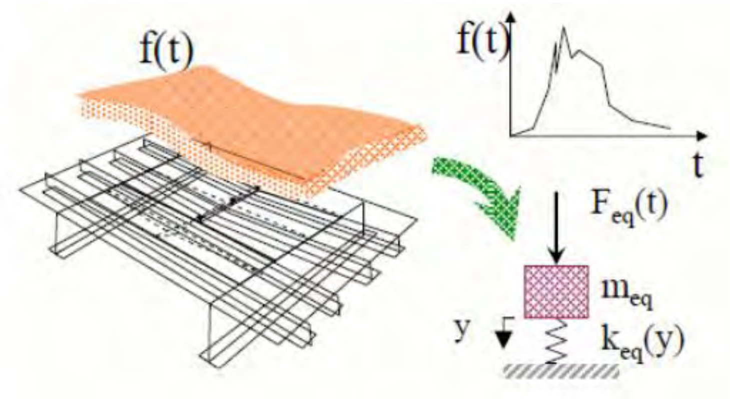


Figure 2.9. SDOF Analysis Procedure (Su, 2012)

b. MDOF System

For scenarios such as a topside frame structure being exposed to a blast load, the problem can no longer be simplified as a SDOF-system, and more advanced methods have to be implemented. The most common method is to use the Finite Element Method (FEM)/Finite Element Analysis (FEA), utilizing its ability to handle complicated geometries and boundaries. The Finite Element Analysis (FEA) will divide the system into elements based on mesh setting on the solver software. Meshing is the process to divide the plates and stiffeners into small elements and solve the numerical integration. This process will integrate these following equations:

$$\{F(t)\} = [K]\{d\} + [B]\{\dot{d}\} + [M]\{\ddot{d}\} \quad \text{.............(20)}$$

Where:

$[K] = \sum_{i=1}^{N}[k_i]$ = Stiffness Matrix

$[B] = \sum_{i=1}^{N}[b_i]$ = Damping Matrix

$[M] = \sum_{i=1}^{N} [m_i]$ = Inertial Matrix

$\{F\} = \sum_{i=1}^{N} \{f_i\}$ = Excitation Force Matrix

The matrices consist of hexahedron elements with 8 nodes (ANSYS, 2010):

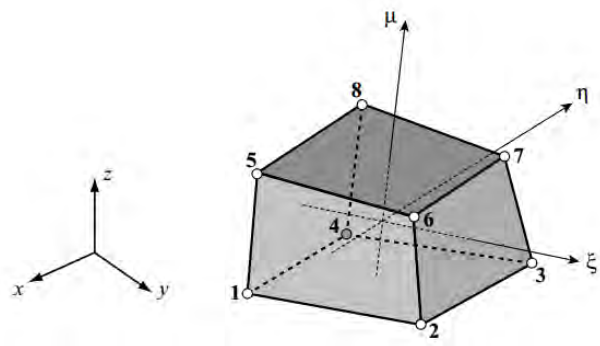


Figure 2.10. Hexahedron elements with 8 nodes (ANSYS, 2012)

2.7 Stiffened Plate Design Criteria based on DNV OS-C101-Design of Offshore Steel Structure, General (LRFD Method)

Design criteria chosen on this project is DNV OS-C101-Design of Offshore Steel Structure, LRFD method. LRFD method provides fairer loading by multiplying both loads and resistance to create safer design and yet give economically beneficial result. (bgstructuralengineering.com, 2008)

2.7.1 Design criteria for plates and girders

a. General Design Format using LRFD Method

The level of safety of a structural element is considered to be satisfactory if the design load (S_d) does not exceed the design resistance (R_d).

$$S_d \leq R_d \quad (21)$$

Or:

$$\gamma_f . F_k \leq \varphi R_k \quad (22)$$

Where the design load factor γ_f and design resistance factor φ is determined by specific limit state condition, in this case, the limit state used is ALS (Accidental Limit State).

b. Minimum Dimension for Plate and Girders

The thickness of plate subjected to lateral pressure shall not be less than:

$$t = \frac{14.3 t_0}{\sqrt{f_{yd}}}\ (mm) \quad \text{......(23)}$$

Where:

f_{yd} = design yield strength (N/mm2),

= fy/γ_m

t_0 = 7 mm for primary structural elements

γ_m = material factor = 1.15 for steel

The section modulus S_s for longitudinals, beams, frames and other stiffeners subjected to lateral pressure shall not be less than:

$$S_S = \frac{l^2 s p_d}{k_m \sigma_{pd} k_{ps}}\ 10^6 (mm^3), minimum\ 15.10^3 (mm^3) \quad \text{......(24)}$$

l = stiffener span (m)

km = bending moment factor

= 12 for fixed ends

σpd = design bending stress (N/mm2)

kps = fixity parameter for stiffeners

= 1.0 if at least one end is fixed

2.7.2 Accidental Limit States (ALS)

As stated by DNV (2011), structures shall be checked in ALS in two steps:

a) Resistance of the structure against design accidental loads
b) Post-accident resistance of the structure against environmental loads should only be checked when the resistance is reduced by structural damage

caused by the design accidental loads (the response exceeds elastic region of the material).

DNV also states that if non-linear, dynamic finite element analysis is applied for design, it shall be verified that all local failure mode, e.g. strain rate, local buckling, joint overloading, joint fracture, are accounted for explicit evaluation.

a. Load and Resistance Factor for ALS

For Accidental Limit State, the load and resistance factors are defined below:

Table 2.4. Load and Resistance Factor for ALS

No.	Parameter	Value	Remarks
1.	γ_f	1.0	Load factor
2.	F_k	Calculated	Characteristic loads
3.	φ	$\frac{1}{\gamma_m}$	Resistance factor
4.	γ_m	1.15	Material factor for steel
5.	R_k	Based on resistance curve for each material	Characteristic resistance

2.8 Resistance Curves (Stress-Strain Curve) based on DNV RP C204-Design against Accidental Loads

Resistance curve defines the relation between the stress (Resistance) and strain (Deformation) relationship of steel material. This curve defines the behavior of the material under its loading. The classifications of resistance properties curve are defined below:

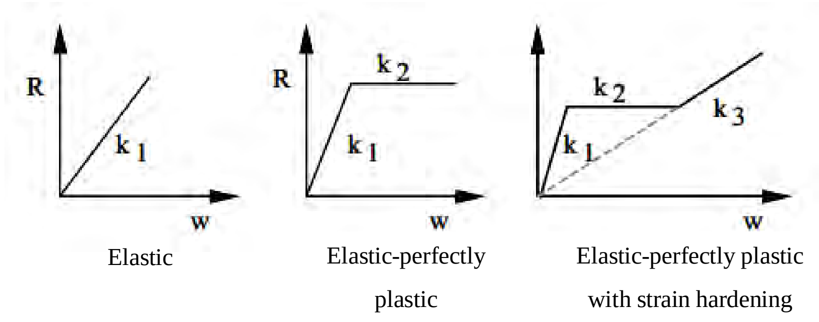


Figure 2.11. Classification of Resistance Properties

- Elastic: Elastic material, small deformations.
- Elastic-perfectly plastic: Elastic perfectly plastic material. The material characteristic after the strain exceeds the elastic region remains plastic (k2).
- Elastic-plastic with strain hardening: Elastic-perfectly plastic material. The material characteristic after the strain exceeds the elastic region remains plastic (k2) until reaching the strain hardening region (k3).

DNV (2010) states that in designing the structures to resist the accidental loads, the effect for strain hardening has to be accounted. And the value of each response should be multiplied by resistance factor as stated in point 2.7.2.a. This figure below represent the resistance curve for ASTM A36 steel, with strain hardening considered, as provided by Bauchio (1994):

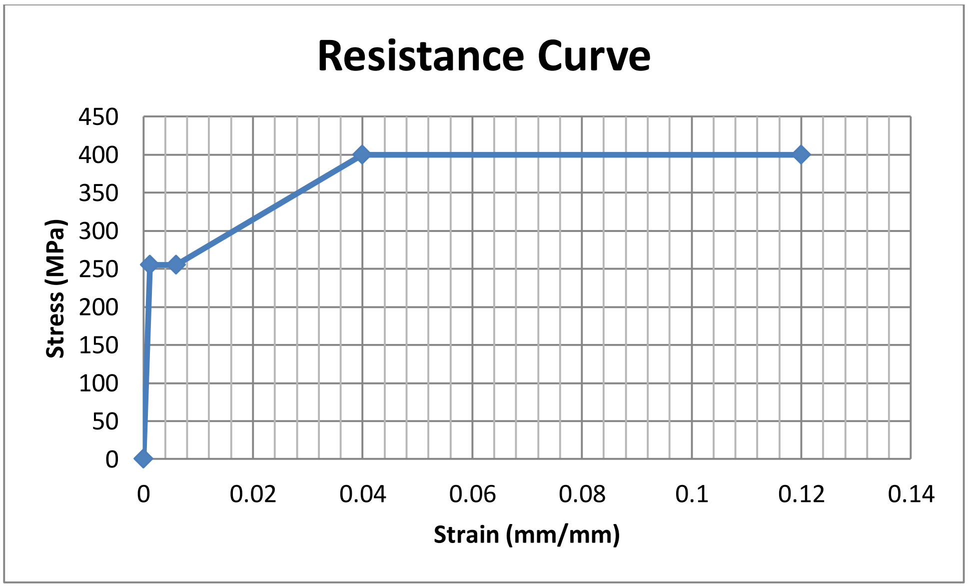


Figure 2.12. Resistance Curve for ASTM A36 (Bauchio, 1994)

2.9 Material Behavior under High Dynamic Loading

In general, materials have a complex response to dynamic loading. The following phenomena needs to be modelled (ANSYS, 2012):

2.9.1 Material Plasticity

If a material is loaded elastically and subsequently unloaded, all the deformation energy is recovered and the material reverts to its initial configuration. If the deformation is too great a material will reach its elastic limit and begin to deform plastically. In Explicit Dynamics, plastic deformation is computed by reference to the Von Mises yield criterion (also known as Prandtl–Reuss yield criterion). This states that the local yield condition is:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2Y^2 \qquad (25)$$

Where the "Y" is the yield stress in simple tension. It can be also written as:

$$\sigma_1{}^2 + \sigma_2{}^2 + \sigma_3{}^2 = \frac{2Y^2}{3} \text{ because } \sigma_1 + \sigma_2 + \sigma_3 = 0$$

In ANSYS, if an incremental change in the stresses exceeds the Von Mises criterion, then each of the principal stress deviators must be adjusted such that the criterion is satisfied. If a new stress state n + 1 is calculated from a state n and found to fall outside the yield surface, it is brought back to the yield surface along a line normal to the yield surface by multiplying each of the stress deviators by the factor C:

$$C = \frac{(\frac{2}{3})^{1/2} Y}{(\sigma_1{}^2 + \sigma_2{}^2 + \sigma_3{}^2)^{1/2}} \qquad (26)$$

By adjusting the stress perpendicular to the yield circle only the plastic components of the stresses are affected. Effects such as work hardening, strain rate hardening, thermal softening, etc. can be considered by making "Y" a dynamic function of these.

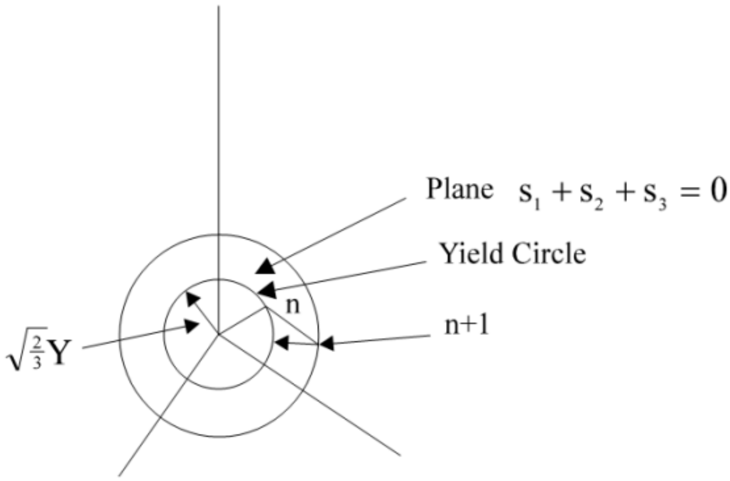


Figure 2.13. Yield Stress Circle (ANSYS, 2012)

During the material modelling in ANSYS, this plasticity behavior is represented by bilinear or multilinear hardening. Bilinear hardening refers to elastic-perfectly plastic resistance curve. The multilinear hardening is the customized stress-strain relationship; user can define up to 10 stress-strain relationship.

2.9.2 Material Failure

When stress occurred in the structure exceeds the strain limit of the material, the failure will happen. After failure initiation, subsequent strength characteristics will change depending on the type of failure model. In ANSYS, there are several failure models representing the material failure:

a. Plastic Strain Failure

The failure will occur while the effective plastic strain in the material exceeds the Maximum Equivalent Plastic Strain. This model should be conjugate with a plasticity material model.

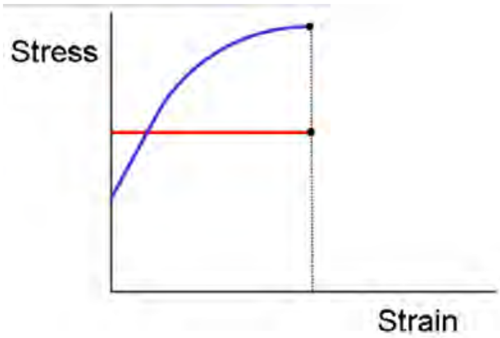


Figure 2.14. Maximum Plastic Strain Failure (ANSYS, 2012)

b. Principal Stress/Strain Failure

This failure will occur when the maximum tensile stress/strain or shear stress/strain exceeded. The ANSYS standard maximum value is $1x10^{20}$.

2.10 Solution Methods for Structural Dynamic Analysis

In FEA (Finite Element Analysis), direct numerical integration methods are used to find approximate solutions to the response problems. These are considered standard solution methods for most FEA Software e.g. ANSYS (Su, 2012). These procedures will enable us to determine the nodal displacements at different time increments for a given dynamic system. The direct numerical integration methods are separated into two methods; implicit and explicit methods. The first is an explicit method known as the central difference method. The second is the implicit methods known as the Newmark-Beta (or Newmark's) method (Logan, 2007).

2.10.1 Explicit Method (Central Difference Method)

The central difference method is based on finite difference expressions in time for velocity and acceleration at time (t) given by (Logan, 2007):

$$\underline{\dot{d}_i} = \frac{\underline{d}_{i+1} - \underline{d}_{i-1}}{2(\Delta t)} \ldots (27)$$

$$\ddot{d}_i = \frac{\underline{\dot{d}}_{i+1} - \underline{\dot{d}}_{i-1}}{2(\Delta t)}$$

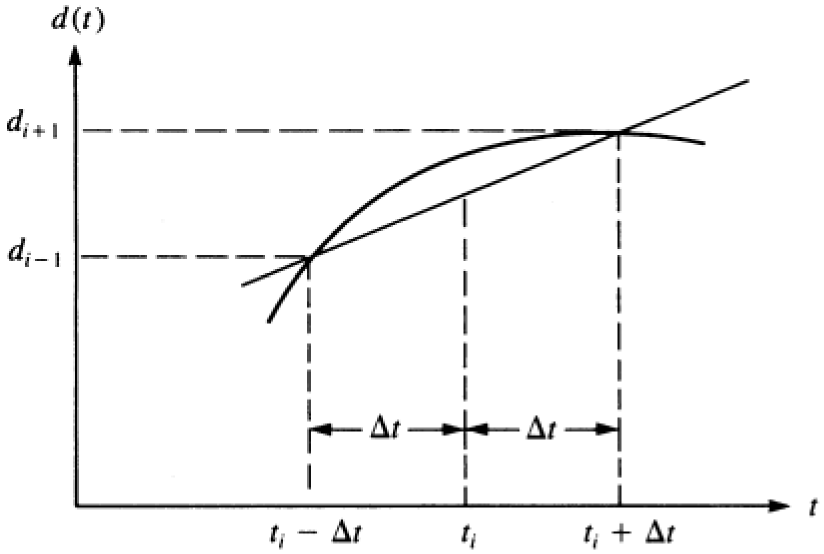


Figure 2.15. The Finite Difference Method (Logan, 2007)

The steps of iteration to get obtain the deformation based on the explicit method are:

1) Given the initial condition $\ddot{d}_0$, $\dot{d}_0$, d_0, and *f(t)*
2) Solve the deformation for the $-\Delta t$

$$d_{-1} = d_0 - (\Delta t)\dot{d}_0 + \frac{(\Delta t)^2}{2}\ddot{d}_0$$

3) Solve the deformation for the time t that is $t_i - \Delta t$

$$d_{i-1} = M^{-1}\{(\Delta t)^2 F_0 + [2M - (\Delta t)^2 K]\}d_0 - Md_{-1}$$

4) Solve the deformation for the time $t_i + \Delta t$

$$d_{i+1} = M^{-1}\{(\Delta t)^2 F_1 + [2M - (\Delta t)^2 K]\}d_1 - Md_0$$

5) Solve the acceleration at $t_i - \Delta t$ and $t_i + \Delta t$

$$\ddot{d}_{i-1} = M^{-1}(F_{i-1} - Kd_{i-1})$$

$$\ddot{d}_{i+1} = M^{-1}(F_{i+1} - Kd_{i+1})$$

6) Solve the velocity at $t_i + \Delta t$

$$\dot{d}_{i+1} = \frac{d_{i+1} - d_{i-1}}{2(\Delta t)} \qquad (28)$$

7) Repeat step 3-6 to obtain the deformation velocity and acceleration at each time steps

2.11 Performance of a Structure against Blast Load

Blast design and analysis are primarily component-based, whereby the applied blast load and response of each component in the building are determined individually. However, performance goals are usually set in terms of life safety, functionality, and reusability for the entire building (Dussenberry, 2010). Therefore, damage or response levels for individual building components must be established to achieve the overall building performance. In this approach, a building Level of Protection is selected based on desired performance goals, as shown **in** Table 2.4. Table 2.5 is then used to determine the associated damage levels for each type of component in the building. Therefore, this approach determines component damage levels that are consistent with an overall building performance goal. It can also be used to assess the Level of Protection provided by an existing building, based on calculated component damage levels.

Table 2.5. Level of Protection Criteria

Level of Protection	**Structure Performance Goals**	**Overall Structure Damages**
I(Very low)	***Collapse prevention***: Surviving occupants will likely be able to evacuate, but the building is not reusable; contents may not remain intact.	Damage is expected, up to the onset of total collapse, but progressive collapse is unlikely.
II (Low)	***Life safety***: Surviving occupants will likely be able to evacuate and then return only temporarily; contents will likely remain intact for retrieval.	Damage is expected, such that the building is not likely to be economically repairable, but progressive collapse is unlikely.
III (Medium)	***Property preservation***: Surviving occupants may have to evacuate temporarily, but will likely be able to return after cleanup and repairs to resume operations; contents will likely remain at least partially functional, but may be impaired for a time.	Damage is expected, but building is expected to be economically repairable, and progressive collapse is unlikely.
IV (High)	***Continuous occupancy***: All occupants will likely be able to stay and maintain operations without interruption	Only superficial damage is expected

Table 2.6. Component Damage Levels

Level of Protection	Component Damage Levels		
	Primary Structural Components	Second Structural Components	Nonstructural Components
I(Very low)	Heavy	Hazardous	Hazardous
II (Low)	Moderate	Heavy	Heavy
III (Medium)	Superficial	Moderate	Moderate
IV (High)	Superficial	Superficial	Superficial

***Hazardous damage*—**The element is likely to fail and produce debris.

***Heavy damage*—**The element is unlikely to fail, but will have significant permanent deformation such that it is not repairable.

***Moderate damage*—**The element is unlikely to fail, but will probably have some permanent deformation such that it is repairable, although replacement may be preferable for economic or aesthetic reasons.

***Superficia damage*—**The element is unlikely to exhibit any visible permanent damage

2.11.1 Response Parameter and Criteria

The response parameters define the structure damage level. As stated by Dussenberry (2010) the response parameter of structure under blast loading are:

a. Support Rotation (θ)

Support rotation parameter is calculated by:

$$\theta = tan^{-1}(\frac{2x_m}{L_{min}}) \quad (29)$$

Where:

x_m = maximum deformation

L_{min} = Shortest distance from maximum deformation to support

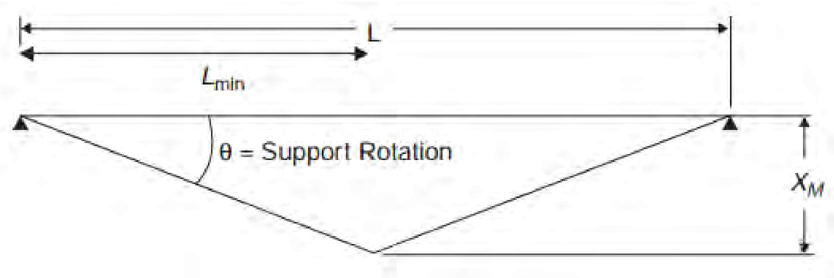


Figure 2.17. Support Rotation

b. Ductility Limit (μ)

Ductility limit is calculated by:

$$\mu = \frac{X_m}{X_y} \text{.............} (30)$$

Where: Xm = Maximum Deformation

Xy = Deformation at yield stress

The response criteria limits the value of response parameter so that the structure can be assessed and categorized as a blast resistant structure. Table 2.6 defines the response criteria:

Table 2.7. Response Criteria (Dussenberry, 2010)

Component	**Superficia Damage**		**Moderate Damage**		**Heavy Damage**	
	μ_{max}	**θ_{max}**	**μ_{max}**	**θ_{max}**	**μ_{max}**	**θ_{max}**
Hot Rolled Steel	3	2	10	6	20	12
Steel Primary Frame Members	1.5	1	2	1.5	3	2
Steel Plates	5	3	10	6	20	12
Open-web steel Joist	1	1	2	3	4	6

2.12 ANSYS Explicit Dynamic Software Modules

An explicit dynamics analysis is used to determine the dynamic response of a structure due to stress wave propagation, impact or rapidly changing time-dependent loads. Momentum exchange between moving bodies and inertial effects are usually important aspects of the type of analysis being conducted. This type of analysis can also be used to model mechanical phenomena that are highly nonlinear. Nonlinearities may stem from the materials, (for example, hyperelasticity, plastic flows, failure), from contact (for example, high speed collisions and impact) and from the geometric deformation (for example, buckling and collapse). Events with time scales of less than 1 second (usually of order 1 millisecond) are efficiently simulated with this type of analysis (for example, blast analysis) (ANSYS, 2012).

ANSYS Explicit Dynamics is one of the Workbench Modules that allows the designer has the step-by-step analysis starting from the model input, setting up the analysis condition, executing the analysis and reviewing the result easily thanks to the project schematics method.

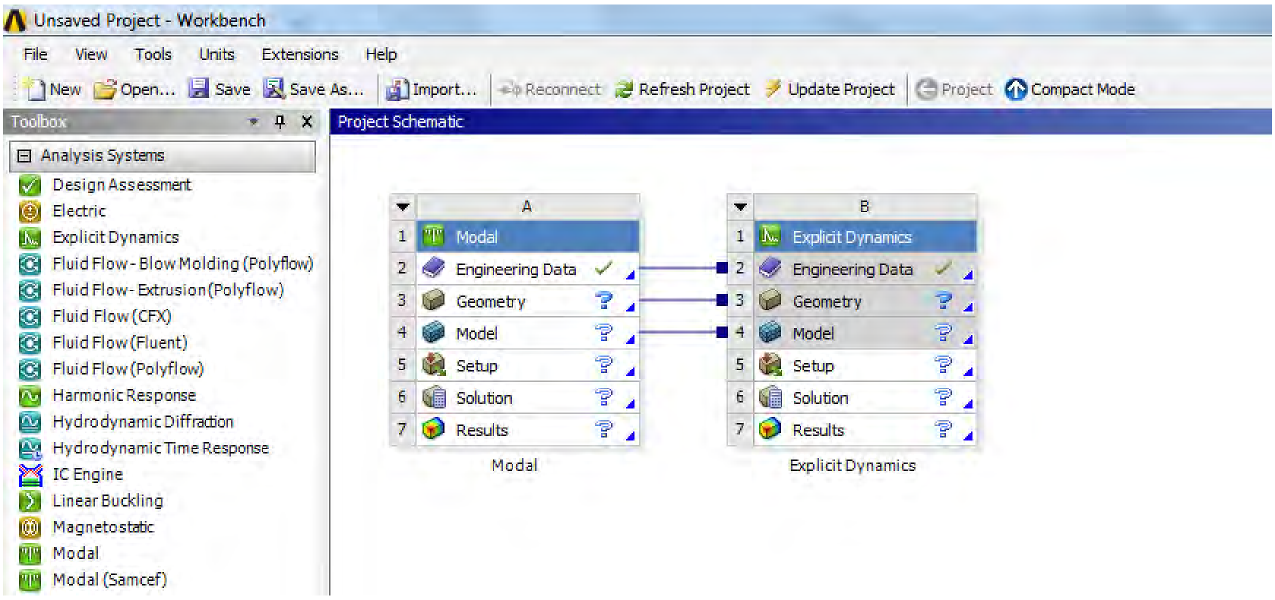


Figure 2.18. Project Schematics in ANSYS Workbench

SECTION III

PROCEDURES & METHODOLOGY

3.1 General Procedures

The steps to do to obtain the result of this project will be as follows:

1. Literature study to obtain the data and supporting theory.
2. Modelling the stiffened plate structure using external CAD software and then importing the model to ANSYS Workbench Design Modeler, AutoCAD 2013 is chosen to support the Design Modeler. There will be 9 sets of models to be generated, namely 3 variations of stiffener geometry and 3 variations of stiffener configuration.
3. Obtaining the natural period for each model using ANSYS Workbench Modal Analysis.
4. Validating the model by hand calculation using simplified SDOF analysis and meshing sensitivity of natural period. If the natural period doesn't exceed 5% deviation, the model considered as a valid plate model. Meshing sensitivity is the iterative steps to obtain the stable result at certain mesh sizing. The weight for each model will be calculated and expected to be equal for the sake of fair comparison. The deviation tolerance is 15%.
5. Calculating t/td. The criteria for analysis setting is:

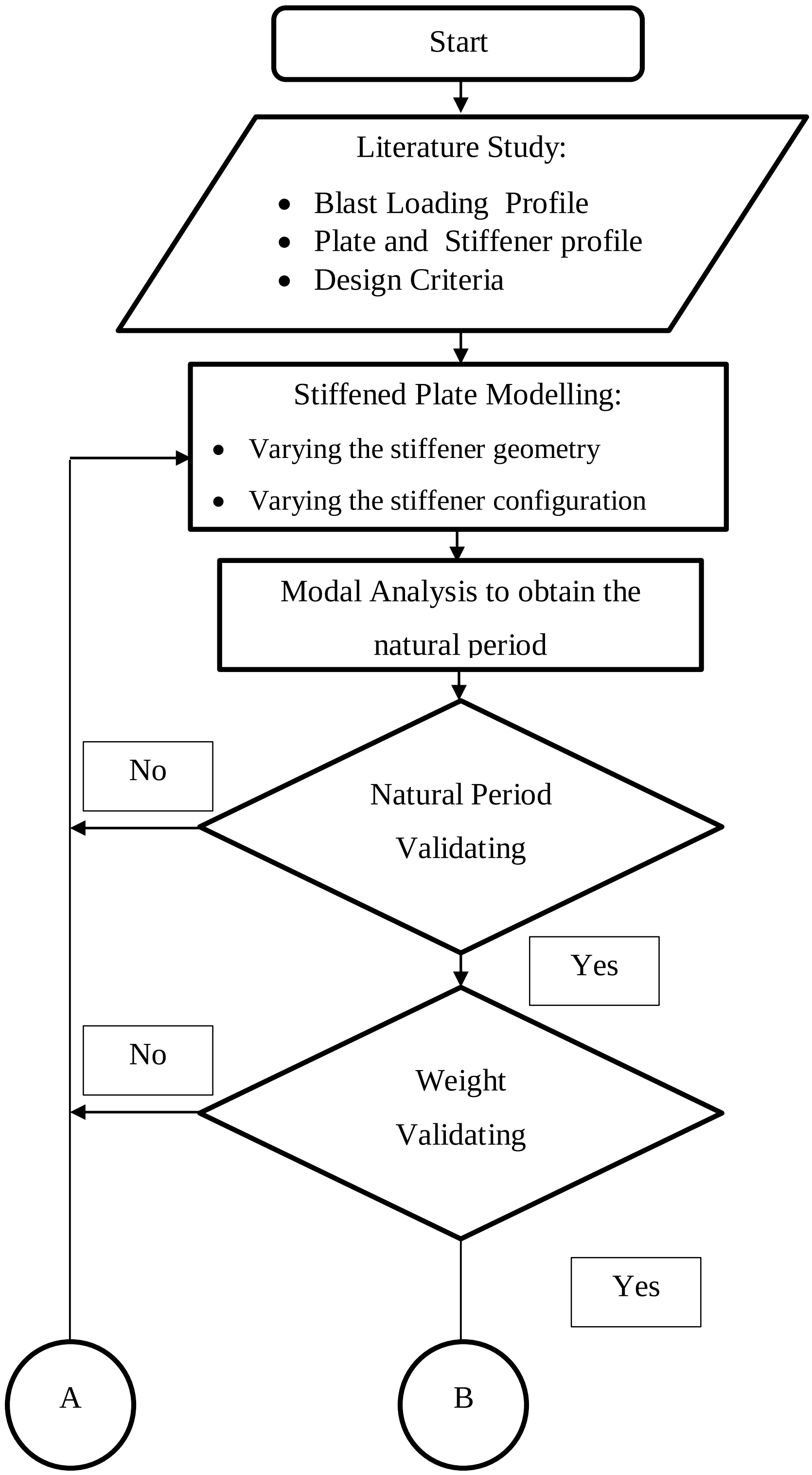
Impulsive domain	$td/T < 0.3$
Dynamic domain	$0.3 < td/T < 3$
Quasi-static domain	$td/T > 3$

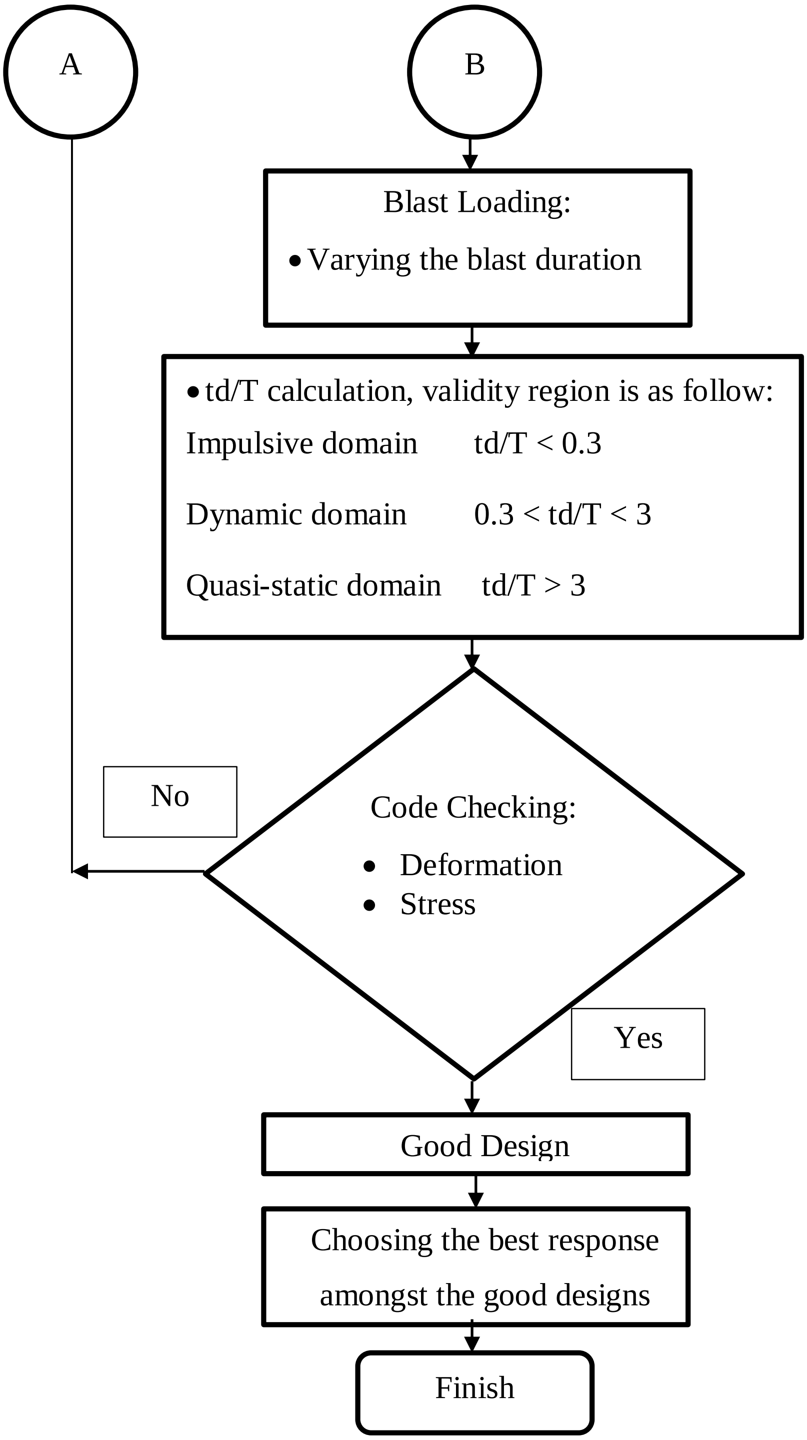
6. Analyzing the model based on the validity region, giving the dynamic blast pressure at various durations and obtaining the result data using ANSYS Workbench Explicit Dynamic Modules.
7. Code checking, the result data (deformation φ and stress σ) of stiffened plates under blast loading will be compared to the codes (DNV – RP C204 – Design against Accidental Loads). If the deformation and stress of stiffened plates do

not exceed the design criteria the plate considered as a proper design of stiffened plate that resist to blast load.

8. Conclusion.

3.2 General Methodology





3.3 Meshing Validation Procedures

1. Modelling the unstiffened plate with provided geometry and materials, taken from paper by Tavakoli, (2012), the geometry modelled using AutoCAD 2013 then exported to ANSYS Design Modeler and dimension is as follow:

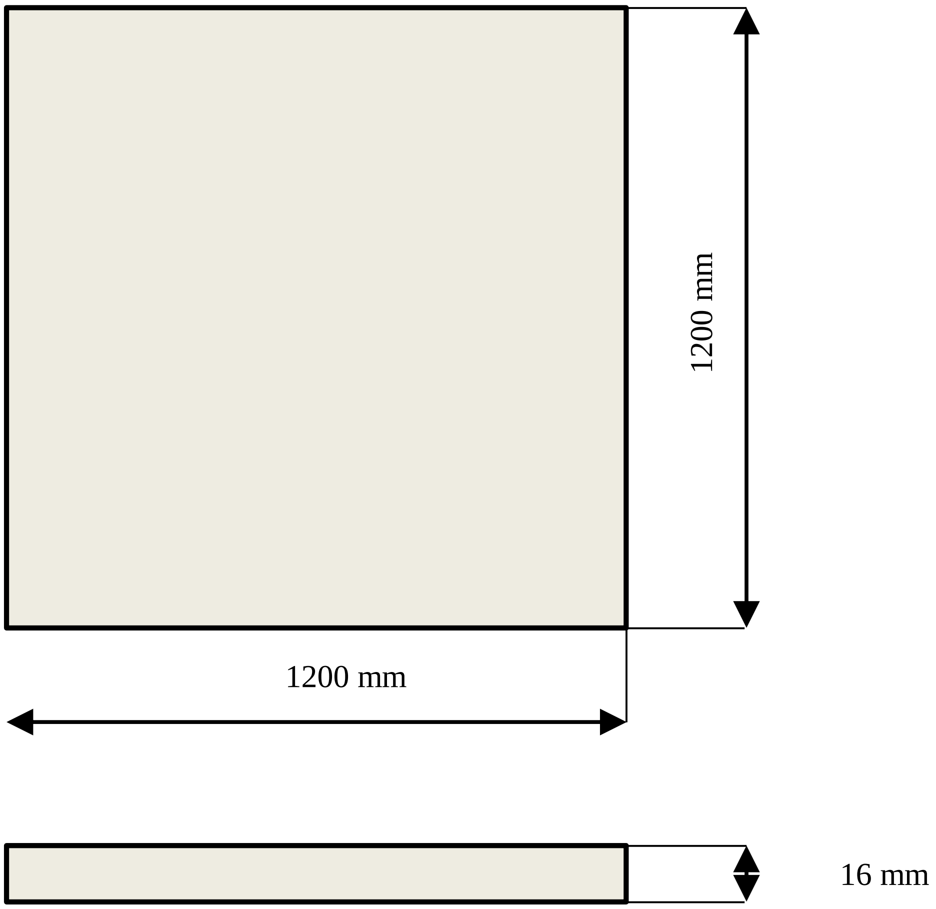


Figure 3.1. Plate Dimension (Tavakoli, 2012)

2. Importing the ANSYS Design Modeler file to ANSYS Modal Analysis and then apply the boundary condition, fixed support at the edges of plate:

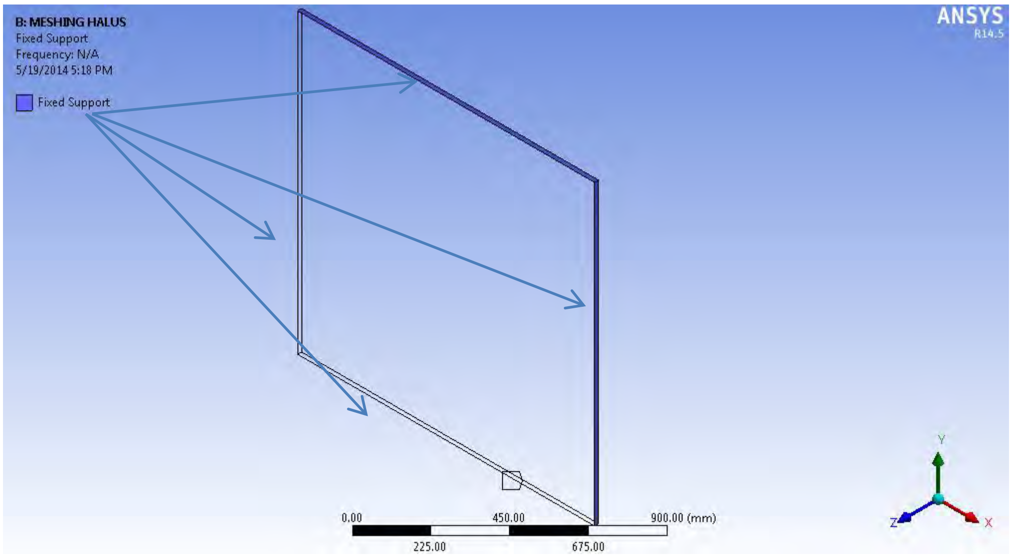
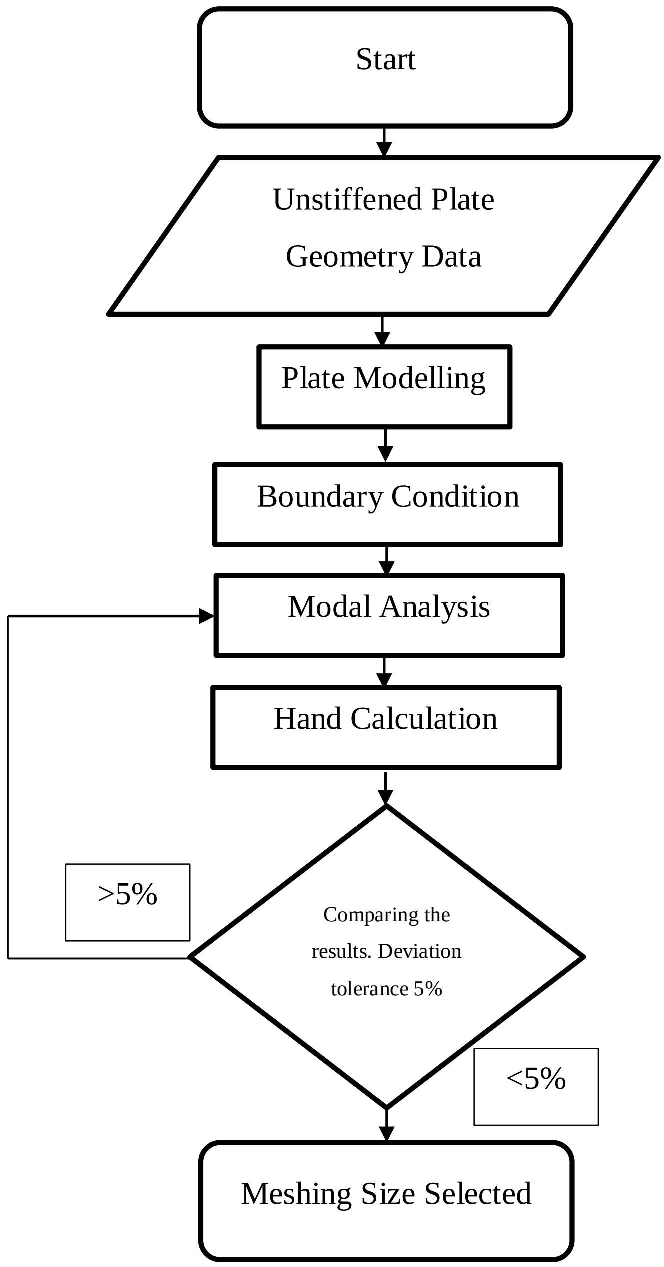


Figure 3.2. Boundary Condition

3. Running the modal analysis with boundary condition stated at point 2 from coarse meshing (120 mm size) with decrement of meshing size 20 mm.
4. Analyzing the 1st shape mode natural period per meshing size.
5. Compare the result to the Tavakoli's model and hand calculation developed by DNV, as stated at equation (6). The deviation tolerance is 5%.
6. Choose the best meshing size based on the comparison.

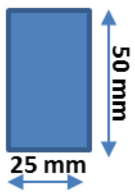
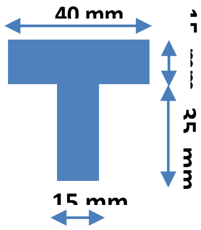
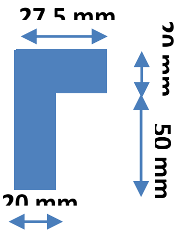
3.4 Meshing Validation Methodology



3.5 Plate Sizing Validation Procedures

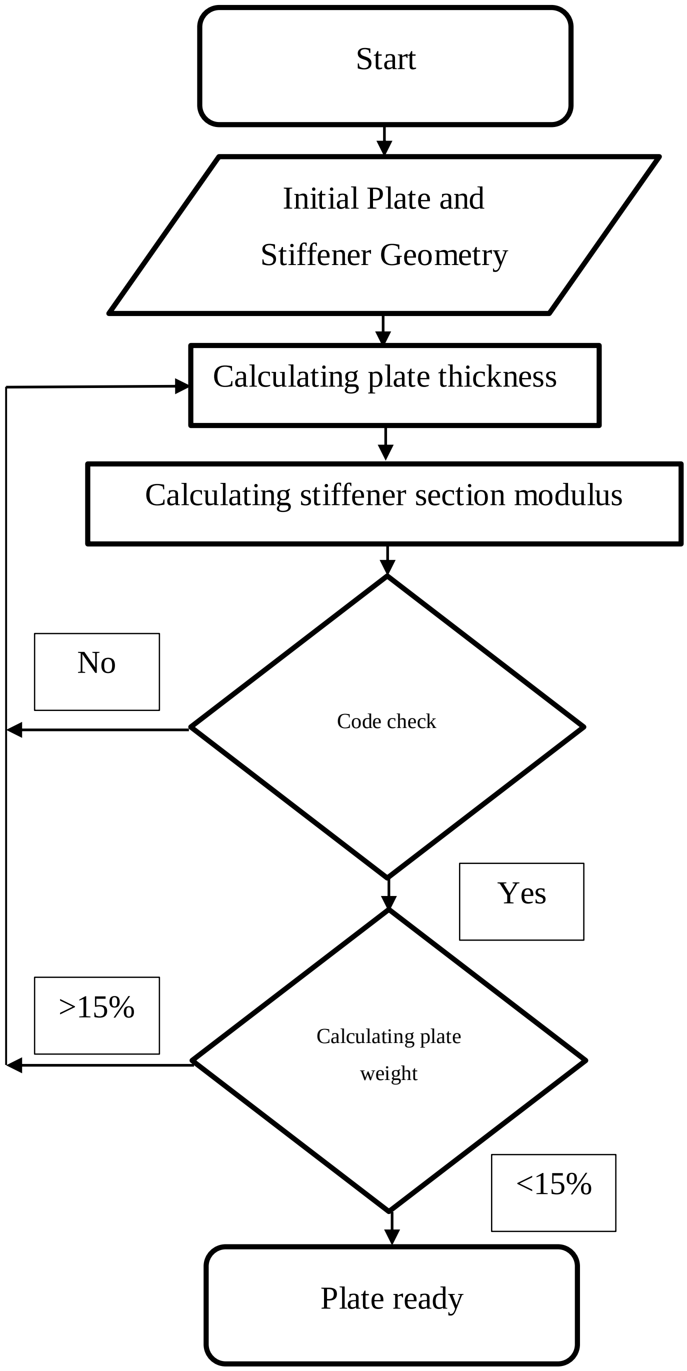
1. Given initial plate span 1000 mm x 1000 mm.
2. Calculating plate thickness using equation developed by DNV as stated at equation (23).
3. Given initial stiffener dimension, b x h = 25 mm x 50 mm
4. Modifying stiffener geometry into "T" and "L" geometry:

Table 3.1. Stiffener Geometry

No	Name	Stiffener Geometry	h (mm)	b (mm)	y=h/2 (mm)	q (kg/m)
1	Stripe Geom		50	25	25	9.81
2	T Geometry		15	40	25	8.83
			35	15	17.5	
3	L Geometry		15	27.5	25	7.36
			35	15	17.5	

5. Calculating minimum stiffener section modulus by equation developed by DNV as stated at equation (24).
6. Calculating the weight of each stiffened plate and then compared to the average weight. The deviation should not be more than 15%.
7. The plate geometries are ready to be analyzed.

3.6 Plate Sizing Validation Methodology



3.7 Blast Analysis Procedures

1. Modal analysis to obtain 1st mode natural period (T). Modal analysis performed using ANSYS Modal Analysis with fixed ends boundary condition.

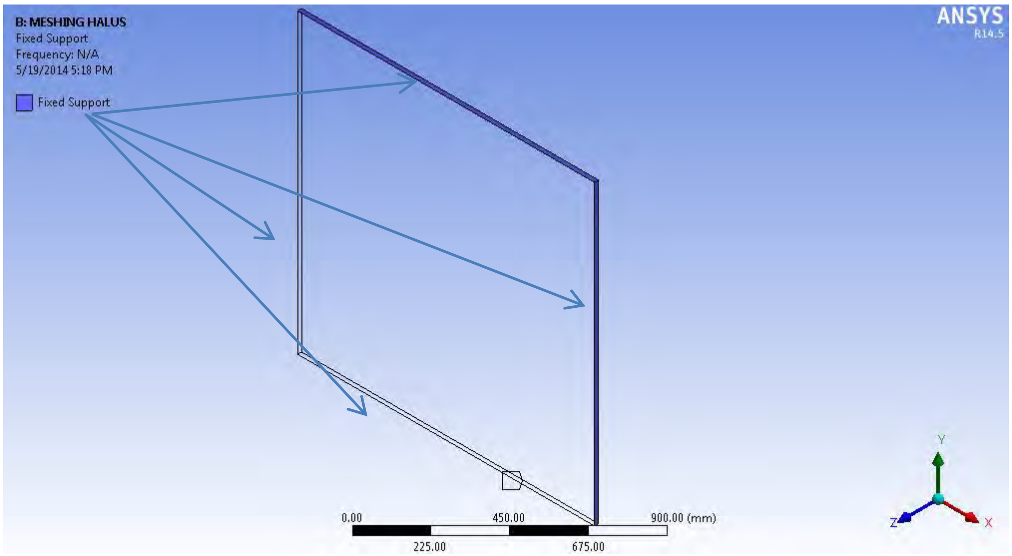


Figure 3.3. Fixed Ends Boundary Condition Modal Analysis

2. Importing the model from ANSYS Design Modeler to ANSYS Explicit Dynamic.
3. Determining the material behavior, resistance curve and failure model of the material, as stated at chapter 2.9.
4. Determining blast duration (td) and peak overpressure (Ps) by equation of drag force as stated by equation (10). This also leads to the load profile calculation.
5. Determining analysis type based on blast duration (Td) relative to natural period (T)

    Impulsive domain $td/T < 0.3$

    Dynamic domain $0.3 < td/T < 3$

    Quasi-static domain $td/T > 3$

6. Changing the analysis setting based on the td/T. Impulsive domain related to high velocity analysis, dynamic domain related to default setting (program controlled), and quasi-static for quasi-static analysis.

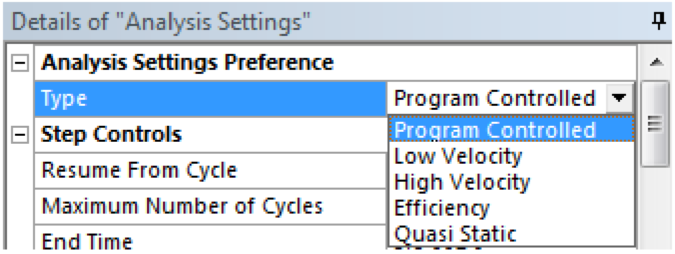


Figure 3.4. Analysis setting configuration

7. Applying the boundary condition to the model, that is the fixed ends boundary condition.
8. Applying pressure load based on the load profile calculation.

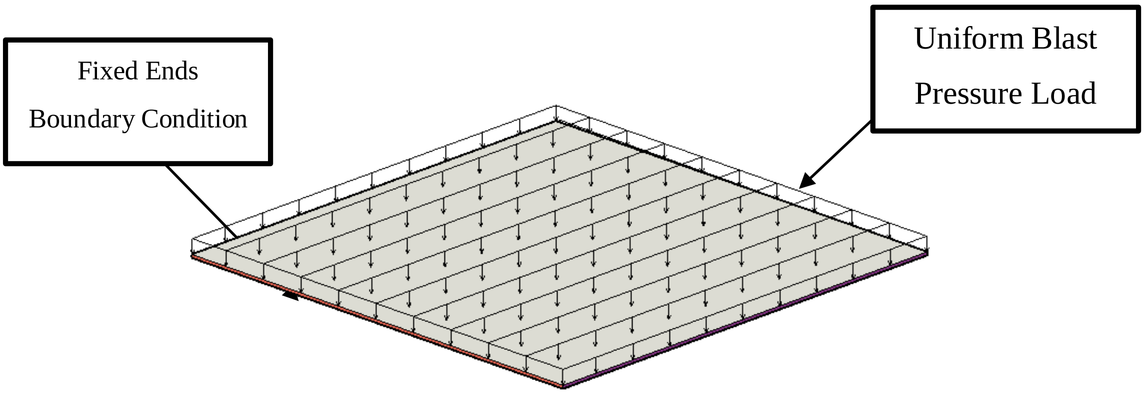
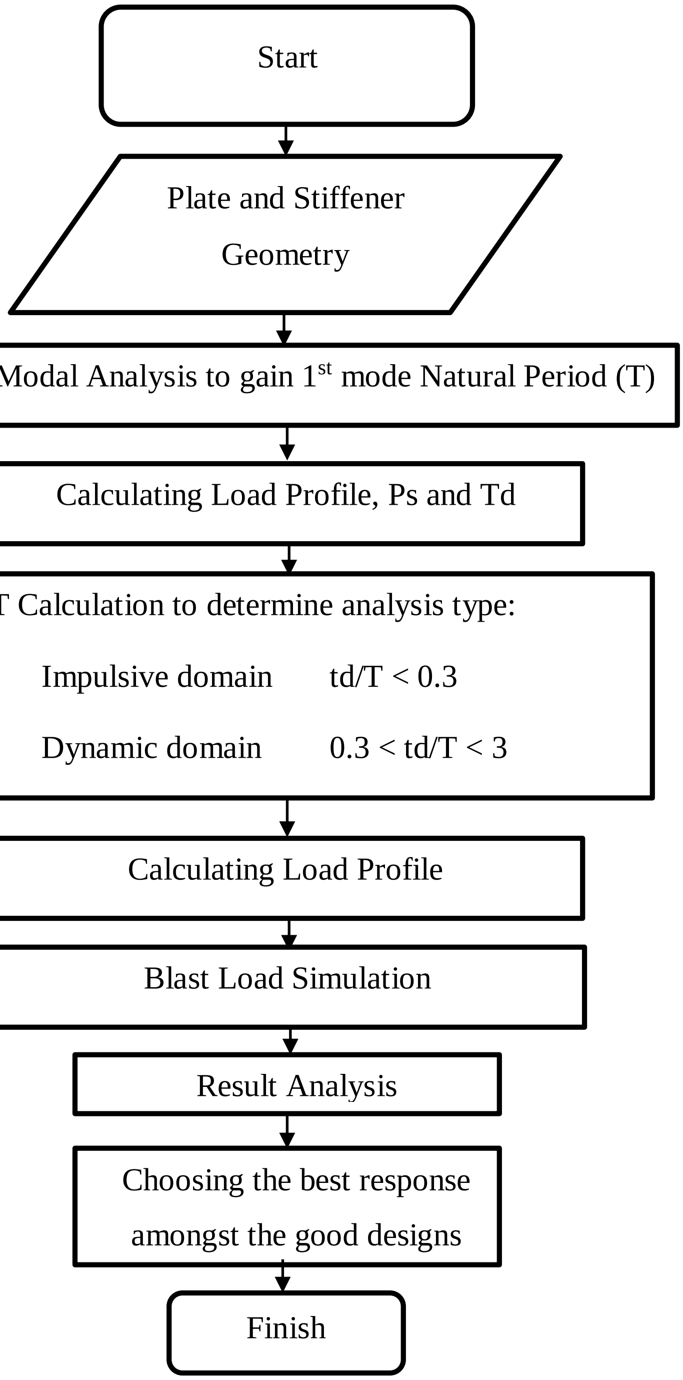


Figure 3.5. Uniform Blast Pressure Load

9. Running the analysis
10. Analyzing the response result data (deformation φ and stress σ). Plate with the best response will be selected to precede to the design procedures.

3.8 Blast Analysis Methodology



3.9 Design Procedures

1. Stiffened plate configuration with best midpoint deformation response is selected.
2. The response criteria limit is chosen to justify whether the design satisfy the criteria. The protection level is set to level II: to keep the occupants survive and be evacuated but the structure will have permanent damage. Level II is selected considering economic benefit, but still fulfills the purpose of blast resistant stiffened plate.

Table 3.2. Selected Structure Protection Level

Level of Protection	Structure Performance Goals	Overall Structure Damages
II (Low)	***Life safety*: Surviving occupants will likely be able to evacuate and then return only temporarily; contents will likely remain intact for retrieval.**	**Damage is expected, such that the building is not likely to be economically repairable, but progressive collapse is unlikely.**

Table 3.3. Selected Structure Damage Level

Level of Protection	Component Damage Levels		
	Primary Structural Components	Second Structural Components	Nonstructural Components
II (Low)	Moderate	Heavy	Heavy

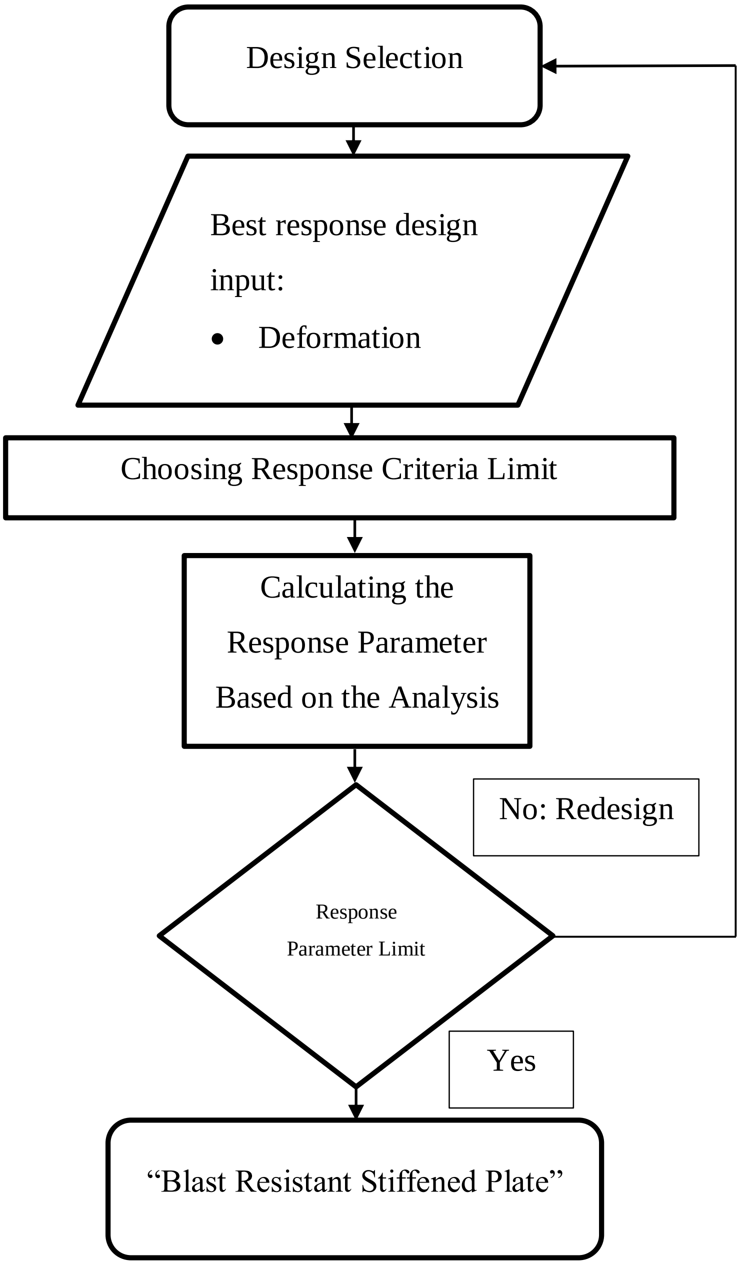
3. The response criteria are the value of the response parameters not to exceed the specified limit. Response parameters are as follows:
   a. Support Rotation (θ)
   b. Ductility Limit (μ)
4. Support rotation and ductility limit are then compared to the response criteria. Based on the designated response criteria, the plate design is evaluated. If plate design exceeds the criteria, it is redesigned and recalculated with the same procedures. Redesign starts from adding plate thickness, then add stiffener dimension.

Table 3.4. Selected Response Parameter

Component	Superficia Damage		Moderate Damage		Heavy Damage	
	μ_{max}	θ_{max}	μ_{max}	θ_{max}	μ_{max}	θ_{max}
Steel Plates	**5**	**3**	**10**	**6**	**20**	**12**

5. The plate is selected as blast resistant stiffened plate if the response met the criteria.

3.10 Design Methodology



SECTION IV

RESULT AND DISCUSSION

4.1 Modelling

4.1.1 Geometry Modelling

a. Plate thickness

Plate thickness is derived from DNV equation as stated in equation (23). The dimension is as follow:

$$t = \frac{14.3t_0}{\sqrt{f_{yd}}} = 5.72 \approx 6(mm)$$

Where:

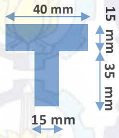
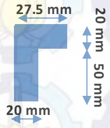
f_{yd} = 255/1.15 (N/mm$_2$),

t_0 = 5 mm (primary structural elements)

b. Stiffener Section Modulus

Stiffener section modulus is calculated and compared to equation from DNV as stated in equation (24). The calculation results satisfy the criteria:

Table 4.1. Stiffener Geometry and Section Modulus

No	Name	Stiffener Geometry	h (mm)	b (mm)	y (mm)	S (mm3)	I (mm4)	Minimum S (mm3)	Check	Weight/m	Δ
1	Stripe Geometry		50	25	25	31250	390625	5314.85	OK	9.81	11.67%
2	T Geometry		15	40	25	28125	535781.3	5314.85	OK	8.83	1.67%
			35	15	17.5						
3	L Geometry		15	27.5	25	23438	418593.8	5314.85	OK	7.36	-13.33%
			35	15	17.5						

Based on the stiffener geometry, the plate and stiffeners configuration are modeled using AutoCAD 2013 and then exported to ANSYS Workbench. The models generated are displayed below:

Table 4.2. Geometry Modelling

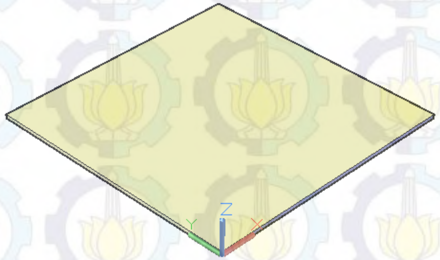
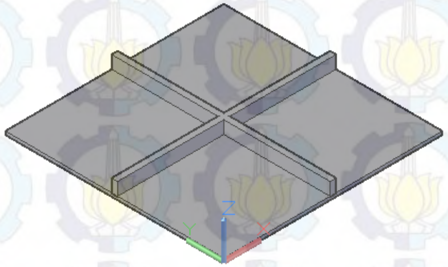
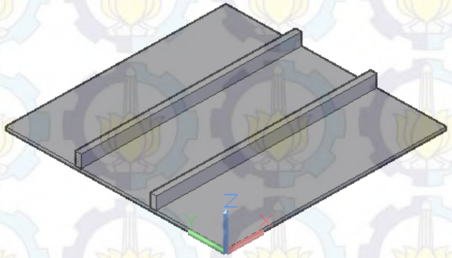
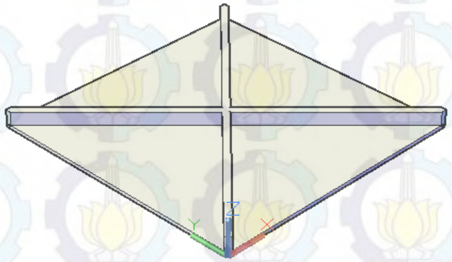
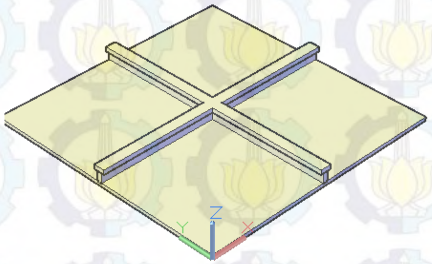
No.	Item	Model	Plate Geometry (mm)	Stiffener Geometry		Weight
				Top (mm)	Bottom (mm)	
1	Unstiffened Plate		1000 x 1000	-	-	47.10
2	Stiffened Plate with "T" Stiffener Configuration and Stripe Geometry		1000 x 1000	25 x 50	-	70.31

Table 4.2. Geometry Modelling (Continued)

No.	Item	Model	Plate Geometry (mm)	Stiffener Geometry		Weight
3	Stiffened Plate with Parallel Stiffener Configuration and Stripe Geometry		1000 x 1000	25 x 50	-	70.65
4	Stiffened Plate with "X" Stiffener Configuration and Stripe Geometry		1000 x 1000	25 x 50	-	79.47
5	Stiffened Plate with "T" Stiffener Configuration and T Geometry		1000 x 1000	40 x 15	15 x 35	68.02

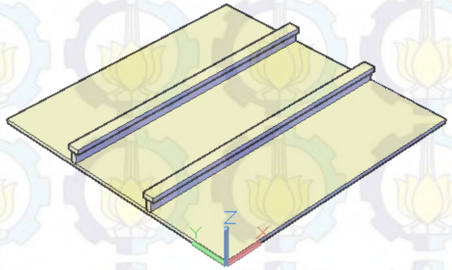
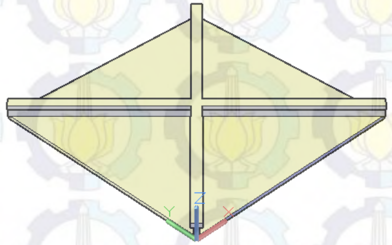
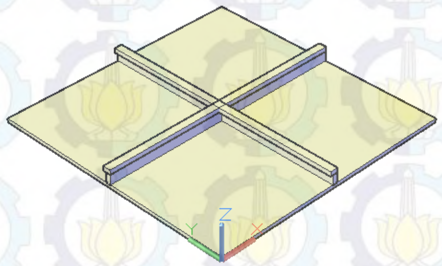
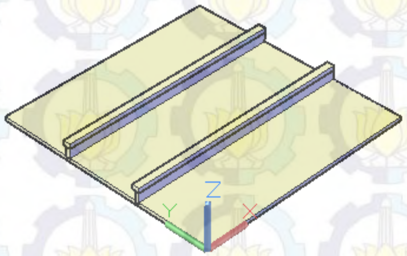
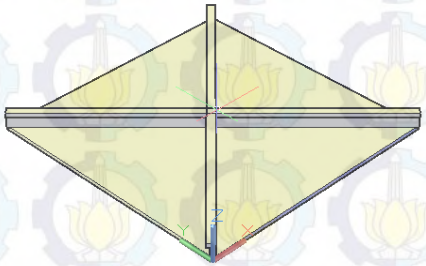
No.	Item	Model	Plate Geometry (mm)	Stiffener Geometry		Weight
6	Stiffened Plate with Parallel Stiffener Configuration and T Geometry		1000 x 1000	40 x 15	15 x 35	68.30
7	Stiffened Plate with "X" Stiffener Configuration and T Geometry		1000 x 1000	40 x 15	15 x 35	76.26
8	Stiffened Plate with "T" Stiffener Configuration and L Geometry		1000 x 1000	27.5 x 15	15 x 35	64.47

Table 4.2. Geometry Modelling (Continued)

No.	Item	Model	Plate Geometry (mm)	Stiffener Geometry		Weight
9	Stiffened Plate with Parallel Stiffener Configuration and L Geometry		1000 x 1000	27.5 x 15	15 x 35	64.76
10	Stiffened Plate with "X" Stiffener Configuration and L Geometry		1000 x 1000	27.5 x 15	15 x 35	71.35

The model is then validated compared to hand calculation, prior studies, and meshing sensitivity.

4.1.1.1 Meshing Validation and Sensitivity Study

Upon the sets of models, one model is validated, that is the unstiffened plate with fixed ends. The model is exported to ANSYS Design Modeler (ANSYS DM), and given the mechanical properties as stated in project limitation. The model compared over the model developed by Tavakoli et. al (2012) and by hand calculation that the procedures developed by DNV as stated at equation (6). Meshing sensitivity is also deployed to gain the steady result of modelling and optimum calculation time. The result is as follows:

Table 4.3. Model Validation and Meshing Sensitivity

Meshing (mm)	Tn (seconds)	Δ (Compared to Tavakoli's Model)	Δ (Compared to Hand Calculation)
250	0.00934	-6.67%	-8.07%
120	0.01005	0.43%	-1.08%
80	0.01016	1.53%	0.01%
40	0.01023	2.27%	0.74%
30	0.01025	2.46%	0.92%
20	0.01027	2.64%	1.10%
10	0.01029	2.79%	1.25%
Tavakoli	***0.01001***		
Hand Calc	***0.01026***		

The result shows that the optimum meshing size is at 40 mm. Despite the 120 and 80 mm size giving the smaller Δ, the sensitivity graph shows that the natural period result showing the steadying tendency begin at size 40 mm. It is clear that the meshing size will be 40 mm, because the plate and stiffener geometry is basic box geometry, and the best mesh type is hexahedron.

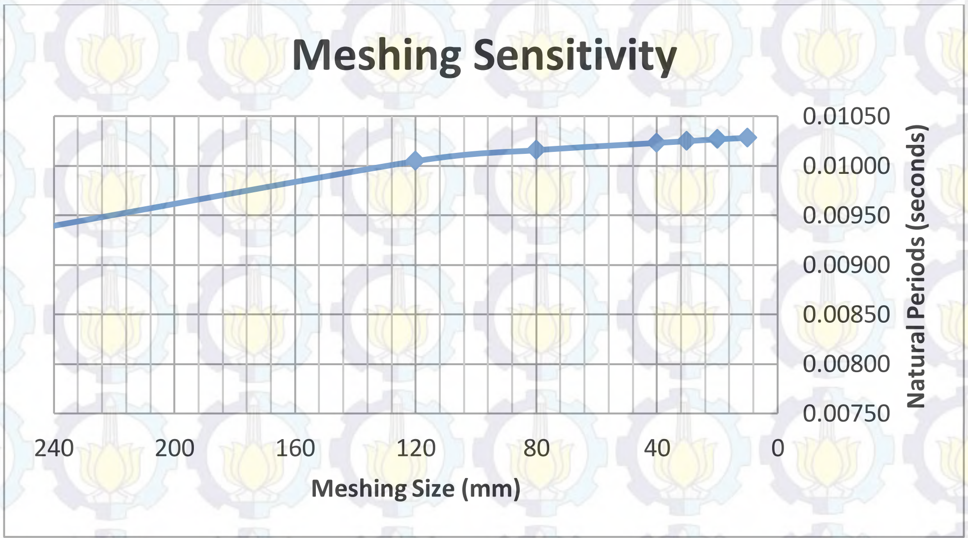


Figure 4.1. Meshing Sensitivity Graph

4.1.2 Weight Validation

The weight for each models are calculated to gain the fair analysis comparison, remembering a dynamic analysis is greatly influenced by the mass factor, so that with averagely same mass but higher inertia, stiffener strength will have significant increase. The weight is calculated and compared over the average weight. The deviations for all models are below 15% so the models are approved as valid.

Table 4.4. Weight Calculation and Ratio

NO	ITEM	WEIGHT (kg)	Δ (based on the AVERAGE)
1	Stiffener “T” Stripe Geometry	70.31	-0.13%
2	Stiffener Parallel Stripe Geometry	70.65	0.36%
3	Stiffened “X” Stripe Geometry	79.47	12.89%
4	Stiffener “T” L Geometry	68.02	-3.38%
5	Stiffened Parallel L Geometry	68.30	-2.99%
6	Stiffened “X” Stiffener L Geometry	76.26	8.33%
7	Stiffened “T” T Geometry	64.47	-8.42%
8	Stiffened Plate Parallel T Geometry	64.76	-8.01%
9	Stiffened Plate “X” T Geometry	71.35	1.35%

4.1.3 Material Modelling

The material used is ASTM A36 with these following properties:

Table 4.5. Material Properties

No.	Properties	Value
1.	Density	7850 kg/m^3
2.	Young's Modulus	200000 MPa
3.	Poisson Ratio	0.3
6.	Yield Strength	255 MPa
7.	Ultimate Strength	400 MPa

Based on DNV OS-C101 LRFD, the yield and ultimate strength (resistance) should be multiplied by material factor γ_m, and based on DNV RP-C204, the material resistance curve which is used should be accounted for strain hardening, therefore, the resistance curve is as follow:

Table 4.6. Resistance Curve Table

Strain (mm/mm)	Factor	Stress (MPa)	Factored Stress (MPa)
0	0.87	0.01	0.0
0.00125	0.87	255	221.7
0.006	0.87	255	221.7
0.04	0.87	400	347.8
0.12	0.87	400	347.8

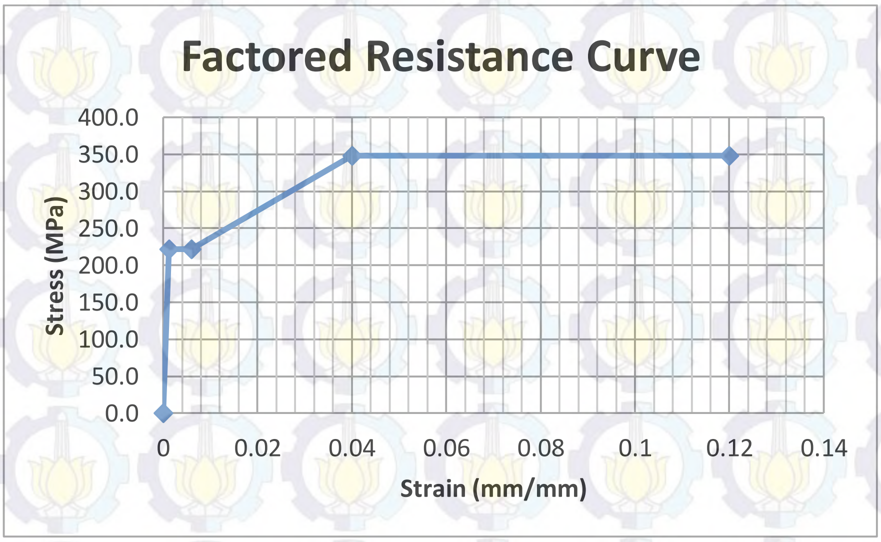


Figure 4.2. Factored Resistance Curve

4.1.4 Load Modelling

The blast load modelled as uniform pressure subjecting perpendicular to plate front face. The properties of exploded propane gas vapor are as follows:

Table 4.7. Propane Gas Explosion Properties

No.	Property	Value
1.	Density (ρ_s)	1.24 kg/m^3
2.	Velocity (v_s)	1,660 m/s

The blast duration, as stated at limitation, is varied at 50, 100 and 200 ms. The effect of duration variation is the most important to be accounted for, due to the short-and-heavy load characteristic of blast load, and it is implies the magnitude of impulse generated from the loads. Peak overpressure Ps, which is the maximum pressure at td/2, produced from the drag force calculated from drag force equation (10):

Hence, the peak overpressure Ps = 1,998,912 Pa = 1.99 MPa ≈ 2MPa

The load profile is graphically represented as follows:

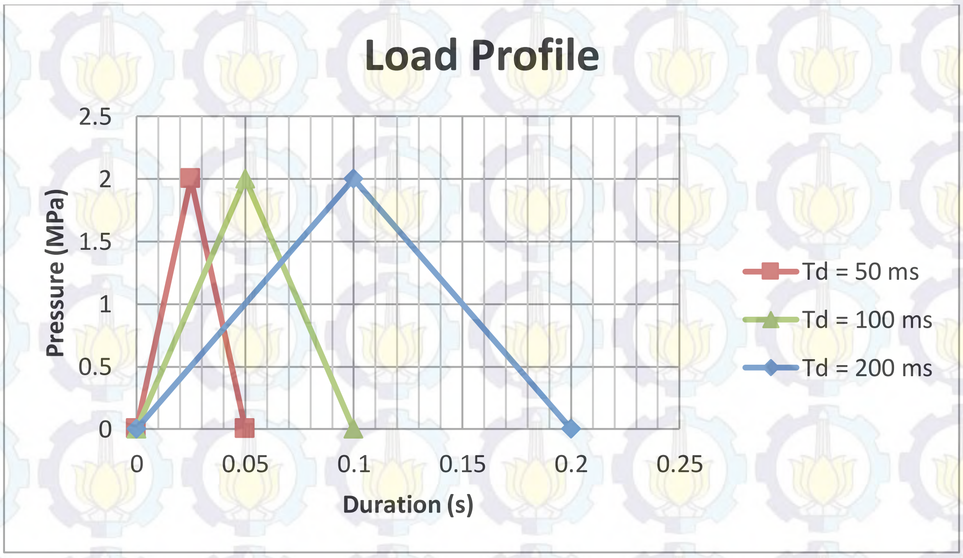


Figure 4.3. Load Profile

4.1.5 Analysis Matrix

Based on the geometry and load variations, there are 30 sets of analysis to be performed:

Table 4.8. Analysis Matrix

No	Item	Blast Loads (MPa)	Blast Duration (ms)
1	Unstiffened Plate	2	50
2			100
3			200
4	Stiffened Plate with "T" Stiffener Configuration and Stripe Geometry	2	50
5			100
6			200
7	Stiffened Plate with Parallel Stiffener Configuration and Stripe Geometry	2	50
8			100
9			200
10	Stiffened Plate with "X" Stiffener Configuration and Stripe Geometry	2	50
11			100
12			200
13	Stiffened Plate with "T" Stiffener Configuration and L Geometry	2	50
14			100
15			200
16	Stiffened Plate with Parallel Stiffener Configuration and L Geometry	2	50
17			100
18			200
19	Stiffened Plate with "X" Stiffener Configuration and L Geometry	2	50
20			100
21			200
22	Stiffened Plate with "T" Stiffener Configuration and T Geometry	2	50
23			100
24			200
25	Stiffened Plate with Parallel Stiffener Configuration and T Geometry	2	50
26			100
27			200
28	Stiffened Plate with "X" Stiffener Configuration and T Geometry	2	50
29			100
30			200

4.2 Analysis Result

Analysis is performed based on the analysis matrix. The analysis result for blast duration Td = 50 ms, Td = 100 ms, and Td = 200 ms is as follows:

4.2.1 Modal Analysis

Modal analysis is performed to obtain the 1st order natural period. The results are shown in Table 4.9 below, meanwhile the complete analysis setting and result served in Appendix A:

Table 4.9. Natural Period and Analysis Region

No.	Item	Natural Period (s)	Td/T	Region
1	Unstiffened Plate	0.1891	1.058	Dynamic
2	Config T Geom Stripe	0.0760	2.632	Dynamic
3	Config Parallel Geom Stripe	0.0812	2.463	Dynamic
4	Config X Geom Stripe	0.0674	2.967	Dynamic
5	Config T Geom L	0.0821	2.436	Dynamic
6	Config Parallel Geom L	0.0715	2.797	Dynamic
7	Config X Geom L	0.0671	2.981	Dynamic
8	Config T Geom T	0.0807	2.478	Dynamic
9	Config Parallel Geom T	0.0798	2.506	Dynamic
10	Config X Geom T	0.0667	2.999	Dynamic

4.2.2 General Midpoint Deformation Result

The midpoint deformation result for each configuration and blast duration are shown in figure 4.4 to figure 4.6. The maximum values are tabulated in table 4.10. The complete analysis setting and result is displayed at Appendix B.

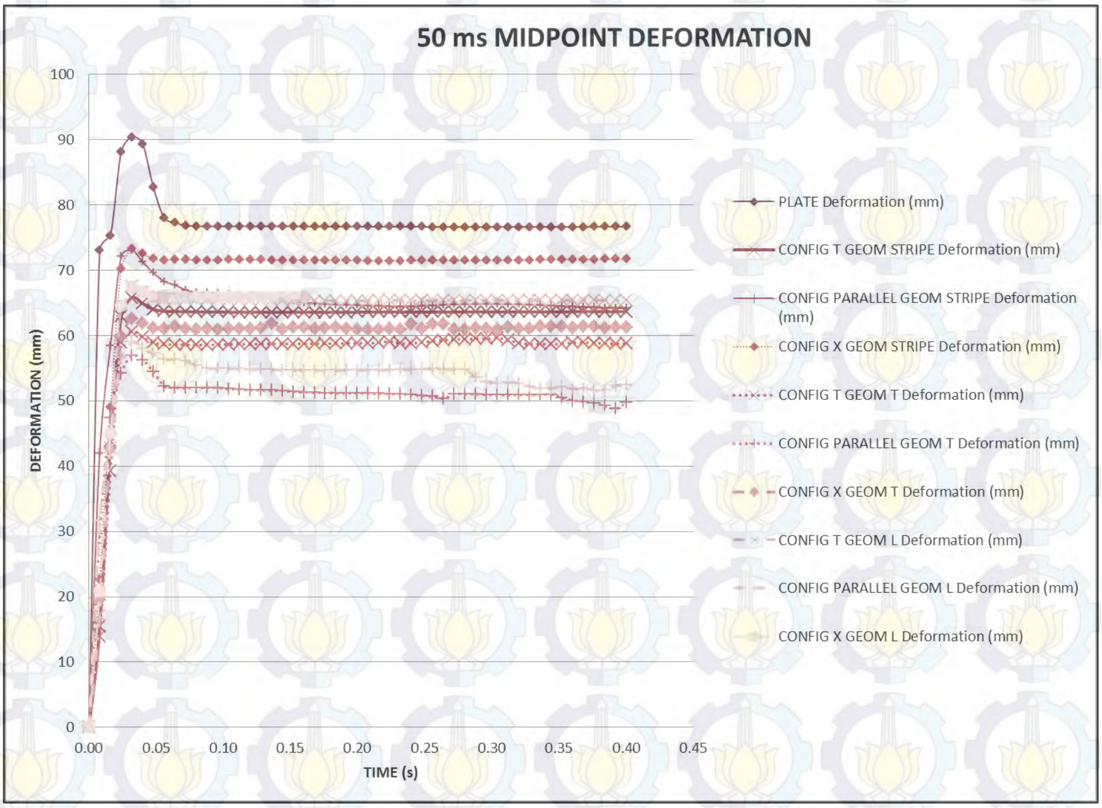


Figure 4.4. Midpoint Deformation 50 ms Blast Duration

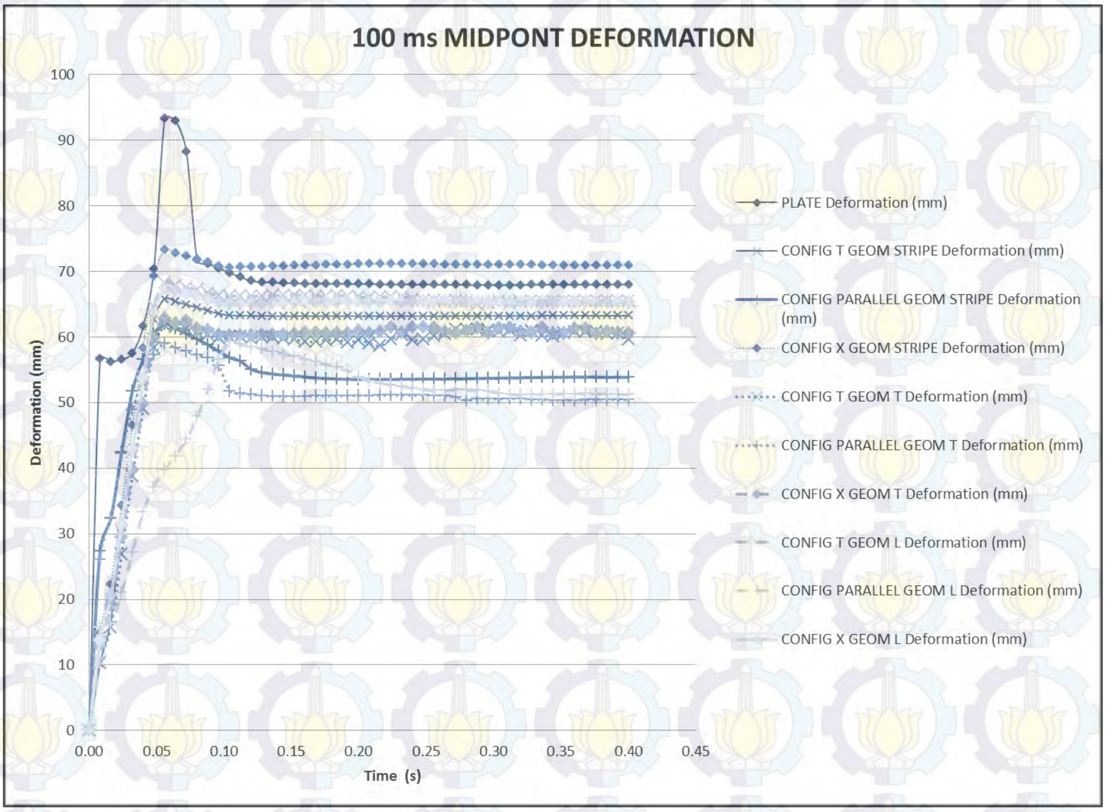


Figure 4.5. Midpoint Deformation 100 ms Blast Duration

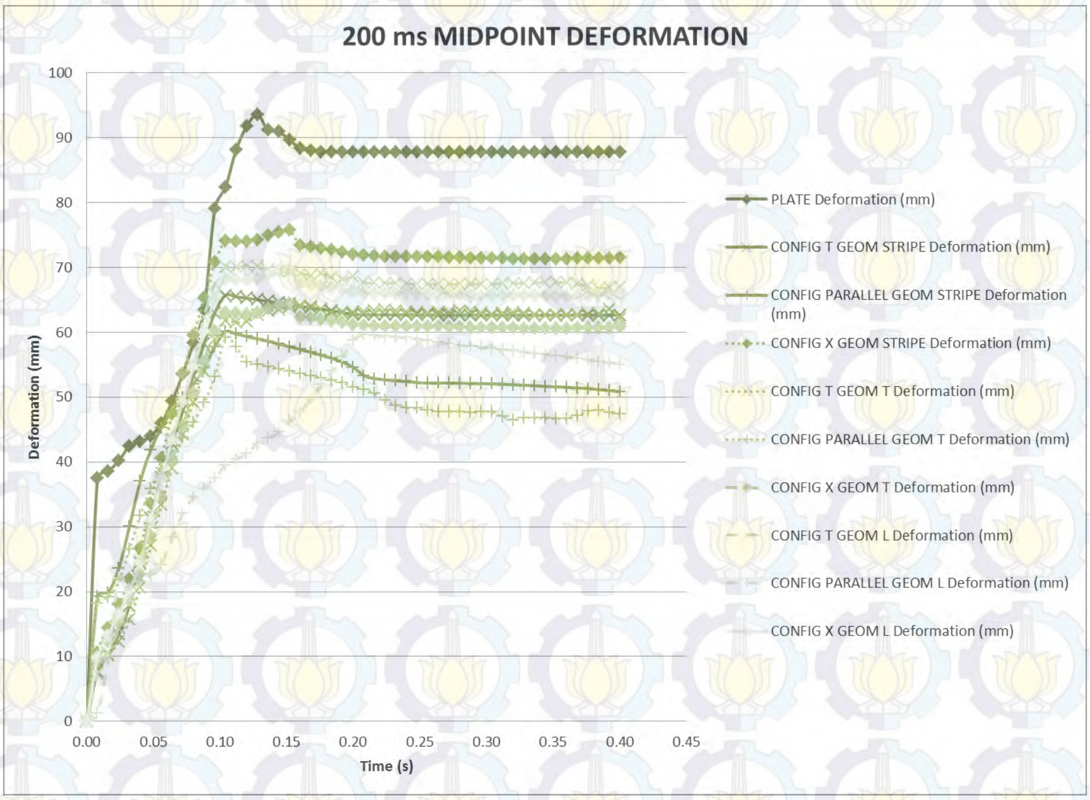


Figure 4.6. Midpoint Deformation 200 ms Blast Duration

Table 4.10. Maximum Midpoint Deformation Value

No	Plate	Midpoint Displacement (mm)		
		50 ms	**100 ms**	**200 ms**
1	UNSTIFFENED PLATE	90.42	93.34	93.50
2	CONFIG T GEOMETRY STRIPE	65.79	65.77	65.69
3	CONFIG PARALLEL GEOM STRIPE	73.11	62.01	60.07
4	CONFIG X GEOMETRY STRIPE	73.26	73.30	75.78
5	CONFIG T GEOMETRY T	60.57	61.74	64.06
6	CONFIG PARALLEL GEOM T	56.90	59.03	59.10
7	CONFIG X GEOMETRY T	62.52	62.80	64.41
8	CONFIG T GEOMETRY L	67.52	68.22	70.22
9	CONFIG PARALLEL GEOM L	59.00	59.22	59.58
10	CONFIG X GEOMETRY L	67.40	67.43	69.72

4.2.3 General Midpoint Von Mises Stress Value

The midpoint von mises result for each configuration and blast duration are shown in figure 4.7 to figure 4.9. The maximum values are tabulated in table 4.11. The complete analysis setting and result is displayed at Appendix B.

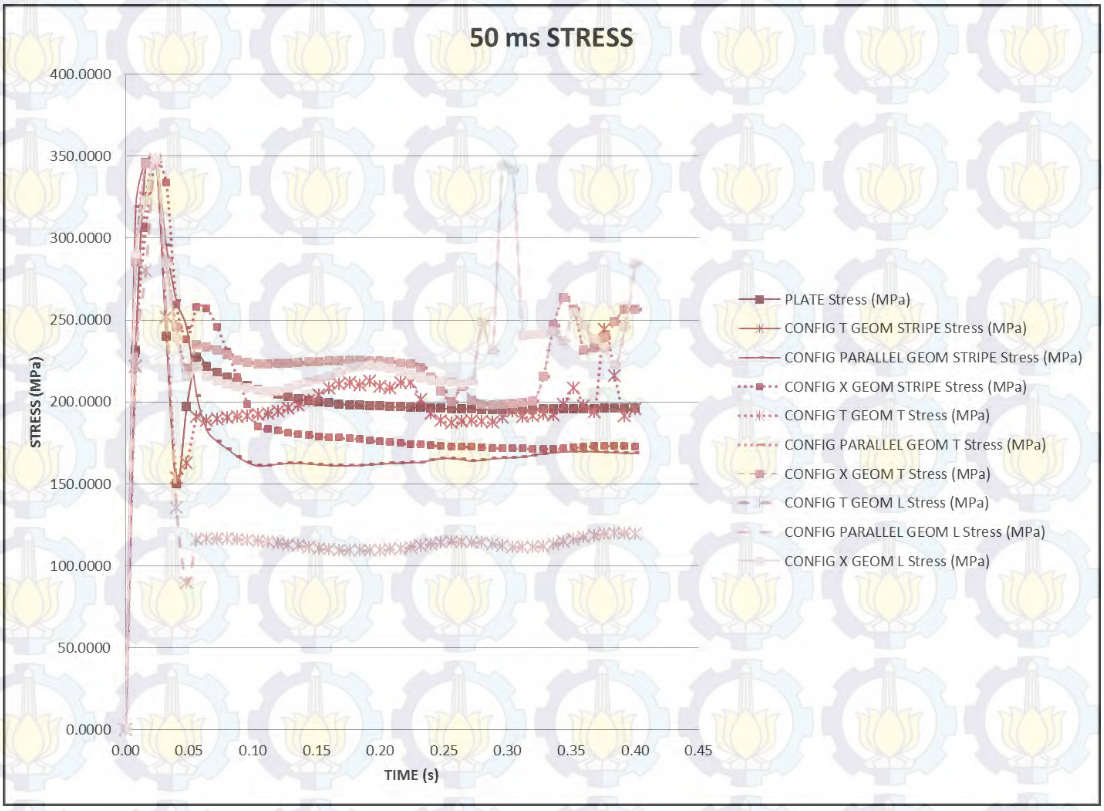


Figure 4.7. Midpoint Von Mises Stress 50 ms Blast Duration

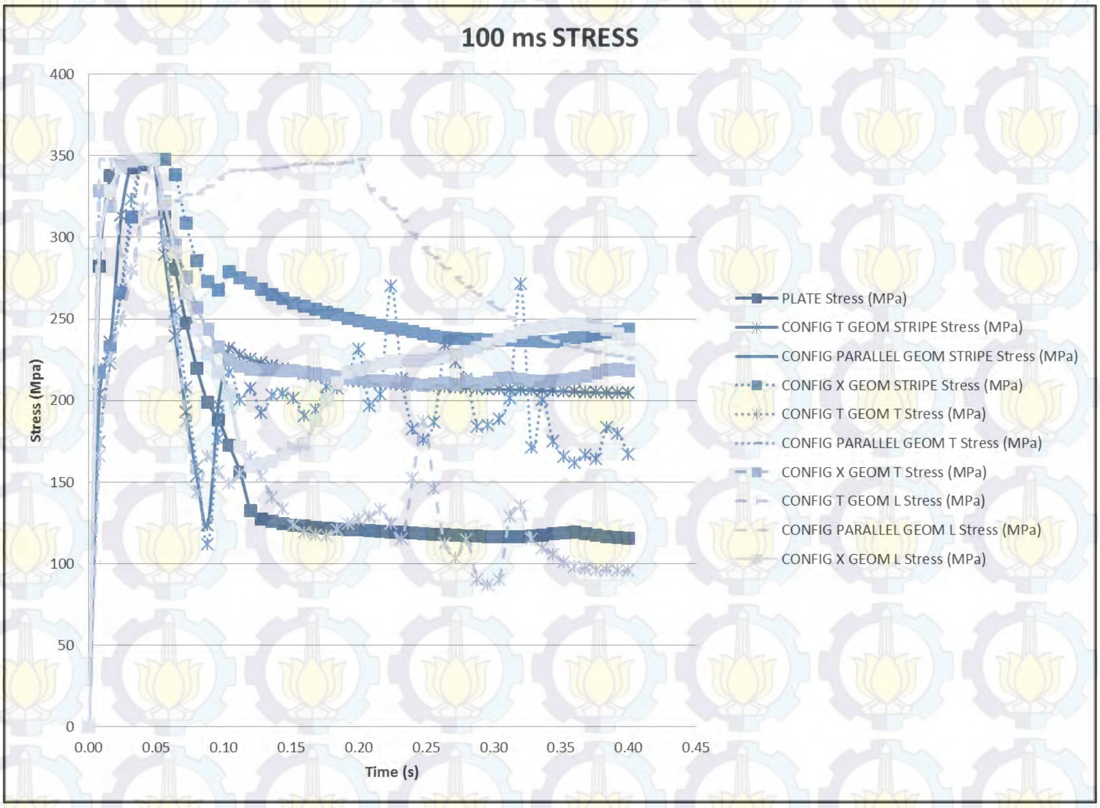


Figure 4.8. Midpoint Von Mises Stress 100 ms Blast Duration

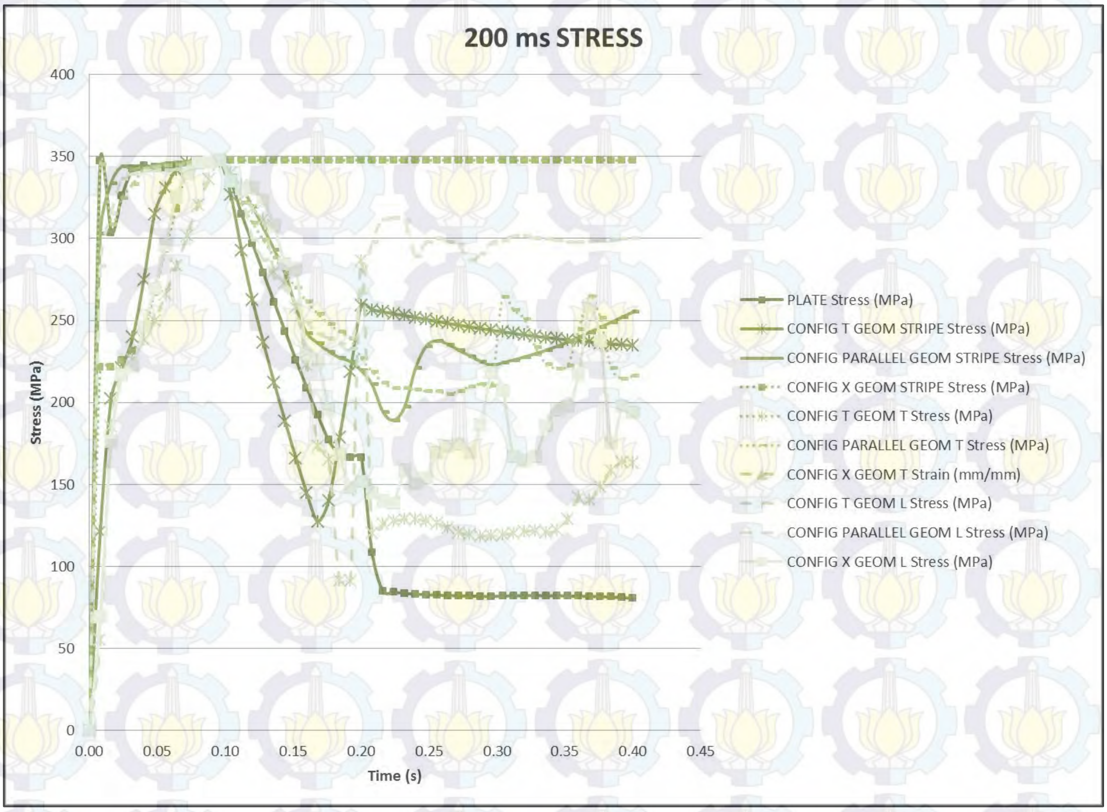


Figure 4.9. Midpoint Von Mises Stress 200 ms Blast Duration

Table 4.11. Maximum Midpoint Deformation Value

No	Plate	Midpoint V Mises Stress (MPa)		
		50 ms	**100 ms**	**200 ms**
1	UNSTIFFENED PLATE	348.00	348.00	348.00
2	CONFIG T GEOMETRY STRIPE	347.81	347.66	347.57
3	CONFIG PARALLEL GEOM STRIPE	347.74	347.57	347.32
4	CONFIG X GEOMETRY STRIPE	347.72	347.75	347.77
5	CONFIG T GEOMETRY T	346.56	346.63	346.65
6	CONFIG PARALLEL GEOM T	346.68	346.78	347.12
7	CONFIG X GEOMETRY T	347.79	347.78	347.80
8	CONFIG T GEOMETRY L	347.80	347.72	347.79
9	CONFIG PARALLEL GEOM L	347.74	347.78	348.00
10	CONFIG X GEOMETRY L	347.74	347.87	347.95

4.3 Discussion

Based on the result displayed, there are some effects that interesting to be discussed. Based on the equation (15) to (18), there are some factors to be considered to control the response of dynamic system. Let's recall the dynamic equilibrium equation as stated by equation (15):

$$m\ddot{u}(t) + b\dot{u}(t) + ku(t) = f(t) \qquad \text{.....................}(15)$$

Where:

$m\ddot{u}(t)$ = Inertial force, the product of mass and acceleration

$b\dot{u}(t)$ = Damping force, the product of viscous damping

$ku(t)$ = Restoring force, the product of stiffness constant K and displacement

$f(t)$ = Excitation Force

Whilst the damping factor is set to be constant, mass, stiffness and excitation force are the factors to be observed to obtain their tendency when increased/decreased. Let's breakdown the mass, stiffness and excitation force factors of continuous system as stated by equation (16) to (19).

$$m = \int_0^l m\varphi^2 dx + \sum_i^n M_i \varphi_i^2 \quad = \textit{generalized mass} \quad (16)$$

$$b = \int_0^l b\varphi^2 dx + \sum_i^n b_i \varphi_i^2 \quad = \textit{generalized damping} \ (17)$$

$$k = \int_0^l EI(\varphi'')^2 dx + \int_0^l k(x\varphi^2) dx + \sum_i^n K_i\varphi_i \quad = \textit{generalized stiffness} \ (18)$$

$$p(t) = \int_0^l q(x,t)\varphi dx + \sum_i^n F_i \varphi_i \quad = \textit{generalized excitation force} \ (19)$$

The stiffness is related to the geometry and its properties especially E (Young Modulus) related to **material** and I (Inertia) related to **geometry** and **configuration**. Excitation force is the equation of external force in time variation, the factors that play important roles is the force magnitude and duration. Whilst the magnitude is set to be constant, the **duration** is studied to investigate its influence to the response.

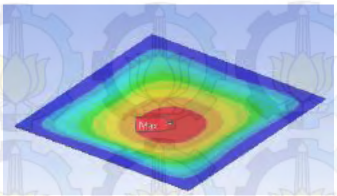
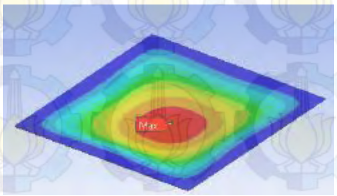
4.3.1 Geometry and Material Condition

The result showed that time at maximum response for all models are mostly identical. Maximum response occurred after peak overpressure from triangular blast load happened. These example below at point a to c is the example of geometry and material condition, for further information please refer to Appendix C.

a. Unstiffened Plate

The unstiffened plate under 50 ms blast loading duration has 90.417 mm midpoint deformation and equivalent stress 348 MPa. Afore mentioned condition occurred at t = 0.032 s or 0.007 second after the blast reached the maximum overpressure. The geometry reached its material plastic region so that the deformation remains large even after the blast loading ends. As provided by Table 4.12, the deformation remains at 76.66 mm, but the plate has not reached its erosion (crack) condition. This condition also occurred at 100 ms and 200 ms blast duration.

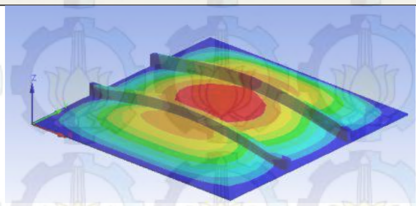
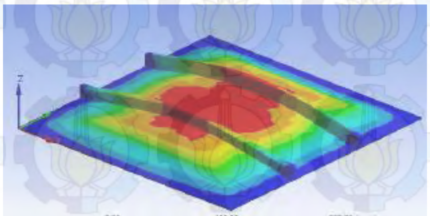
Table 4.12. Geometry and Material Condition, Unstiffened Plate 50 ms

Plate	Max State	t (s)	0.032
Unstiffened		Deformation (mm)	**90.417**
		Stress (MPa)	**348.00**
		Strain (mm/mm)	**0.0389**
	End Time	t (s)	0.4
		Deformation (mm)	**76.662**
		Stress (MPa)	**80.539**
		Strain (mm/mm)	**0.0624**

b. Stripe Geometry

The stripe geometry with parallel configuration under 100 ms blast loading duration has 62.01 mm midpoint deformation and equivalent stress 347.63 MPa. Afore mentioned condition occurred at t = 0.0563 s or 0.0063 second after the blast reached the maximum overpressure. The geometry reached its material plastic region so that the deformation remains large even after the blast loading ends. As provided by Table 4.13, the deformation remains at 53.63 mm, but the plate and stiffener has not reached its erosion (crack) condition. This condition also occurred at 50 ms and 200 ms blast duration.

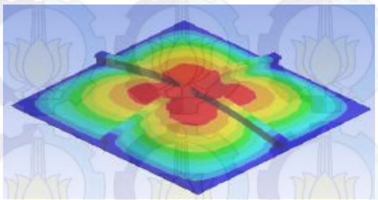
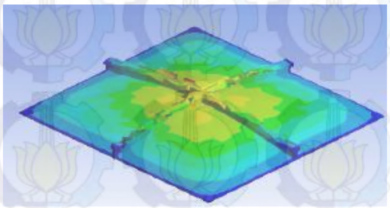
Table 4.13. Geometry and Material Condition, Geometry Stripe 100 ms

Plate	Max State	t (s)	0.0563
Config Parallel Geom Stripe		Deformation (mm)	**62.01**
		Stress (MPa)	**347.75**
		Strain (mm/mm)	**0.0338**
	End Time	t (s)	0.4
		Deformation (mm)	**53.842**
		Stress (MPa)	**237.46**
		Strain (mm/mm)	**0.0229**

c. T Geometry

The T geometry with T configuration under 100 ms blast loading duration has 61.74 mm midpoint deformation and equivalent stress 346.63 MPa. Afore mentioned condition occurred at t = 0.0563 s or 0.0063 second after the blast reached the maximum overpressure. The geometry reached its material plastic region so that the deformation remains large even after the blast loading ends. As provided by Table 4.14, the deformation remains at 59.63 mm and the stiffener reached its erosion condition. This condition also occurred at 50 ms and 200 ms blast duration.

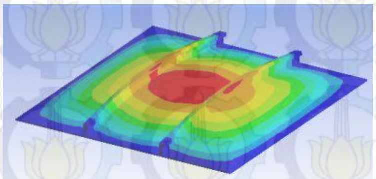
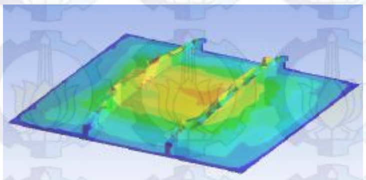
Table 4.14. Geometry and Material Condition, Config T Geom T, 100 ms

Plate	Max State	t (s)	0.0563
Config T Geom T		Deformation (mm)	**61.74**
		Stress (MPa)	**346.63**
		Strain (mm/mm)	**0.0170**
	End Time	t (s)	0.4
		Deformation (mm)	**59.629**
		Stress (MPa)	**166.72**
		Strain (mm/mm)	**0.0148**

d. L Geometry

The L geometry with parallel configuration under 200 ms blast loading duration has 59.58 mm midpoint deformation and equivalent stress 347.74 MPa. Afore mentioned condition occurred at t = 0.128 s or 0.028 second after the blast reached the maximum overpressure. The geometry reached its material plastic region so that the deformation remains large even after the blast loading ends. As provided by Table 4.15, the deformation remains at 55.63 mm and the stiffener reached its erosion condition. This condition also occurred at 50 ms and 100 ms blast duration.

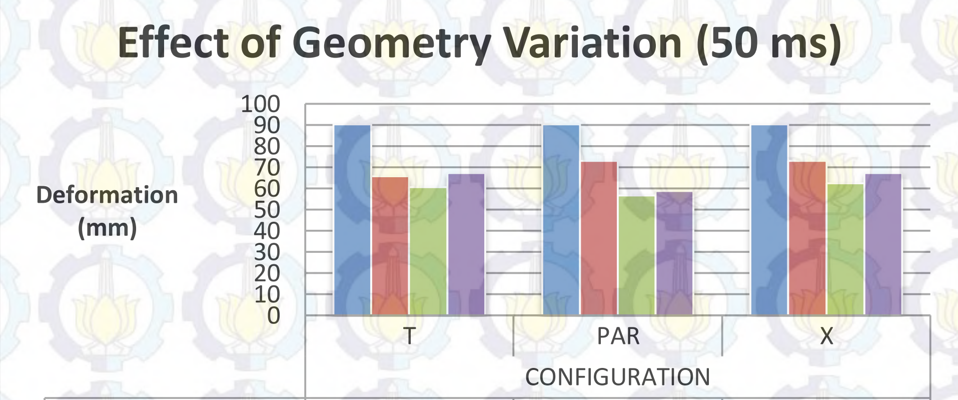
Table 4.15. Geometry and Material Condition, Config L Geom Parallel,200 ms

Plate	Max State	t (s)	0.128
Config Parallel Geom L		Deformation (mm)	**59.58**
		Stress (MPa)	**347.74**
		Strain (mm/mm)	**0.0345**
	End Time	t (s)	0.4
		Deformation (mm)	**55.042**
		Stress (MPa)	**300.26**
		(mm/mm)	**0.0515**

The plate deformations at analysis end time remain high. Because of response deformation exceed the elastic limit condition. Whilst the stress fluctuation remains high at several plate configurations, the deformation remains unchanged. Again, this is caused by the plastic deformation of the plates.

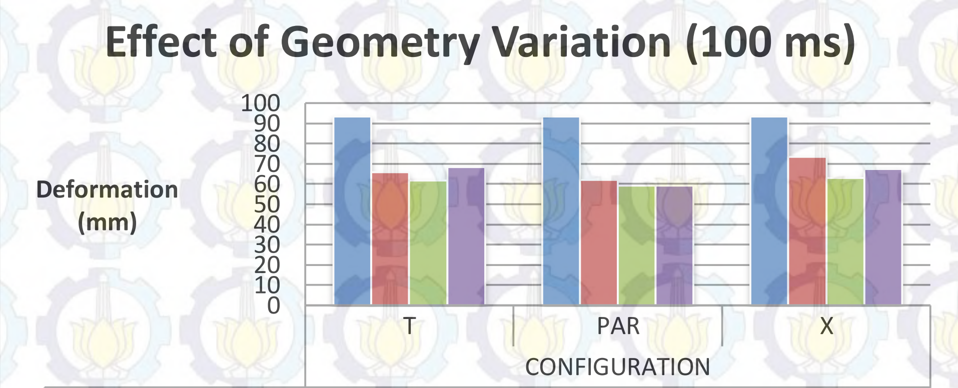
4.3.2 Effect of Stiffener Geometry

Based on analysis result, it is shown that the stiffener geometry has important effect to the deformation response. Figure 4.10 to Figure 4.12 give the graphical comparisons of maximum midpoint deformation for each blast durations and stiffener geometry. In all blast duration simulated, the result give consistent tendency that the lowest deformation is at “T” geometry:



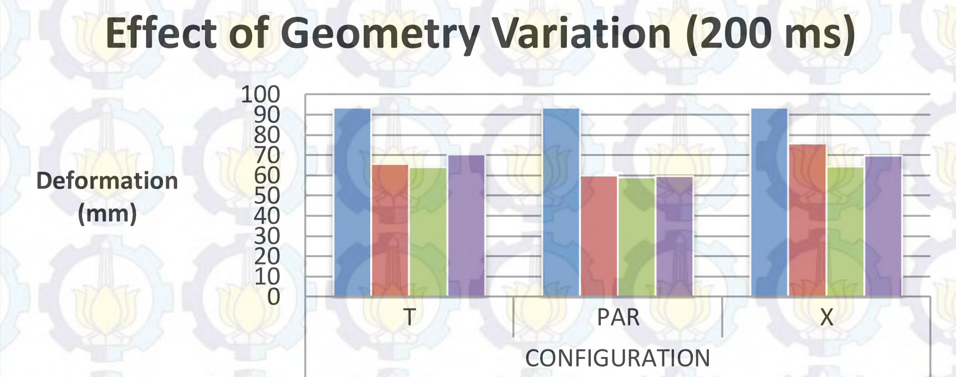
	T	PAR	X
UNSTIFFENED PLATE	90.417	90.417	90.417
GEOMETRY STRIPE	65.793	73.108	73.263
GEOMETRY T	60.57	56.90	62.52
GEOMETRY L	67.517	58.997	67.40196

Figure 4.10. Effect of Stiffener Geometry 50 ms



	T	PAR	X
UNSTIFFENED PLATE	93.344	93.344	93.344
GEOMETRY STRIPE	65.765	62.005	73.297
GEOMETRY T	61.736	59.029	62.80245
GEOMETRY L	68.215	59.218	67.43324

Figure 4.11. Effect of Stiffener Geometry 100 ms



	T	PAR	X
UNSTIFFENED PLATE	93.495	93.495	93.495
GEOMETRY STRIPE	65.686	60.073	75.779
GEOMETRY T	64.055	59.099	64.41215
GEOMETRY L	70.217	59.577	69.71668

Figure 4.12. Effect of Stiffener Geometry 200 ms

The blast loading simulation resulting that the **T geometry** is the best geometry to be used. Tables 4.16 to Table 4.19 serve the percentage of midpoint deformation reduction compared to the unstiffened plate. **T geometry** can reduce up to 33.74% of unstiffened plate deformation.

Table 4.16 Stiffener Geometry Reduction at 50 ms Blast Duration

50 ms		GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
CONFIGURATION	T	-27.23%	-33.01%	-25.33%
	PAR	-19.14%	-37.07%	-34.75%
	X	-18.97%	-30.85%	-25.45%
AVERAGE		**-21.78%**	**-33.64%**	**-28.51%**

Table 4.17 Stiffener Geometry Reduction at 100 ms Blast Duration

100 ms		GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
CONFIGURATION	T	-29.55%	-33.86%	-26.92%
	PAR	-33.57%	-36.76%	-36.56%
	X	-21.48%	-32.72%	-27.76%
AVERAGE		**-28.20%**	**-34.45%**	**-30.41%**

Table 4.18 Stiffener Geometry Reduction at 200 ms Blast Duration

200 ms		GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
CONFIGURATION	T	-29.74%	-31.49%	-24.90%
	PAR	-35.75%	-36.79%	-36.28%
	X	-18.95%	-31.11%	-25.43%
AVERAGE		**-28.15%**	**-33.13%**	**-28.87%**

Table 4.19 Summary of Stiffener Geometry Reduction

Averaged from All Blast Duration	GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
AVERAGE	**-26.04%**	**-33.74%**	**-29.26%**

4.3.3 Effect of Stiffener Configuration

Based on the analysis result, it is shown that the stiffener configurations have important role for the responses. Figure 4.13 to Figure 4.15 give the graphical comparisons:

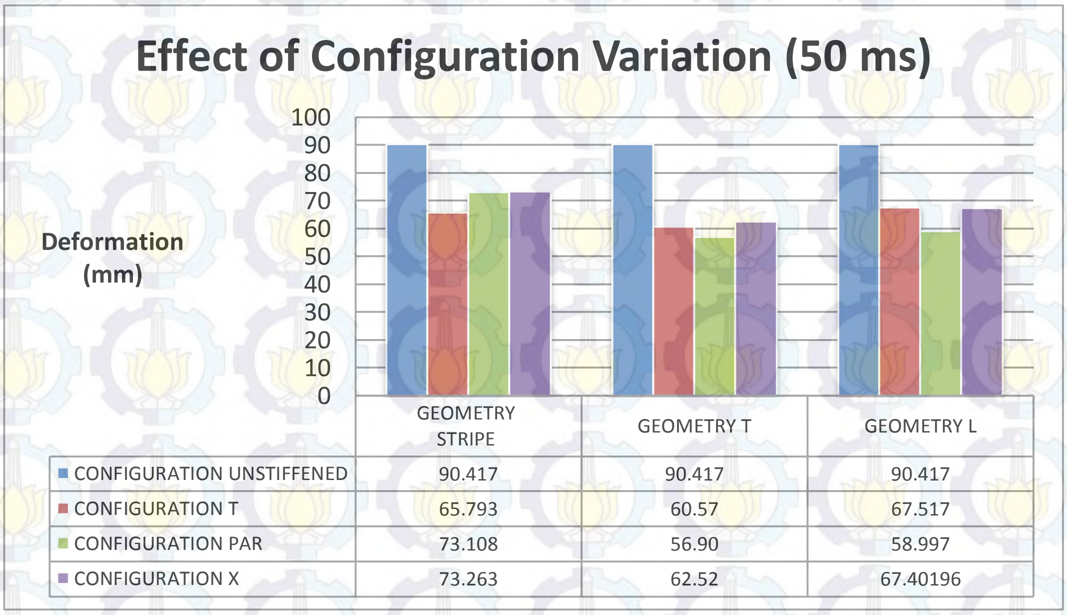
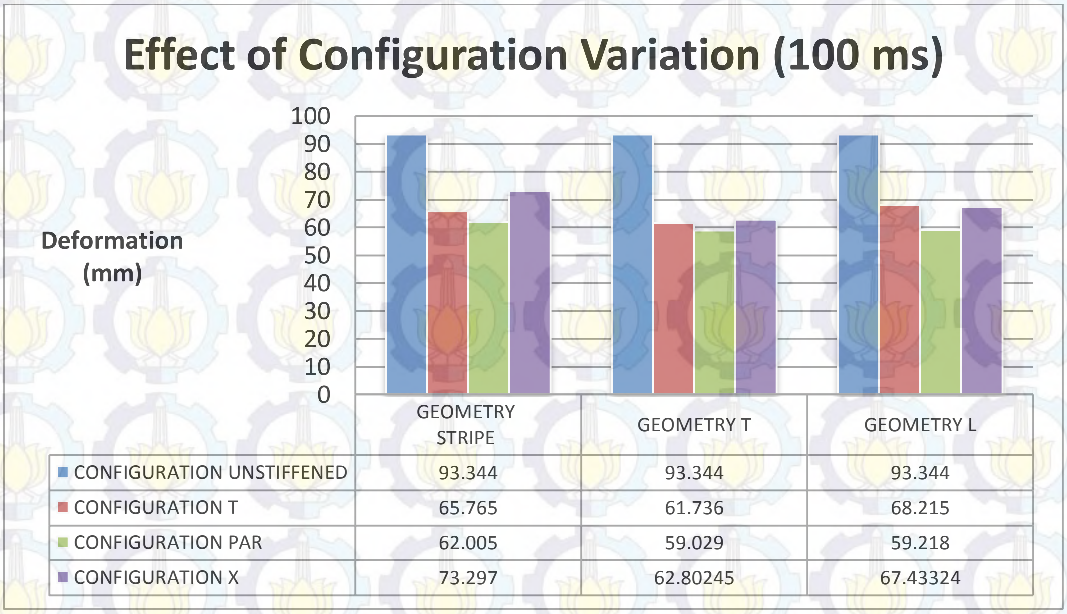
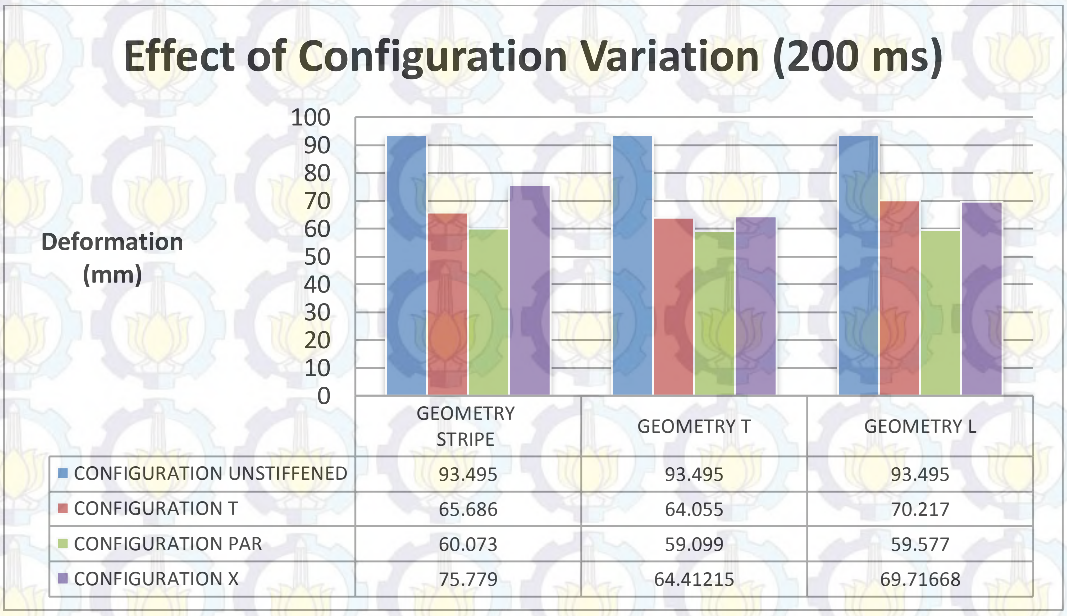


Figure 4.13. Effect of Stiffener Configuration 50 ms



	GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
CONFIGURATION UNSTIFFENED	93.344	93.344	93.344
CONFIGURATION T	65.765	61.736	68.215
CONFIGURATION PAR	62.005	59.029	59.218
CONFIGURATION X	73.297	62.80245	67.43324

Figure 4.14. Effect of Stiffener Configuration 100 ms



	GEOMETRY STRIPE	GEOMETRY T	GEOMETRY L
CONFIGURATION UNSTIFFENED	93.495	93.495	93.495
CONFIGURATION T	65.686	64.055	70.217
CONFIGURATION PAR	60.073	59.099	59.577
CONFIGURATION X	75.779	64.41215	69.71668

Figure 4.15. Effect of Stiffener Configuration 100 ms

The blast loading simulation resulting that the **Parallel Configuration** is the best geometry to be used. Tables 4.20 to Table 4.23 serve the percentage of midpoint deformation reduction compared to the unstiffened plate. **Parallel Configuration** can reduce up to **31.81%** of unstiffened plate deformation.

Table 4.20 Stiffener Configuration Reduction at 50 ms Blast Duration

50 ms	CONFIGURATION		
	T	PAR	X
GEOMETRY STRIPE	-27.23%	-19.14%	-18.97%
GEOMETRY T	-33.01%	-37.07%	-30.85%
GEOMETRY L	-25.33%	-34.75%	-25.45%
AVERAGE	**-28.52%**	**-30.32%**	**-25.09%**

Table 4.21 Stiffener Configuration Reduction at 100 ms Blast Duration

100 ms	CONFIGURATION		
	T	PAR	X
GEOMETRY STRIPE	-29.52%	-21.68%	-21.51%
GEOMETRY T	-35.11%	-39.04%	-33.02%
GEOMETRY L	-27.67%	-36.80%	-27.79%
AVERAGE	**-30.77%**	**-32.51%**	**-27.44%**

Table 4.22 Stiffener Configuration Reduction at 200 ms Blast Duration

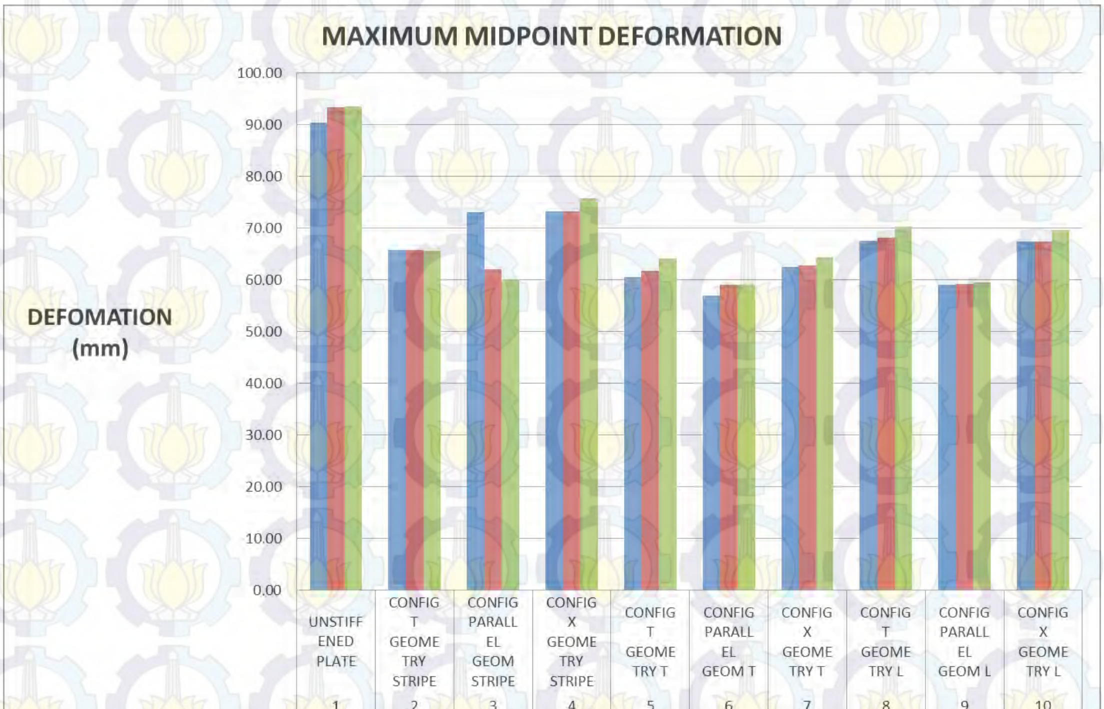
200 ms	CONFIGURATION		
	T	PAR	X
GEOMETRY STRIPE	-29.63%	-21.81%	-21.64%
GEOMETRY T	-35.22%	-39.14%	-33.13%
GEOMETRY L	-27.79%	-36.90%	-27.91%
AVERAGE	**-30.88%**	**-32.62%**	**-27.56%**

Table 4.23 Summary of Stiffener Configuration Reduction

50 ms	CONFIGURATION		
	T	PAR	X
AVERAGE	**-30.06%**	**-31.81%**	**-26.70%**

4.3.4 Effect of Blast Duration

The graphical result shows that the longer the duration, the higher the deformation. 9 of the 10 models show this tendency. Exception happens at parallel stiffener configuration with stripe geometry. The overall result shows that the best stiffened plate is parallel configuration with T geometry.



	UNSTIFFENED PLATE 1	CONFIG T GEOMETRY STRIPE 2	CONFIG PARALLEL GEOM STRIPE 3	CONFIG X GEOMETRY STRIPE 4	CONFIG T GEOMETRY T 5	CONFIG PARALLEL GEOM T 6	CONFIG X GEOMETRY T 7	CONFIG T GEOMETRY L 8	CONFIG PARALLEL GEOM L 9	CONFIG X GEOMETRY L 10
Midpoint Displacement (mm) 50 ms	90.42	65.79	73.11	73.26	60.57	56.90	62.52	67.52	59.00	67.40
Midpoint Displacement (mm) 100 ms	93.34	65.77	62.01	73.30	61.74	59.03	62.80	68.22	59.22	67.43
Midpoint Displacement (mm) 200 ms	93.50	65.69	60.07	75.78	64.06	59.10	64.41	70.22	59.58	69.72

Figure 4.16. Effect Blast Duration

Maximum overpressure at 50 ms blast duration occurred at t = 0.025s and maximum response at 50 ms occurred at t = 0.032 s. The time delay from maximum load to maximum response is **0.007 s**. Maximum overpressure at 100 ms blast duration occurred at t = 0.05 s and maximum response at 100 ms occurred at t = 0.0563 s. The time delay from maximum load to maximum response is **0.0063 s**. Maximum overpressure at 200 ms blast duration occurred at t = 0.1 s and maximum response at 200 ms occurred at t = 0.128 s. The time delay from maximum load to maximum response is **0.028 s**. Figure 4.17 shows the graphical representation of load vs midpoint deformation, at Parallel Plate Configuration with T Geometry.

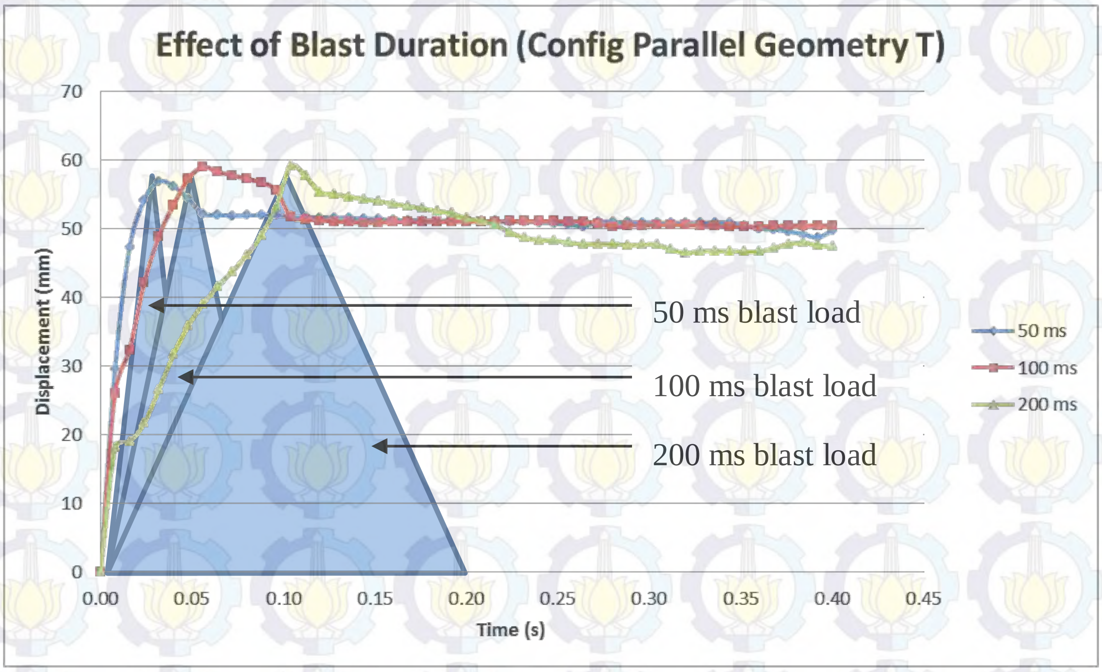


Figure 4.17 Load vs Midpoint Deformation

4.3.5 Effect of Mass

There is no consistent tendency regarding the effect of mass. But from the analysis came the fact that the heavier plate not always results the better response. Table 4.24 below shows the summary, the configuration is sorted descending from the heaviest to lightest plates. The yellow shaded cell shows the smallest midpoint deformation.

Table 4.24 Effect of mass variation

NO	ITEM	WEIGHT (kg)	Deformation (mm)
1	CONFIG X GEOMETRY STRIPE	79.47	73.30
2	CONFIG X GEOMETRY T	76.26	62.80
3	CONFIG X GEOMETRY L	71.35	67.43
4	CONFIG PARALLEL GEOM STRIPE	70.65	62.01
5	CONFIG T GEOMETRY STRIPE	70.31	65.77
6	CONFIG PARALLEL GEOM T	68.30	59.03
7	CONFIG T GEOMETRY T	68.02	61.74
8	CONFIG PARALLEL GEOM L	64.76	59.22
9	CONFIG T GEOMETRY L	64.47	68.22

4.4 Design of Blast Resistant Stiffened Plate

The design of blast resistant stiffened plate as stated in chapter 3.9 and 3.10 is performed in this chapter. The best midpoint deformation of analyzed and discussed plates in chapter 4.3 is selected and further accounted for the response parameter criteria.

4.4.1 Choosing the Best Response Stiffened Plate

The best response stiffened plate based on chapter 4.3 is plate with **parallel configuration and T geometry.** This plate reduces 36.87% deformation of unstiffened plate.

Table 4.25 Best response stiffened plate

No	Plate	50 ms	100 ms	200 ms	
1	UNSTIFFENED PLATE	90.42	93.34	93.50	
6	CONFIG PARALLEL GEOM T	56.90	59.03	59.10	**AVERAGE**
	REDUCTION	**-37.07%**	**-36.76%**	**-36.79%**	**-36.87%**

4.4.2 Calculating Response Parameter

The response parameter is calculated in table 4.24. Midpoint deformation used is the highest (200 ms) deformation. Maximum static elastic deformation is investigated using ANSYS Static Structural with same meshing and boundary condition. The analysis performed with increasing the pressure until the simulation reached its maximum elastic strain (0.00125 mm/mm). Please refer to Appendix D for further details. Analysis result gives the maximum elastic deformation 9.6 mm. using equation (29) to calculate support rotation and equation (30) to calculate ductility limit, the result is shown in Table 4.24.

Table 4.26 Response Parameter Calculation

Deformation (mm)	Max Elastic Deformation (mm)	Support Rotation (°)	Ductility Limit
59.1	9.6	0.002	6.15625

4.4.3 Response Criteria Comparison

The response parameter calculated in chapter 4.4.2 is compared with response criteria in Table 3.4. Results in table 4.24 shown that the plate is not needed to be redesigned because of the values satisfy the criteria.

Table 4.27 Response criteria comparison

Item	Value	Max Value	Status
Support Rotation	0.002	6	OK
Ductility Limit	6.15625	10	OK

APPENDIX A

Modal Analysis is conducted to obtain the natural period for each plate. And the unstiffened plate natural period is validated using manual calculation displayed below:

1. MODEL FROM TAVAKOLI'S PAPER

From basic of structural dynamics, vibration equation is stated as follows:

$$m\ddot{u}(t) + ku(t) = f(t)$$

Where:

m= Mass coefficient

k= Stiffness coefficient

Based on DNV RP C-204, the calculation of component of vibration equation is as follows:

$$D = E\frac{t^3}{12(1-v^2)} = \text{plate bending stiffness}$$

$$k_1 = \psi\frac{D}{b^4} = \text{plate stiffness}$$

$$T = \frac{2\pi}{\eta}\sqrt{\frac{\rho t b^2}{D}} = \text{natural period of vibration}$$

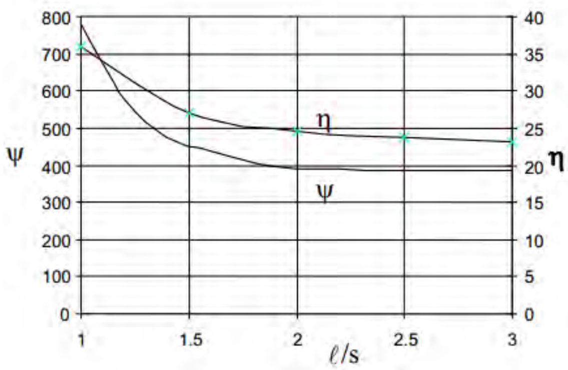
Where:

E =Elasticity Modulus = 200000 MPa

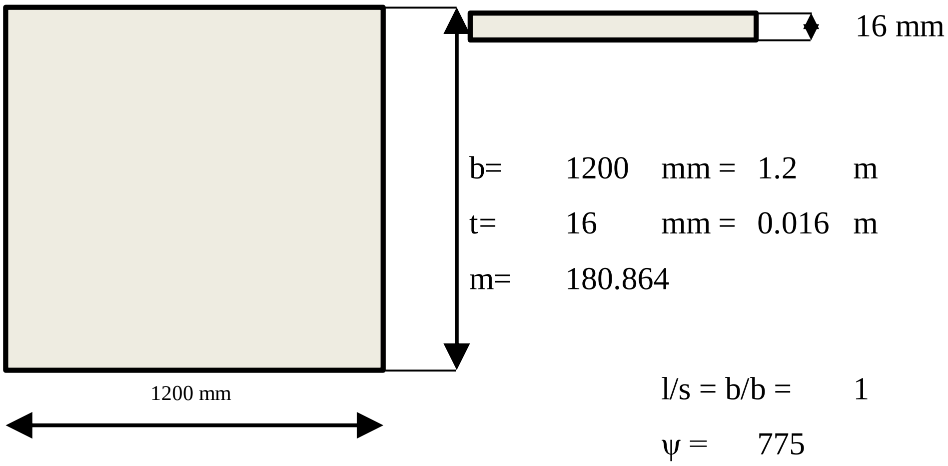
t = Plate thickness

v = Poisson Ratio

the ψ and η is determined from graphic below:



For this project's plate, the properties are as follows:



b=	1200	mm =	1.2	m
t=	16	mm =	0.016	m
m=	180.864			

l/s = b/b = 1

ψ = 775

η = 40

Hence the bending stiffness of plate above is:

D = 0.068266667

k = 25.51440329

And the natural period is:

Tn = 0.01026

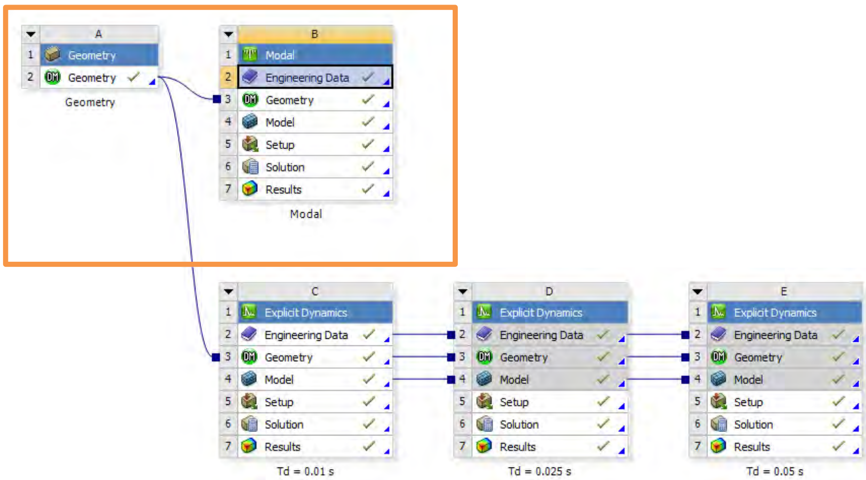
fn = 97.44452832

2. PLATE MODELS, 1st ORDER NATURAL PERIOD USING ANSYS MODAL ANALYSIS

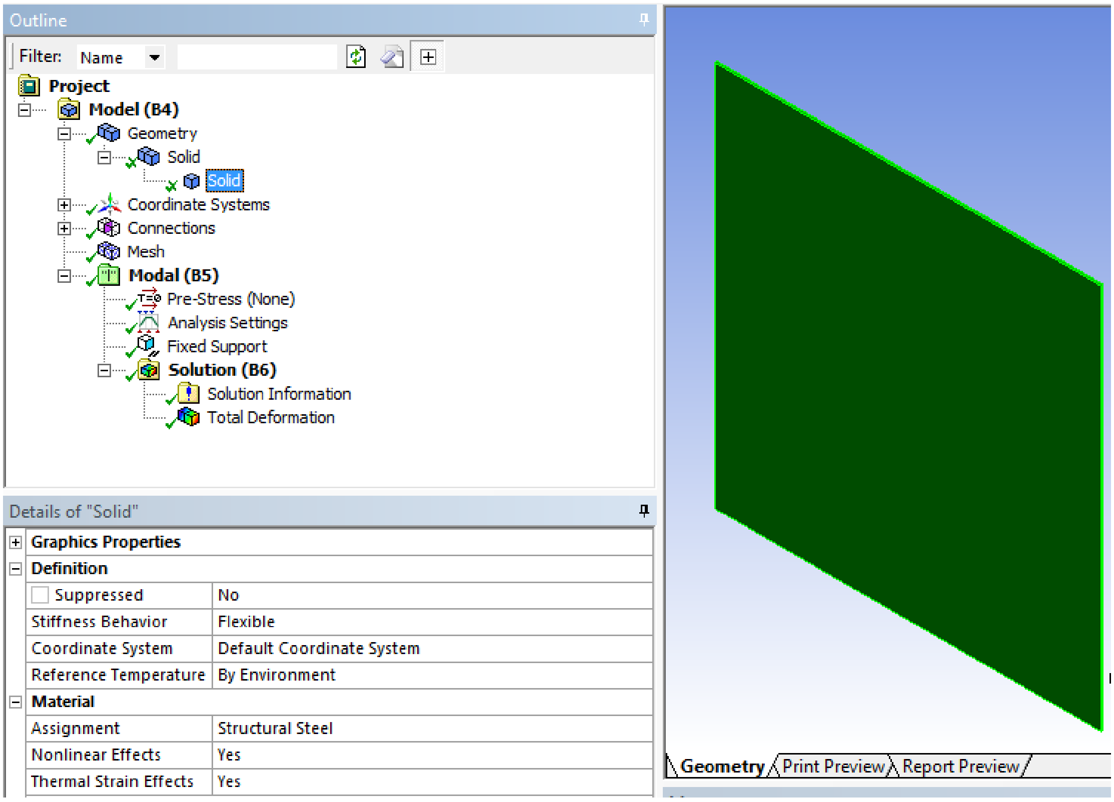
2.1. Analysis Setting

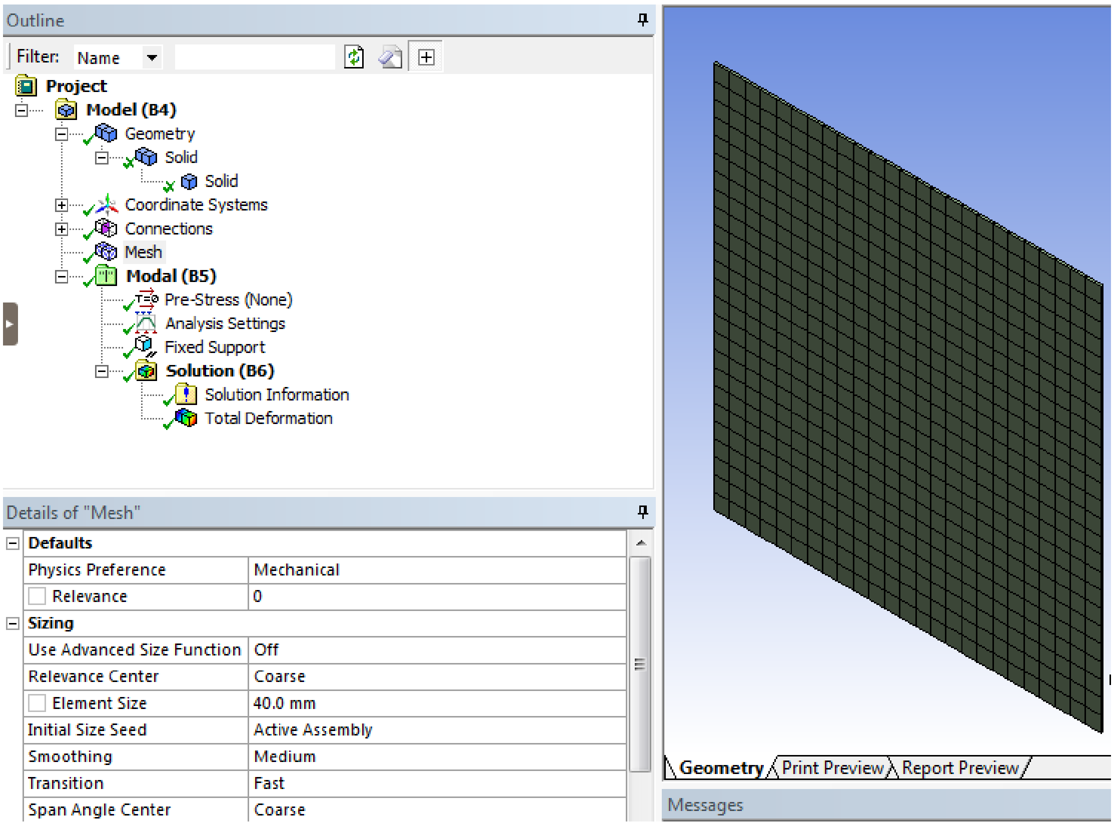
The steps to do to analyze 1st order Natural Period is as follow

- Determining the analysis workflow (Modal Analysis)

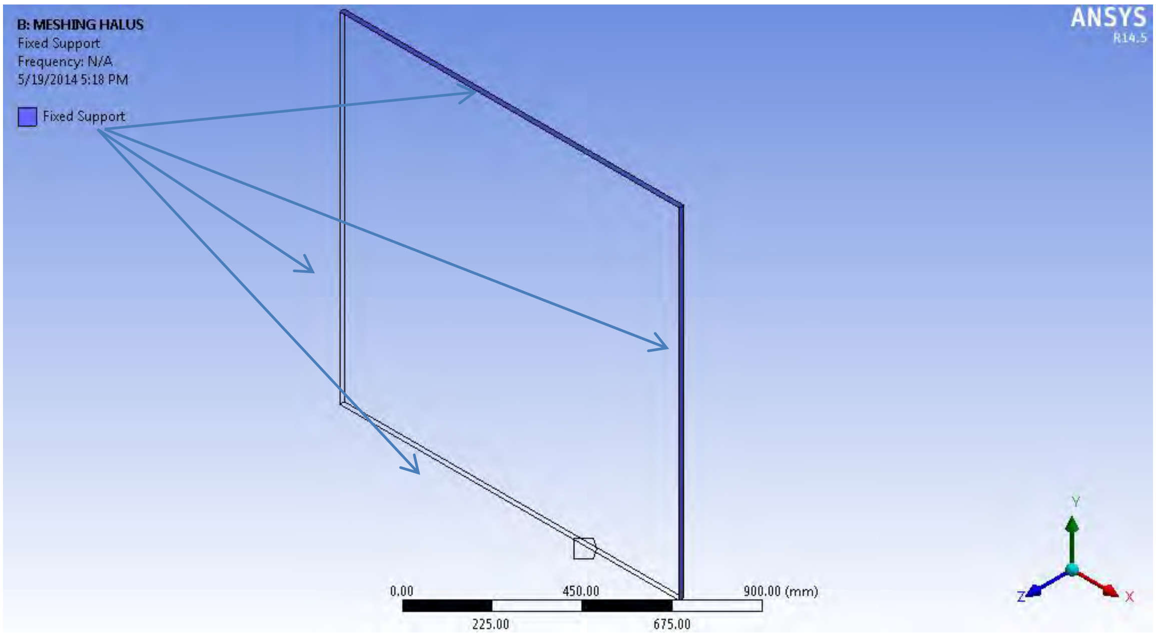


- Preparing the material, geometry, and meshing size (from meshing sensitivity study = 40 mm)

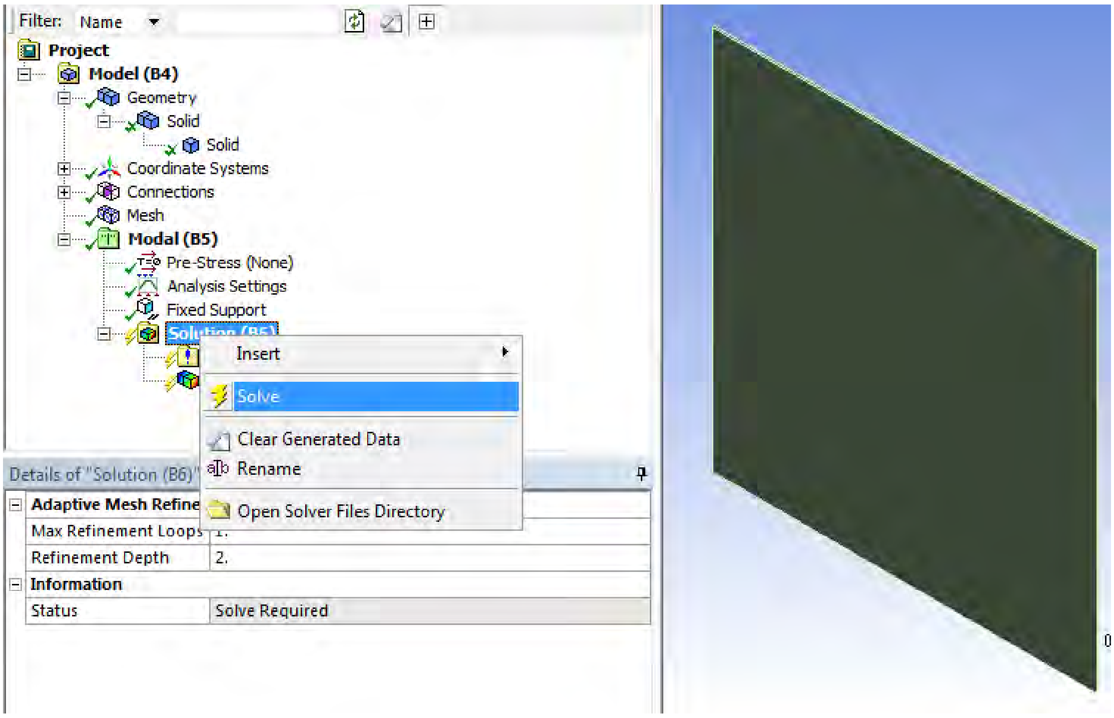




- Determining the boundary condition (fixed ends)

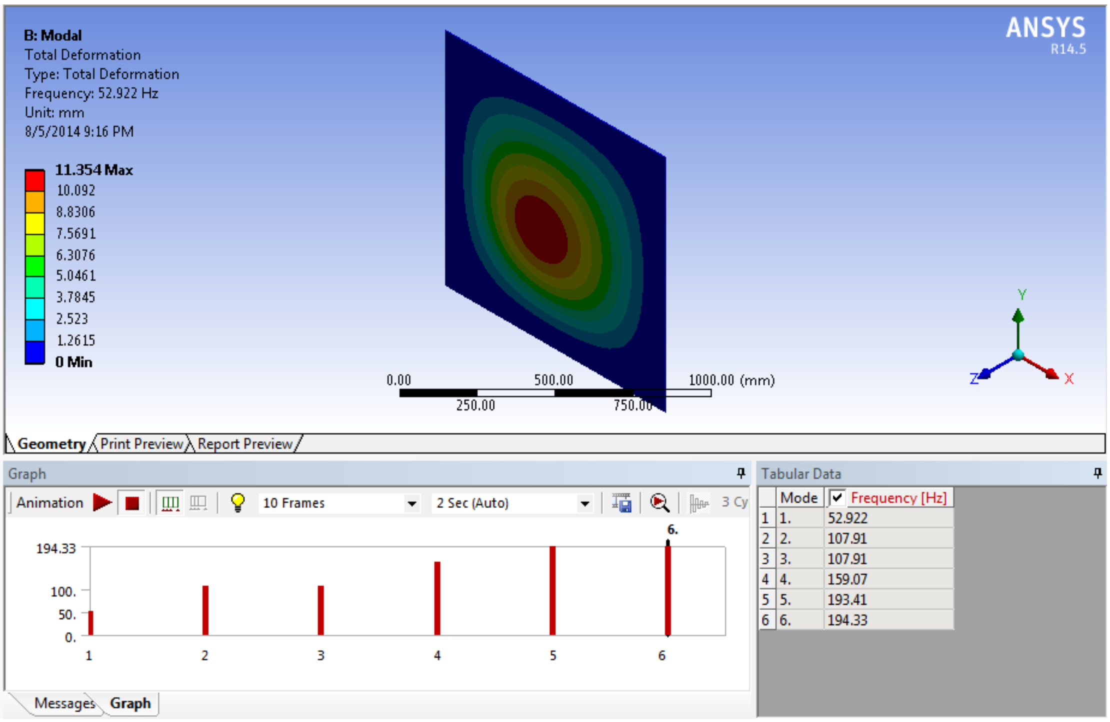


- Solving the analysis (Right Mouse Button Menu > Solve)



2.2. Result

The visual and tabular result is as follow:



2.3. Tabular results for other plates:

No.	Item	Natural Period (s)
1	Unstiffened Plate	0.1891
2	Config T Geom Stripe	0.0760
3	Config Parallel Geom Stripe	0.0812
4	Config X Geom Stripe	0.0674
5	Config T Geom L	0.0821
6	Config Parallel Geom L	0.0715
7	Config X Geom L	0.0671
8	Config T Geom T	0.0807
9	Config Parallel Geom T	0.0798
10	Config X Geom T	0.0667

APPENDIX D

Static analysis performed to obtain deformation at maximum elastic strain condition (deformation at von mises strain ε = 0.00125 mm/mm. This analysis is performed with pushover method parity with load increment of 0.01 MPa Starting from 0.5 MPa until the strain reached the designated value. Using Static Structural Workbench Module, with exactly same steps at Appendix B, the result is provided in table below:

No.	Stress	Strain	Deformation
1	237.8	0.00116569	8.915
2	242.65	0.00118946	9.097
3	247.5	0.00121324	9.279
4	251.25	0.00123162	9.419
5	255	0.00125	9.560

APPENDIX C

Complete material and geometry status are displayed below:

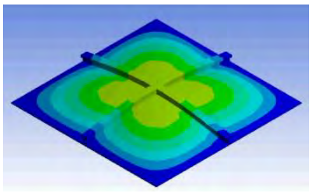
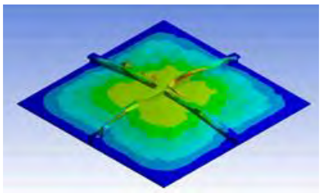
Plate	Max State	t (s)	0.0563
Config T Geom T		Deformation (mm)	**61.74**
		Stress	**346.63**
		Strain	**0.0115**
	End Time	t (s)	0.4
		Deformation (mm)	**59.629**
		Stress (MPa)	**166.72**
		Strain	**0.0107**

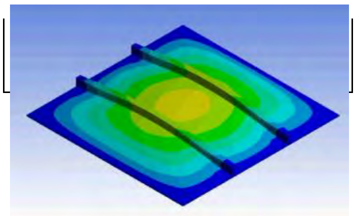
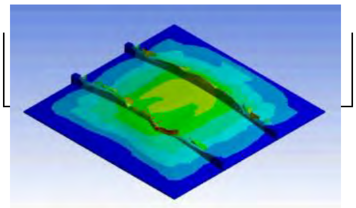
Plate	Max State	t (s)	0.128
Config Parallel Geom L		Deformation (mm)	**59.58**
		Stress	**347.74**
		Strain	**0.0369**
	End Time	t (s)	0.4
		Deformation (mm)	**55.042**
		Stress (MPa)	**300.26**
		Strain	**0.0280**

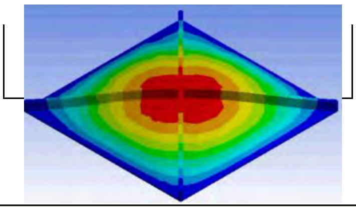
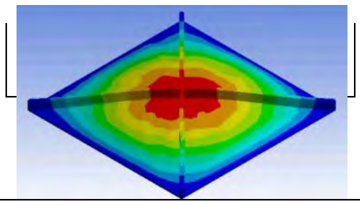
Plate	Max State	t (s)	0.128
Config X Geom T		Deformation (mm)	**62.80**
		Stress	**347.78**
		Strain	**0.0063**
	End Time	t (s)	0.4
		Deformation (mm)	**60.5354**
		Stress (MPa)	**218.46**
		Strain	**0.0034**

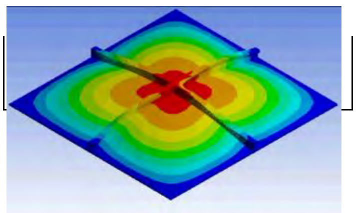
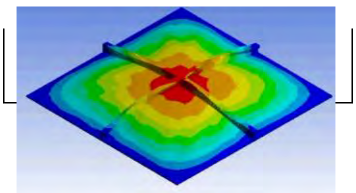
Plate	Max State	t (s)	0.0563
Config T Geom L		Deformation (mm)	**68.22**
		Stress	**347.72**
		Strain	**0.0127**
	End Time	t (s)	0.4
		Deformation (mm)	**68.22**
		Stress (MPa)	**95.69**
		Strain	**0.0118**

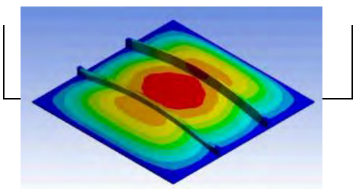
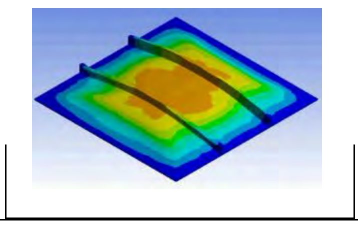
Plate	Max State	t (s)	0.0563
Config Parallel Geom Stripe		Deformation (mm)	**62.01**
		Stress	**347.57**
		Strain	**0.0324**
	End Time	t (s)	0.4
		Deformation (mm)	**53.842**
		Stress (MPa)	**237.46**
		Strain	**0.0276**

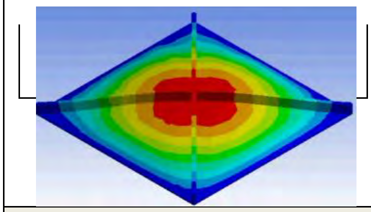
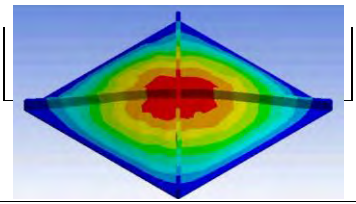
Plate	Max State	t (s)	0.0563
Config X Geom L		Deformation (mm)	**67.43**
		Stress	**347.87**
		Strain	**0.006444**
	End Time	t (s)	0.4
		Deformation (mm)	**65.25008**
		Stress (MPa)	**237.46**
		Strain	**0.0037**

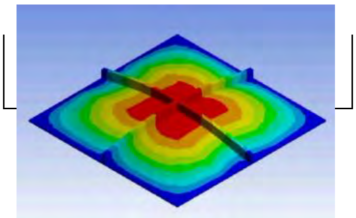
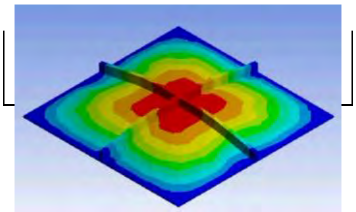
Plate	Max State	t (s)	0.0563
Config T Geom Stripe		Deformation (mm)	**65.77**
		Stress	**347.66**
		Strain	**0.0170**
	End Time	t (s)	0.4
		Deformation (mm)	**63.226**
		Stress (MPa)	**204.43**
		Strain	**0.01423**

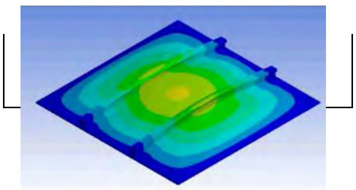
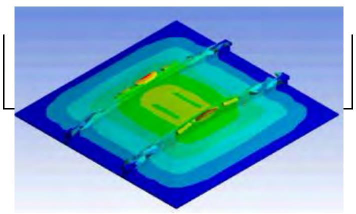
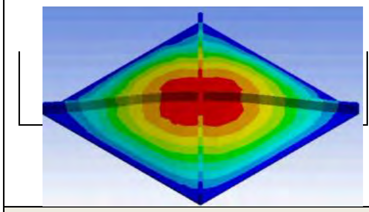
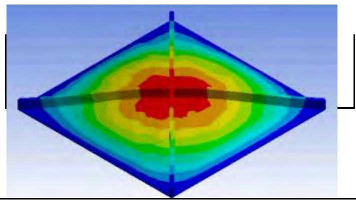
Plate	Max State	t (s)	0.0563
Config Parallel Geom T		Deformation (mm)	**59.03**
		Stress	**346.78**
		Strain	**0.0529**
	End Time	t (s)	0.4
		Deformation (mm)	**50.448**
		Stress (MPa)	**218.46**
		Strain	**0.052933**

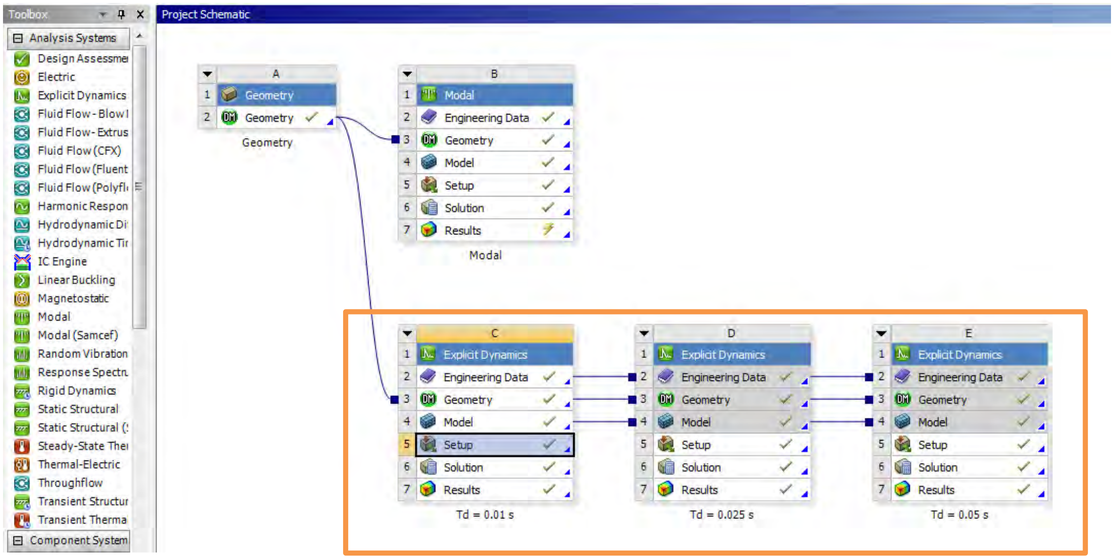
Plate	Max State	t (s)	0.0563
Config X Geom Parallel		Deformation (mm)	**67.43**
		Stress	**347.87**
		Strain	**0.0064**
	End Time	t (s)	0.4
		Deformation (mm)	**65.25008**
		Stress (MPa)	**237.46**
		Strain	**0.006444**

APPENDIX B

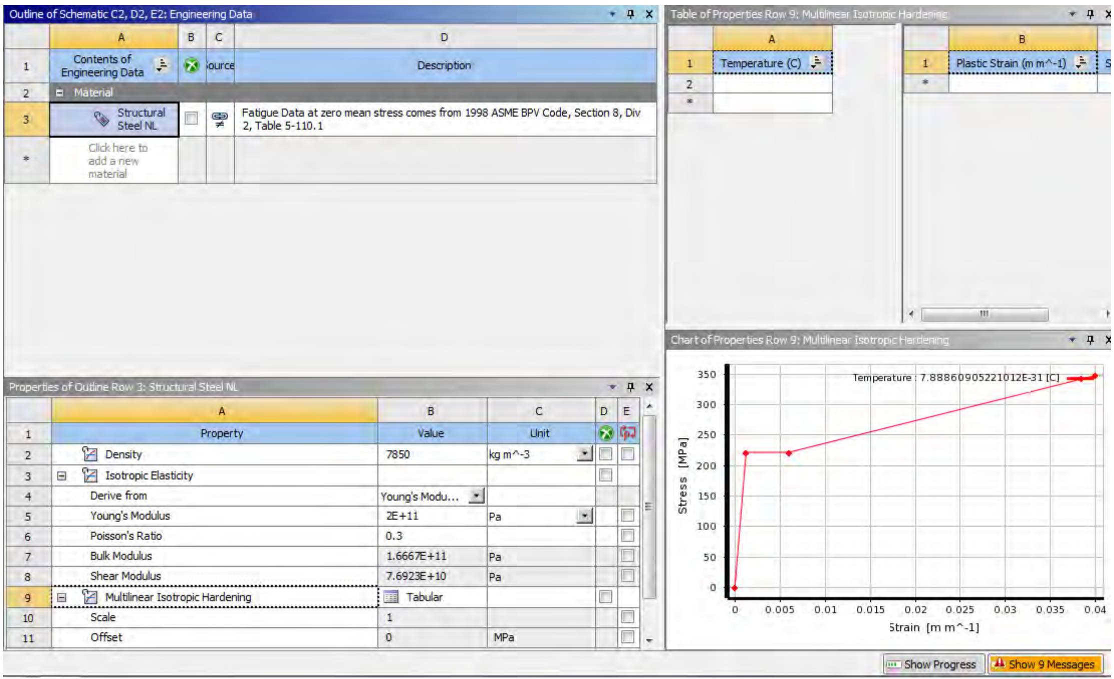
Blast analysis is performed using ANSYS Workbench Explicit Dynamic Modules, the software analysis procedures and complete results are provided in this section.

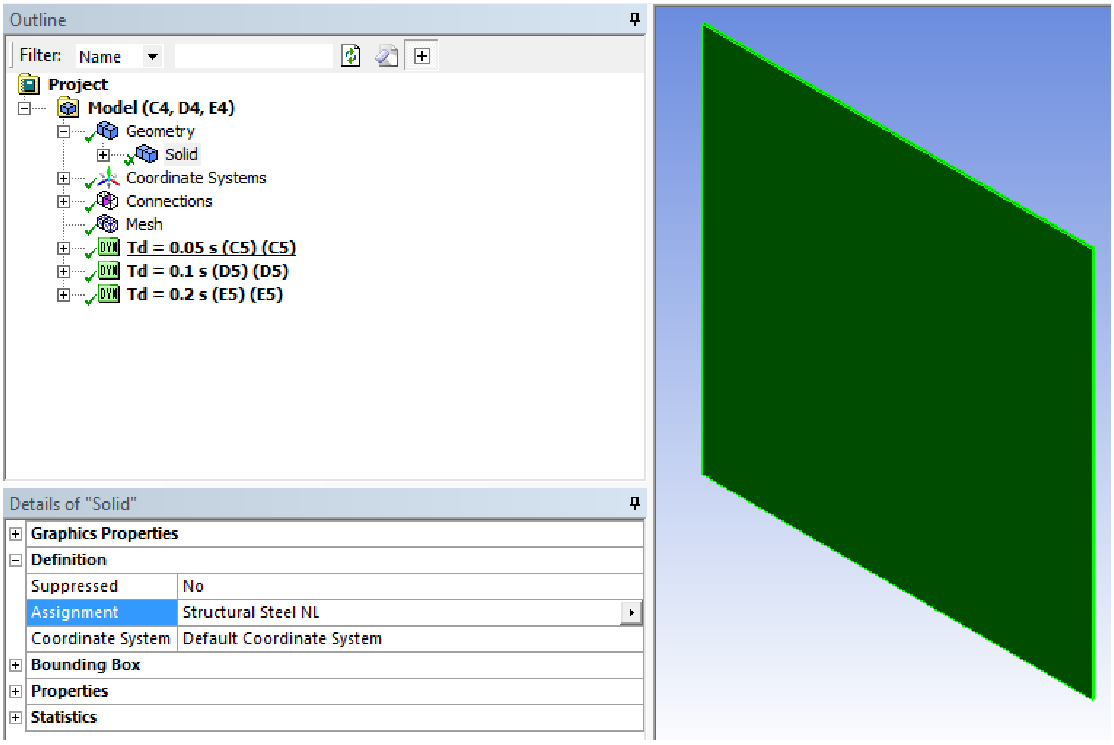
1. BLAST ANALYSIS PROCEDURES

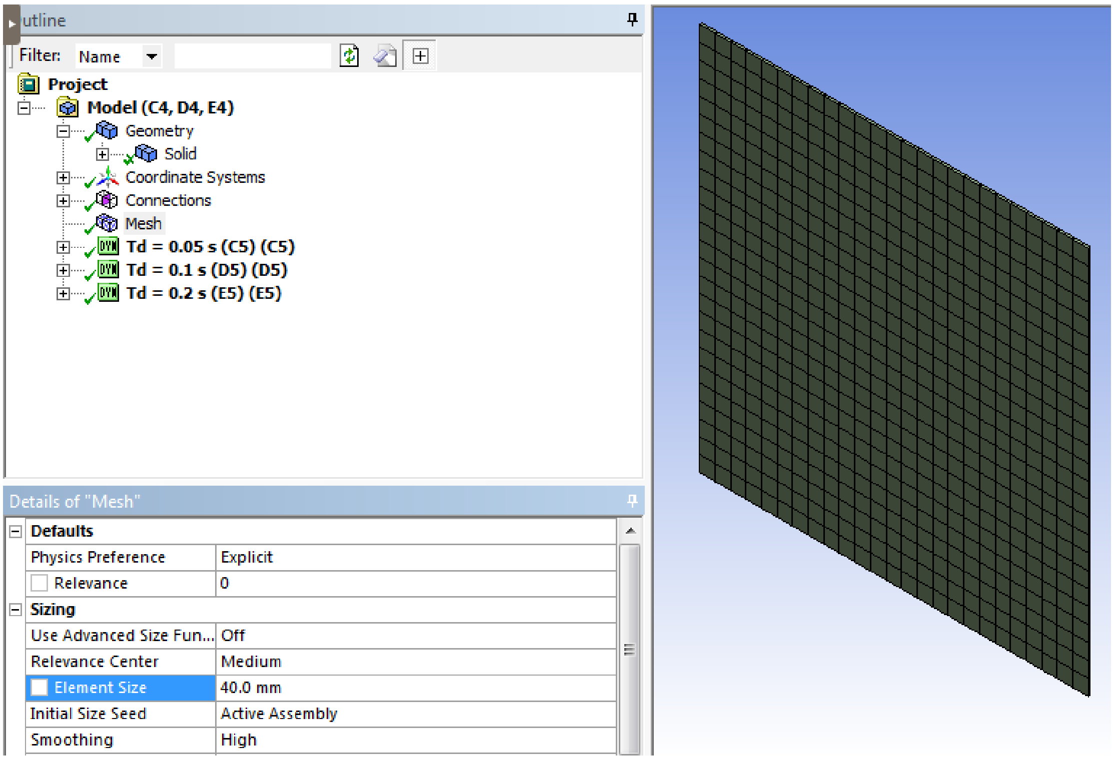
- Determining the analysis workflow (Explicit Dynamics)



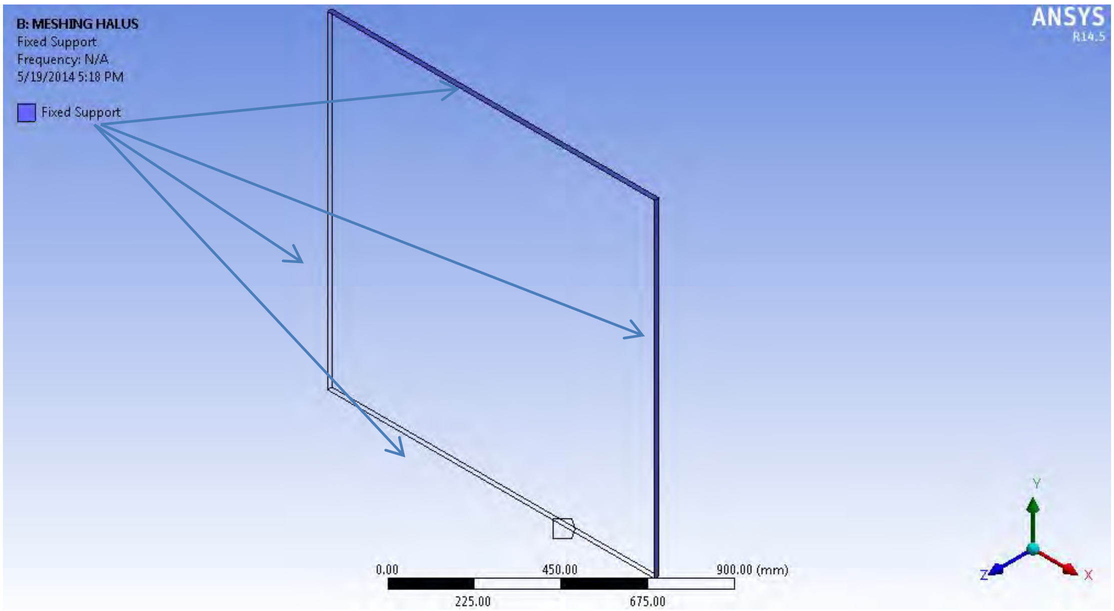
- Preparing the material, geometry, and meshing size (from meshing sensitivity study = 40 mm)

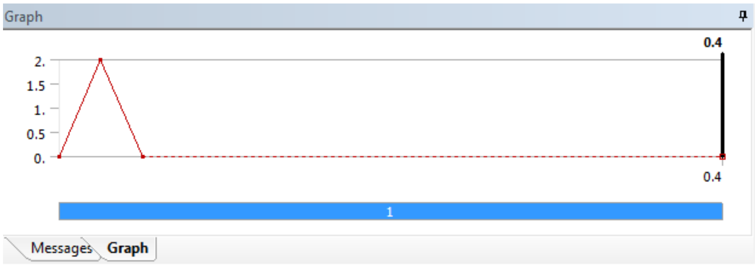






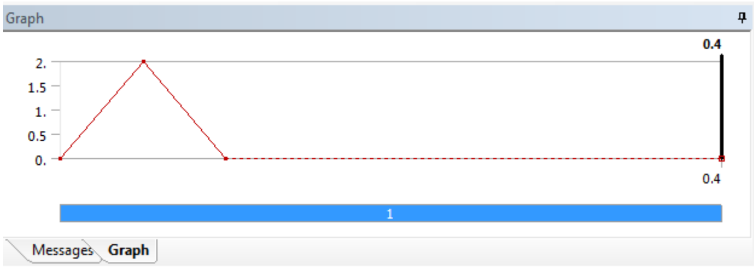
- Preparing the boundary condition and time history loads





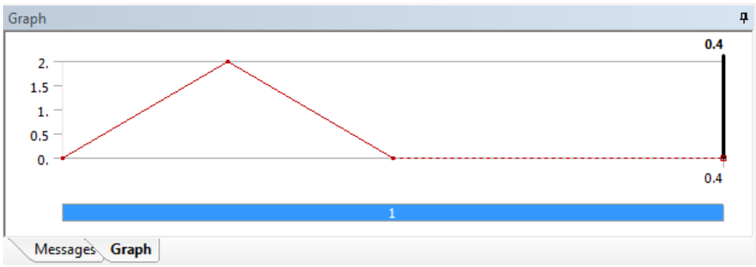
Tabular Data

	Steps	Time [s]	Pressure [MPa]
1	1	0.	0.
2	1	2.5e-002	2.
3	1	5.e-002	0.
4	1	0.4	= 0.
*			



Tabular Data

	Steps	Time [s]	Pressure [MPa]
1	1	0.	0.
2	1	5.e-002	2.
3	1	0.1	0.
4	1	0.4	= 0.
*			

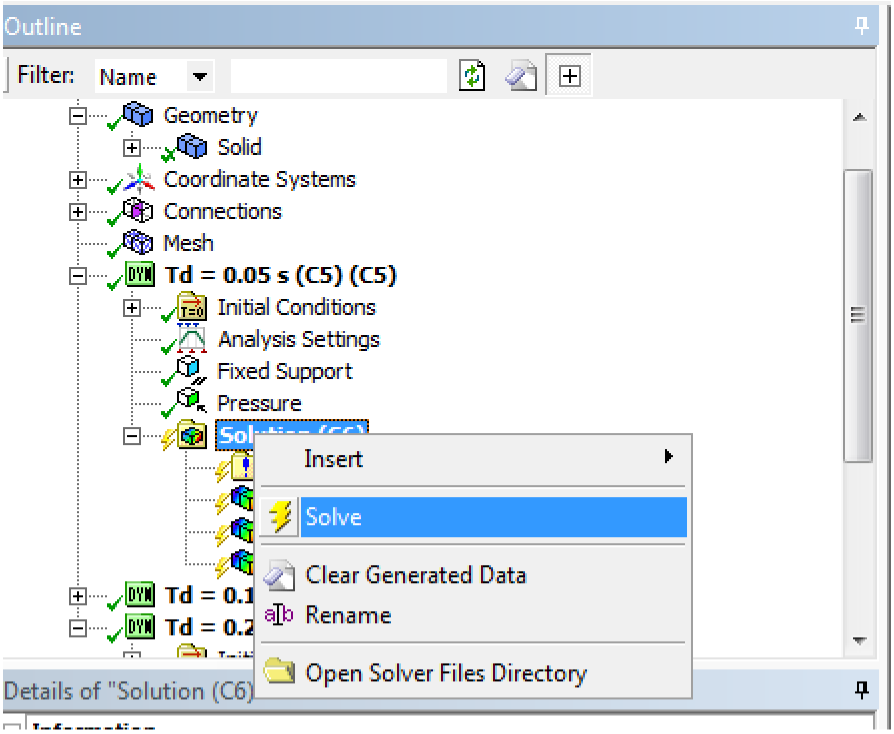


Tabular Data

	Steps	Time [s]	Pressure [MPa]
1	1	0.	0.
2	1	0.1	2.
3	1	0.2	0.
4	1	0.4	= 0.
*			

- Configuring analysis duration (0.4 seconds), Maximum Geometric Strain Limit (1), Material Failure Setting (Set: Yes, Default: No), Output control (50 time points with equally spaced points, critical viscous damping coefficient (Default: 0.1)

- Solving the analysis (Right Mouse Button Menu > Solve)



2. COMPLETE TABULATED RESULTS

The complete tabulated result from analysis solver is provided in the table below:

a. 50 ms blast duration

Time	PLATE			CONFIG T GEOM STRIPE			CONFIG PARALLEL GEOM STRIPE			CONFIG X GEOM STRIPE			CONFIG T GEOM T		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	73.039	313.28	0.0353	15.4950	231.3700	0.0012	42.0200	318.8600	0.0357	22.6810	229.0500	0.0012	13.9070	221.5700	0.0011
0.02	75.272	346.45	0.0318	43.8140	346.0100	0.0043	58.4520	347.6200	0.0359	49.0010	306.0700	0.0019	39.2520	324.2400	0.0029
0.02	88.142	348	0.0379	62.9680	347.8100	0.0146	72.1550	347.7400	0.0456	70.2040	347.7200	0.0050	58.8830	346.5600	0.0095
0.03	90.417	262.21	0.0406	65.7930	240.0900	0.0170	73.1080	295.6000	0.0463	73.2630	333.4700	0.0056	60.5700	251.6500	0.0107
0.04	89.288	197.59	0.0401	64.9060	150.1600	0.0158	71.2480	261.5200	0.0460	72.5230	259.1400	0.0053	59.7300	153.8600	0.0103
0.05	82.666	170.07	0.0396	63.9860	196.9400	0.0151	69.5820	245.0600	0.0483	71.7190	238.0900	0.0051	58.8680	162.8800	0.0099
0.06	78.043	152.06	0.0488	63.7180	227.1700	0.0151	68.2810	203.6400	0.0608	71.5760	257.8000	0.0051	58.6550	190.7200	0.0097
0.06	77.318	109.68	0.0658	63.6760	221.6000	0.0151	67.7360	182.7300	0.0660	71.5920	256.8000	0.0051	58.6130	188.6700	0.0098
0.07	76.807	87.317	0.0699	63.6420	217.8700	0.0151	66.9850	175.9300	0.0679	71.5800	245.4500	0.0051	58.5590	189.3100	0.0098
0.08	76.736	86.118	0.0700	63.6160	214.8200	0.0152	66.5910	171.3500	0.0706	71.5710	230.4700	0.0051	58.5350	190.3400	0.0098
0.09	76.706	85.395	0.0700	63.5960	212.1200	0.0152	66.5210	166.6500	0.0739	71.5690	214.7700	0.0051	58.5660	191.0300	0.0098
0.10	76.698	85.039	0.0700	63.5820	209.6700	0.0152	66.4600	162.9600	0.0768	71.5730	198.5900	0.0051	58.5980	191.5200	0.0097
0.10	76.7	84.567	0.0699	63.5720	207.5600	0.0152	66.3850	161.0400	0.0788	71.5810	184.8700	0.0050	58.6240	192.2000	0.0097
0.11	76.704	84.038	0.0698	63.5650	205.8400	0.0152	66.2630	161.4000	0.0803	71.5860	183.4400	0.0050	58.6480	193.0100	0.0097
0.12	76.708	83.664	0.0697	63.5610	204.3600	0.0152	66.0910	162.1200	0.0817	71.5870	182.2800	0.0050	58.6700	194.2700	0.0097
0.13	76.711	83.461	0.0697	63.5590	203.0200	0.0152	65.8790	162.6200	0.0828	71.5850	181.2100	0.0050	58.6900	195.9600	0.0098
0.14	76.711	83.256	0.0696	63.5580	201.8300	0.0152	65.6480	162.6200	0.0837	71.5790	180.3200	0.0050	58.7070	197.9200	0.0099
0.14	76.71	83.041	0.0695	63.5580	200.8300	0.0153	65.4280	162.2200	0.0843	71.5730	179.4600	0.0050	58.7180	200.6300	0.0100
0.15	76.708	82.797	0.0695	63.5590	199.9600	0.0153	65.2340	161.7300	0.0848	71.5660	178.6800	0.0051	58.7240	204.2300	0.0101
0.16	76.704	82.545	0.0694	63.5610	199.2100	0.0153	65.0560	161.3100	0.0853	71.5560	178.3800	0.0051	58.7270	208.1900	0.0103
0.17	76.699	82.283	0.0694	63.5620	198.6100	0.0153	64.8970	161.1600	0.0856	71.5430	178.0700	0.0051	58.7380	210.6800	0.0105
0.18	76.693	82	0.0693	63.5650	198.2200	0.0153	64.8150	161.0800	0.0860	71.5290	177.6000	0.0052	58.7650	211.6100	0.0106

0.18	76.686	81.71	0.0693	63.5670	197.9800	0.0153	64.7460	161.3700	0.0863	71.5120	177.0700	0.0052	58.7720	210.4100	0.0109
0.19	76.68	81.434	0.0692	63.5700	197.7500	0.0153	64.6880	161.8000	0.0865	71.4900	176.3400	0.0052	58.7970	212.3800	0.0112
0.20	76.673	81.188	0.0691	63.5730	197.4800	0.0153	64.6340	162.2000	0.0867	71.4640	175.7000	0.0053	58.8230	209.1700	0.0113
0.21	76.667	80.966	0.0690	63.5760	197.1700	0.0153	64.5780	162.5000	0.0870	71.4400	175.2300	0.0053	58.8230	208.1600	0.0113
0.22	76.662	80.754	0.0690	63.5790	196.8800	0.0153	64.5160	162.8000	0.0872	71.4470	174.7000	0.0053	58.8950	211.4600	0.0112
0.22	76.658	80.562	0.0689	63.5820	196.6100	0.0153	64.4530	163.0400	0.0875	71.4530	174.1700	0.0053	59.0860	211.5500	0.0112
0.23	76.653	80.609	0.0688	63.5860	196.3800	0.0153	64.3990	163.1700	0.0877	71.4590	173.7400	0.0054	58.7460	201.1000	0.0108
0.24	76.648	80.653	0.0687	63.5900	196.2000	0.0153	64.4480	164.5700	0.0879	71.4640	173.3800	0.0054	58.7820	192.9000	0.0107
0.25	76.644	80.71	0.0686	63.5940	196.0200	0.0153	64.5330	165.5400	0.0882	71.4670	173.0500	0.0054	58.9580	188.5500	0.0106
0.26	76.639	80.843	0.0684	63.5970	195.8600	0.0153	64.6030	165.6100	0.0884	71.4690	172.7400	0.0054	59.1160	187.0100	0.0106
0.26	76.635	81.016	0.0683	63.6010	195.6600	0.0153	64.6930	164.8900	0.0887	71.4720	172.5600	0.0054	59.2490	187.9300	0.0105
0.27	76.631	81.199	0.0682	63.6050	195.4900	0.0152	64.7570	163.9200	0.0889	71.4790	172.3900	0.0054	59.3550	188.4700	0.0104
0.28	76.627	81.411	0.0681	63.6070	195.3800	0.0152	64.7980	164.6500	0.0891	71.4900	172.1600	0.0054	59.4450	188.0500	0.0103
0.29	76.623	81.625	0.0679	63.6100	195.3300	0.0152	64.8170	165.2900	0.0893	71.5020	171.8300	0.0054	59.4860	187.4400	0.0102
0.30	76.621	81.879	0.0678	63.6120	195.3100	0.0152	64.8210	165.7500	0.0895	71.5140	171.5900	0.0055	59.4720	190.6700	0.0101
0.30	76.618	82.124	0.0676	63.6140	195.2900	0.0152	64.8110	166.0900	0.0897	71.5270	171.5700	0.0057	59.6110	194.2900	0.0101
0.31	76.617	82.341	0.0675	63.6160	195.2900	0.0151	64.7890	166.4200	0.0898	71.5410	171.4700	0.0058	59.2740	190.7300	0.0105
0.32	76.617	82.533	0.0673	63.6180	195.3400	0.0151	64.7550	167.5900	0.0899	71.5560	171.3300	0.0060	58.8610	191.3700	0.0106
0.33	76.618	82.724	0.0671	63.6210	195.4100	0.0151	64.7070	168.4600	0.0899	71.5740	171.2100	0.0061	58.6480	192.2700	0.0102
0.34	76.62	82.799	0.0668	63.6240	195.5000	0.0151	64.6450	169.1100	0.0899	71.5920	171.2700	0.0063	58.6810	191.6600	0.0105
0.34	76.623	82.762	0.0666	63.6260	195.5800	0.0150	64.5700	169.5800	0.0899	71.6090	171.5400	0.0064	58.6500	198.5500	0.0107
0.35	76.627	82.602	0.0663	63.6290	195.6600	0.0150	64.4850	169.8100	0.0899	71.6280	171.9600	0.0065	58.6910	208.5300	0.0108
0.36	76.633	82.639	0.0661	63.6320	195.7500	0.0150	64.4010	169.8700	0.0898	71.6490	172.5500	0.0067	58.8630	197.7200	0.0107
0.37	76.641	82.54	0.0660	63.6340	195.8300	0.0149	64.3400	169.7600	0.0897	71.6690	173.0300	0.0068	58.9290	193.7400	0.0103
0.38	76.647	82.33	0.0660	63.6370	195.9100	0.0149	64.2840	169.4700	0.0896	71.6870	173.1200	0.0070	58.8350	244.1700	0.0109
0.38	76.653	81.963	0.0661	63.6390	195.9500	0.0149	64.2370	169.0900	0.0895	71.7030	173.1000	0.0071	58.7740	215.8200	0.0119

0.39	76.656	81.462	0.0662	63.6400	196.0100	0.0149	64.1990	168.7800	0.0895	71.7170	172.9300	0.0073	58.7180	191.2600	0.0116
0.40	76.662	80.85	0.0664	63.6410	196.0800	0.0148	64.1640	168.7500	0.0895	71.7310	172.6500	0.0074	58.7460	195.5200	0.0116

50 ms blast duration

Time	CONFIG PARALLEL GEOM T			CONFIG X GEOM T			CONFIG T GEOM L			CONFIG PARALLEL GEOM L			CONFIG X GEOM L		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	29.6380	285.3700	0.0138	19.4217	285.3700	0.0357	17.1210	222.1600	0.0011	31.6490	289.6500	0.0150	20.8665	289.6500	0.0357
0.02	47.3680	345.2100	0.0235	42.6509	345.2100	0.0359	42.8140	280.0400	0.0028	44.6810	322.6500	0.0242	45.0809	322.6500	0.0359
0.02	54.1930	346.6800	0.0285	59.8401	347.7900	0.0456	64.7480	347.8000	0.0098	56.5980	347.7400	0.0311	64.5877	347.7400	0.0456
0.03	56.8980	285.8700	0.0297	62.5236	285.8700	0.0463	67.5170	251.1000	0.0111	58.9970	284.0300	0.0328	67.4020	284.0300	0.0463
0.04	56.2250	245.3800	0.0292	61.8946	245.3800	0.0460	66.6940	135.1600	0.0107	58.0290	238.9300	0.0321	66.7212	238.9300	0.0460
0.05	54.4570	219.9200	0.0275	61.1040	219.9200	0.0483	65.8030	89.5530	0.0102	57.2140	215.5000	0.0305	65.9815	215.5000	0.0483
0.06	52.2430	234.9700	0.0276	61.0063	234.9700	0.0608	65.5390	115.8400	0.0100	56.3460	221.2300	0.0324	65.8499	221.2300	0.0608
0.06	52.0130	233.2100	0.0286	61.3532	233.2100	0.0660	65.5100	116.7200	0.0100	56.3610	215.4500	0.0345	65.8646	215.4500	0.0660
0.07	51.9320	231.5300	0.0297	61.0930	231.5300	0.0679	65.4990	116.6000	0.0100	56.1460	212.6000	0.0363	65.8536	212.6000	0.0679
0.08	51.9590	228.4100	0.0318	60.9782	228.4100	0.0706	65.4920	116.3700	0.0100	55.3560	210.5800	0.0395	65.8453	210.5800	0.0706
0.09	52.0150	225.4900	0.0340	61.0337	225.4900	0.0739	65.4830	116.1100	0.0101	54.9880	209.3900	0.0424	65.8435	209.3900	0.0739
0.10	51.9850	223.8600	0.0346	60.9799	223.8600	0.0768	65.4700	115.7000	0.0101	54.9140	208.3100	0.0449	65.8472	208.3100	0.0768
0.10	51.8290	223.1100	0.0347	61.0105	223.1100	0.0788	65.4530	115.1200	0.0101	54.9000	206.8600	0.0467	65.8545	206.8600	0.0788
0.11	51.7100	223.0300	0.0348	61.0981	223.0300	0.0803	65.4320	114.4300	0.0101	54.8820	206.1600	0.0474	65.8591	206.1600	0.0803
0.12	51.6590	223.2100	0.0348	61.0156	223.2100	0.0817	65.4090	113.7200	0.0101	54.8450	206.5300	0.0474	65.8600	206.5300	0.0817
0.13	51.6220	223.5200	0.0348	61.1806	223.5200	0.0828	65.3860	112.9100	0.0101	54.8030	208.4900	0.0471	65.8582	208.4900	0.0828
0.14	51.5700	223.8600	0.0348	61.8422	223.8600	0.0837	65.3660	112.0900	0.0101	54.7650	210.3600	0.0465	65.8527	210.3600	0.0837
0.14	51.4940	224.2000	0.0348	60.9799	224.2000	0.0843	65.3520	111.2300	0.0101	54.7330	211.9700	0.0460	65.8472	211.9700	0.0843
0.15	51.4030	224.5300	0.0348	61.3311	224.5300	0.0848	65.3460	110.5700	0.0101	54.7050	213.6000	0.0454	65.8407	213.6000	0.0848
0.16	51.3150	224.8300	0.0348	61.3226	224.8300	0.0853	65.3350	109.9700	0.0101	54.6910	215.5100	0.0452	65.8315	215.5100	0.0853
0.17	51.2420	225.0800	0.0348	61.0116	225.0800	0.0856	65.3250	109.5700	0.0101	54.6840	217.9500	0.0454	65.8196	217.9500	0.0856
0.18	51.2060	225.1900	0.0348	61.1330	225.1900	0.0860	65.3240	109.3500	0.0101	54.6780	220.3800	0.0457	65.8067	220.3800	0.0860

0.18	51.1800	225.1500	0.0348	61.2852	225.1500	0.0863	65.3240	109.2100	0.0101	54.6790	221.7500	0.0459	65.7910	221.7500	0.0863
0.19	51.1610	224.9900	0.0348	61.0165	224.9900	0.0865	65.3270	109.2400	0.0100	54.6830	222.0000	0.0462	65.7708	222.0000	0.0865
0.20	51.1440	224.7000	0.0348	60.9111	224.7000	0.0867	65.3310	109.4000	0.0100	54.6910	221.3400	0.0465	65.7469	221.3400	0.0867
0.21	51.1270	224.2900	0.0347	60.9740	224.2900	0.0870	65.3360	109.7400	0.0100	54.7010	219.9900	0.0467	65.7248	219.9900	0.0870
0.22	51.1040	223.6200	0.0346	60.9300	223.6200	0.0872	65.3420	110.4200	0.0100	54.7160	218.2100	0.0470	65.7312	218.2100	0.0872
0.22	51.0740	222.8100	0.0345	61.0684	222.8100	0.0875	65.3470	111.3700	0.0100	54.7390	216.3000	0.0472	65.7368	216.3000	0.0875
0.23	51.0220	220.5500	0.0344	60.9068	220.5500	0.0877	65.3530	112.4200	0.0100	54.7710	214.5400	0.0474	65.7423	214.5400	0.0877
0.24	50.9240	214.8000	0.0343	61.7444	214.8000	0.0879	65.3600	113.3300	0.0100	54.8130	213.3000	0.0476	65.7469	213.3000	0.0879
0.25	50.7840	206.6100	0.0344	60.9970	206.6100	0.0882	65.3670	114.0900	0.0100	54.8530	212.5500	0.0477	65.7496	212.5500	0.0882
0.26	50.6350	199.9800	0.0344	61.7487	199.9800	0.0884	65.3730	114.5300	0.0100	54.8770	212.1800	0.0478	65.7515	212.1800	0.0884
0.26	50.3670	209.3400	0.0352	61.7512	209.3400	0.0887	65.3770	114.6100	0.0100	54.8560	210.2300	0.0481	65.7542	210.2300	0.0887
0.27	51.0090	200.8400	0.0335	60.9572	200.8400	0.0889	65.3800	114.3700	0.0100	54.8130	212.5300	0.0480	65.7607	212.5300	0.0889
0.28	51.0070	198.6700	0.0331	60.9665	198.6700	0.0891	65.3800	113.9900	0.0100	54.8200	248.4800	0.0487	65.7708	248.4800	0.0891
0.29	50.9730	197.9900	0.0329	61.1100	197.9900	0.0893	65.3800	113.3100	0.0100	53.5710	231.6200	0.0507	65.7818	231.6200	0.0893
0.30	50.9220	198.3100	0.0329	61.0369	198.3100	0.0895	65.3850	112.3700	0.0101	52.8590	343.8600	0.0515	65.7929	343.8600	0.0895
0.30	50.8810	198.7900	0.0329	60.9408	198.7900	0.0897	65.3910	111.5100	0.0101	52.6990	341.1500	0.0522	65.8048	341.1500	0.0897
0.31	50.8620	199.4900	0.0329	61.3099	199.4900	0.0898	65.3960	111.1100	0.0101	52.8150	240.5200	0.0530	65.8177	240.5200	0.0898
0.32	50.8740	200.2600	0.0329	60.9893	200.2600	0.0899	65.3990	111.2400	0.0101	52.6420	240.8800	0.0527	65.8315	240.8800	0.0899
0.33	50.8760	215.5600	0.0328	61.0046	215.5600	0.0899	65.4000	111.9500	0.0102	52.2130	241.1200	0.0525	65.8481	241.1200	0.0899
0.34	50.9010	246.5800	0.0325	61.3532	246.5800	0.0899	65.3990	113.0800	0.0102	51.9000	242.9000	0.0519	65.8646	242.9000	0.0899
0.34	50.9530	263.3800	0.0323	61.3677	263.3800	0.0899	65.3960	114.4700	0.0102	51.9020	237.0000	0.0517	65.8803	237.0000	0.0899
0.35	50.5000	256.2100	0.0311	61.3838	256.2100	0.0899	65.3920	115.9400	0.0102	52.1090	254.6600	0.0516	65.8978	254.6600	0.0899
0.36	50.0280	231.3300	0.0322	61.1017	231.3300	0.0898	65.3880	117.3000	0.0102	51.8460	246.5200	0.0523	65.9171	246.5200	0.0898
0.37	49.9030	232.8700	0.0326	61.4187	232.8700	0.0897	65.3830	118.5100	0.0102	51.7970	238.2300	0.0524	65.9355	238.2300	0.0897
0.38	49.6400	239.0500	0.0329	61.4340	239.0500	0.0896	65.3770	119.3900	0.0102	51.6300	232.7800	0.0529	65.9520	232.7800	0.0896
0.38	49.2390	248.8600	0.0329	61.1142	248.8600	0.0895	65.3710	119.8100	0.0102	51.6190	222.3600	0.0533	65.9668	222.3600	0.0895
0.39	48.7560	256.6300	0.0327	61.2928	256.6300	0.0895	65.3650	119.8800	0.0102	52.2840	245.5000	0.0536	65.9796	245.5000	0.0895
0.40	49.7450	256.3800	0.0333	61.2214	256.3800	0.0895	65.3610	119.4000	0.0102	52.4840	284.2600	0.0534	65.9925	284.2600	0.0895

b. 100 ms blast duration

Time	PLATE			CONFIG T GEOM STRIPE			CONFIG PARALLEL GEOM STRIPE			CONFIG X GEOM STRIPE			CONFIG T GEOM T		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	56.679	282.4	0.0530	10.1550	203.6100	0.0011	27.3870	295.2500	0.0209	14.9010	217.3000	0.0011	10.2270	174.4700	0.0009
0.02	56.268	337.97	0.0470	16.8560	235.6700	0.0012	32.3020	328.4700	0.0207	22.3100	232.8400	0.0012	15.7500	222.5800	0.0011
0.02	56.561	343.34	0.0464	31.0580	313.4400	0.0022	42.4250	343.2100	0.0218	34.2760	265.9500	0.0014	26.9060	267.8600	0.0016
0.03	57.56	342.76	0.0458	43.0330	345.9100	0.0044	51.7430	346.8900	0.0297	46.5870	312.4000	0.0018	38.7850	323.2100	0.0029
0.04	61.616	344.71	0.0433	52.9170	346.5900	0.0083	56.5530	347.5700	0.0338	58.3690	347.7500	0.0031	48.9710	345.2200	0.0054
0.05	70.394	348	0.0481	62.7280	347.6600	0.0145	60.4580	347.3600	0.0383	69.3150	347.7500	0.0049	58.3460	346.6300	0.0093
0.06	93.344	315.27	0.0507	65.7650	289.5200	0.0170	62.0050	320.6100	0.0399	73.2970	347.7500	0.0059	61.7360	299.1100	0.0111
0.06	92.94	280.57	0.0502	65.3730	239.6800	0.0169	61.2720	290.9700	0.0394	72.8300	338.1700	0.0064	61.4880	254.6500	0.0110
0.07	88.286	247.62	0.0496	64.9450	192.6800	0.0166	60.4990	265.6500	0.0387	72.3670	308.4800	0.0064	61.1670	207.6900	0.0108
0.08	71.736	219.82	0.0493	64.4950	153.6800	0.0160	59.6510	242.9900	0.0377	71.8960	285.6800	0.0063	60.7440	159.1500	0.0107
0.09	71.147	199.09	0.0489	64.0300	123.4900	0.0152	58.7970	228.8000	0.0364	71.3930	273.0200	0.0060	60.2790	111.9800	0.0106
0.10	70.513	188.07	0.0493	63.5480	197.2400	0.0142	57.8220	217.2500	0.0341	70.8670	267.6000	0.0057	59.8940	176.3500	0.0104
0.10	69.766	172.55	0.0568	63.2810	232.0100	0.0142	56.8590	203.7400	0.0409	70.6310	279.1600	0.0053	59.9480	217.5000	0.0102
0.11	69.144	156.23	0.0709	63.2470	227.8400	0.0142	56.3030	171.6800	0.0546	70.6610	275.4500	0.0051	60.0470	200.3600	0.0102
0.12	68.547	132.29	0.0868	63.2220	225.2900	0.0142	55.0850	159.9000	0.0596	70.6920	271.8400	0.0049	59.7860	207.5700	0.0101
0.13	68.382	127.3	0.0901	63.2030	223.1000	0.0143	54.5640	161.1300	0.0619	70.7350	268.1100	0.0050	59.9620	192.5400	0.0103
0.14	68.293	126.06	0.0908	63.1900	221.0700	0.0143	54.3520	162.8200	0.0635	70.7850	264.9900	0.0050	59.9260	203.0600	0.0101

0.14	68.213	124.68	0.0912	63.1810	219.2900	0.0143	54.1920	166.7800	0.0645	70.8350	262.5400	0.0050	59.7800	203.9600	0.0101
0.15	68.165	123.63	0.0912	63.1760	217.6900	0.0143	54.0380	170.9000	0.0651	70.8850	259.9000	0.0051	59.6210	201.3900	0.0100
0.16	68.137	122.96	0.0910	63.1730	216.2600	0.0143	53.8920	173.7200	0.0655	70.9370	257.7700	0.0051	59.2840	190.4100	0.0100
0.17	68.12	122.39	0.0908	63.1710	215.0500	0.0144	53.7630	187.4000	0.0658	70.9900	256.0900	0.0051	59.2740	194.3600	0.0102
0.18	68.107	121.88	0.0906	63.1690	214.0300	0.0144	53.6610	200.2700	0.0661	71.0370	254.1800	0.0051	59.5070	208.5500	0.0103
0.18	68.095	121.41	0.0904	63.1680	213.1700	0.0144	53.5900	210.7900	0.0662	71.0740	252.4400	0.0051	59.6060	207.2000	0.0103
0.19	68.083	120.94	0.0903	63.1680	212.3500	0.0144	53.5470	217.4800	0.0664	71.0990	250.4900	0.0052	59.1380	213.6500	0.0106
0.20	68.069	120.58	0.0901	63.1680	211.6400	0.0144	53.5250	218.8800	0.0664	71.1140	248.7600	0.0052	59.5210	231.2300	0.0110
0.21	68.055	120.23	0.0900	63.1700	211.0300	0.0144	53.5170	220.4500	0.0664	71.1240	247.4000	0.0052	59.0220	196.6000	0.0104
0.22	68.04	119.86	0.0898	63.1710	210.4900	0.0144	53.5200	222.3000	0.0663	71.1300	246.1000	0.0052	58.6300	203.8400	0.0105
0.22	68.023	119.51	0.0897	63.1730	210.0500	0.0144	53.5280	223.6700	0.0661	71.1350	244.8400	0.0053	59.6210	269.8900	0.0104
0.23	68.005	119.16	0.0895	63.1750	209.7000	0.0144	53.5420	224.1800	0.0657	71.1370	243.6800	0.0053	60.3010	212.9700	0.0107
0.24	67.989	118.82	0.0894	63.1780	209.4600	0.0144	53.5570	224.2400	0.0650	71.1370	242.2500	0.0053	59.5260	182.4900	0.0107
0.25	67.974	118.47	0.0893	63.1810	209.1700	0.0144	53.5700	224.4600	0.0634	71.1340	240.6600	0.0053	59.6040	176.0400	0.0100
0.26	67.96	118.13	0.0891	63.1840	208.8800	0.0144	53.5770	225.2400	0.0608	71.1200	239.3500	0.0053	60.1470	186.5200	0.0105
0.26	67.948	117.8	0.0890	63.1880	208.5100	0.0144	53.5910	226.5200	0.0577	71.1020	238.5400	0.0053	60.5060	233.6800	0.0109
0.27	67.939	117.47	0.0888	63.1910	208.0900	0.0144	53.6100	228.1800	0.0556	71.0840	238.1200	0.0054	61.1110	223.4000	0.0115
0.28	67.932	117.16	0.0888	63.1950	207.7000	0.0144	53.6310	230.2200	0.0545	71.0680	237.6300	0.0056	61.1330	212.8900	0.0115
0.29	67.926	116.86	0.0887	63.2000	207.4100	0.0144	53.6560	232.4900	0.0540	71.0530	237.4400	0.0057	61.2040	183.9000	0.0109
0.30	67.923	116.58	0.0886	63.2040	207.1300	0.0144	53.6830	234.9100	0.0538	71.0390	237.2700	0.0058	61.0960	184.5800	0.0106
0.30	67.922	116.4	0.0884	63.2090	206.8500	0.0144	53.7130	237.3300	0.0537	71.0270	237.1200	0.0059	60.8430	188.6400	0.0104
0.31	67.923	116.3	0.0880	63.2120	206.6400	0.0144	53.7450	239.6000	0.0537	71.0150	236.9000	0.0060	61.0490	201.5200	0.0106

0.32	67.926	116.39	0.0876	63.2150	206.4600	0.0144	53.7760	241.6900	0.0537	71.0040	236.7200	0.0061	60.1700	271.4400	0.0107
0.33	67.93	116.86	0.0870	63.2180	206.2800	0.0144	53.8040	243.4900	0.0537	70.9960	236.4200	0.0061	60.8930	171.3200	0.0106
0.34	67.936	117.4	0.0865	63.2200	206.0700	0.0144	53.8280	245.0100	0.0537	70.9890	236.2400	0.0062	60.2230	200.2900	0.0106
0.34	67.94	118.25	0.0861	63.2220	205.8300	0.0144	53.8470	246.1500	0.0536	70.9810	236.2200	0.0062	60.1400	174.9400	0.0105
0.35	67.944	118.97	0.0856	63.2240	205.6000	0.0143	53.8610	246.8700	0.0535	70.9720	237.3000	0.0063	60.5950	165.6800	0.0105
0.36	67.955	119.13	0.0851	63.2250	205.3500	0.0143	53.8670	247.0800	0.0534	70.9630	238.2800	0.0063	60.8220	161.7100	0.0106
0.37	67.966	118.62	0.0845	63.2260	205.1000	0.0143	53.8670	246.6900	0.0533	70.9550	239.3900	0.0064	60.7540	166.5100	0.0105
0.38	67.978	117.65	0.0840	63.2260	204.8800	0.0143	53.8620	245.6000	0.0531	70.9470	240.5000	0.0064	60.7760	164.1800	0.0104
0.38	67.991	116.45	0.0833	63.2260	204.7100	0.0143	53.8550	243.6900	0.0530	70.9400	241.6200	0.0064	60.4890	183.1900	0.0105
0.39	68.007	116.02	0.0826	63.2260	204.5500	0.0142	53.8480	240.9600	0.0530	70.9320	242.5000	0.0064	60.5150	179.5600	0.0105
0.40	68.027	115.65	0.0824	63.2260	204.4300	0.0142	53.8420	237.4600	0.0529	70.9240	243.4900	0.0064	59.6290	166.7200	0.0107

100 ms blast duration

Time	CONFIG PARALLEL GEOM T			CONFIG X GEOM T			CONFIG T GEOM L			CONFIG PARALLEL GEOM L			CONFIG X GEOM L		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	26.1040	328.2500	0.0222	12.8659	328.2500	0.0011	10.5700	165.7800	0.0008	15.7140	347.7800	0.0018	13.7089	295.2500	0.0011
0.02	32.3940	318.9400	0.0185	19.1302	318.9400	0.0012	19.0640	226.4600	0.0012	16.2660	347.7800	0.0070	20.5252	328.4700	0.0012
0.02	42.1490	343.5700	0.0182	29.4679	343.5700	0.0014	30.3510	248.4500	0.0015	21.0020	288.3900	0.0164	31.5339	343.2100	0.0014
0.03	48.9530	346.2400	0.0231	39.8490	346.2400	0.0018	42.4850	279.8600	0.0028	27.1720	278.3900	0.0126	42.8600	346.8900	0.0018
0.04	53.4800	346.7800	0.0290	49.8137	347.7800	0.0031	54.0650	317.8000	0.0056	33.2910	308.7400	0.0125	53.6995	347.8700	0.0031
0.05	57.2490	346.7800	0.0339	59.9178	347.7800	0.0049	64.6550	347.7200	0.0098	37.1790	311.9600	0.0129	63.7698	347.3600	0.0049

0.06	59.0290	321.8800	0.0362	62.8025	321.8800	0.0059	68.2150	296.2900	0.0116	39.7560	317.8000	0.0134	67.4332	320.6100	0.0059
0.06	58.2890	295.4800	0.0355	62.0722	295.4800	0.0064	67.8750	247.7800	0.0114	41.8990	322.1800	0.0149	67.0036	290.9700	0.0064
0.07	57.8120	275.8600	0.0351	62.5120	275.8600	0.0064	67.5360	187.3500	0.0113	44.3860	326.2300	0.0174	66.5776	265.6500	0.0064
0.08	57.2610	256.9300	0.0345	61.3116	256.9300	0.0063	67.1210	143.4900	0.0111	47.7970	327.1200	0.0190	66.1443	242.9900	0.0063
0.09	56.7740	243.5500	0.0339	61.0174	243.5500	0.0060	66.7400	165.4300	0.0116	51.9180	331.1100	0.0198	65.6816	228.8000	0.0060
0.10	55.6020	232.6800	0.0331	60.3798	232.6800	0.0057	66.3610	156.4300	0.0116	56.5190	336.0700	0.0214	65.1976	217.2500	0.0057
0.10	51.7850	224.8500	0.0356	60.1792	224.8500	0.0053	66.2370	149.0600	0.0111	59.2180	340.7700	0.0233	64.9805	203.7400	0.0053
0.11	51.3870	220.9000	0.0379	60.2047	220.9000	0.0051	66.2610	155.2600	0.0112	58.9120	341.1600	0.0241	65.0081	171.6800	0.0051
0.12	51.2130	219.3400	0.0399	60.2311	219.3400	0.0049	66.1870	165.0600	0.0114	58.4870	341.4100	0.0249	65.0366	159.9000	0.0049
0.13	51.0440	218.7100	0.0420	60.3248	218.7100	0.0050	66.2140	153.1600	0.0110	58.2240	341.7600	0.0265	65.0762	161.1300	0.0050
0.14	50.9640	218.5900	0.0436	60.3339	218.5900	0.0050	66.3040	140.6200	0.0110	57.7690	341.9700	0.0272	65.1222	162.8200	0.0050
0.14	50.9490	218.4700	0.0444	60.3526	218.4700	0.0050	66.3210	133.5800	0.0110	57.4240	343.0800	0.0280	65.1682	166.7800	0.0050
0.15	50.9530	218.0400	0.0447	60.3951	218.0400	0.0051	66.3640	123.7600	0.0111	57.0560	344.7100	0.0291	65.2142	170.9000	0.0051
0.16	50.9640	217.2100	0.0448	60.6298	217.2100	0.0051	66.3550	118.7100	0.0116	56.5990	344.7700	0.0299	65.2620	173.7200	0.0051
0.17	50.9810	216.1900	0.0450	60.6748	216.1900	0.0051	66.2680	117.3100	0.0114	56.1660	344.9000	0.0311	65.3108	187.4000	0.0051
0.18	51.0000	215.2200	0.0452	60.5815	215.2200	0.0051	66.1850	117.1500	0.0110	55.7230	345.1800	0.0325	65.3540	200.2700	0.0051
0.18	51.0180	214.3200	0.0454	60.5796	214.3200	0.0051	66.3080	120.7800	0.0110	55.3350	345.5200	0.0337	65.3881	210.7900	0.0051
0.19	51.0360	213.5500	0.0456	60.5770	213.5500	0.0052	66.2780	124.3600	0.0114	54.7980	345.9600	0.0350	65.4111	217.4800	0.0052
0.20	51.0550	212.8700	0.0459	60.9469	212.8700	0.0052	66.0860	127.0500	0.0118	53.8860	347.6600	0.0365	65.4249	218.8800	0.0052
0.21	51.0740	212.3200	0.0463	60.6221	212.3200	0.0052	65.9640	128.8300	0.0119	53.2140	329.3100	0.0369	65.4341	220.4500	0.0052
0.22	51.0930	211.9200	0.0467	60.7938	211.9200	0.0052	66.0680	133.0400	0.0120	52.9170	323.6300	0.0369	65.4396	222.3000	0.0052
0.22	51.1050	211.6900	0.0472	61.4648	211.6900	0.0053	66.1130	124.3100	0.0120	52.6360	317.7100	0.0369	65.4442	223.6700	0.0053

0.23	51.1080	211.2000	0.0477	60.6331	211.2000	0.0053	66.1620	115.2300	0.0120	52.4200	310.1500	0.0369	65.4460	224.1800	0.0053
0.24	51.1090	210.2100	0.0479	61.4665	210.2100	0.0053	65.7200	152.3700	0.0122	52.1500	301.6300	0.0368	65.4460	224.2400	0.0053
0.25	51.1070	209.4900	0.0480	61.4639	209.4900	0.0053	65.5330	187.2100	0.0124	51.9510	293.6800	0.0367	65.4433	224.4600	0.0053
0.26	51.0880	210.0900	0.0480	61.4520	210.0900	0.0053	65.6550	145.7700	0.0127	51.8170	287.3500	0.0365	65.4304	225.2400	0.0053
0.26	51.0770	210.6500	0.0479	60.7700	210.6500	0.0053	65.4520	112.0800	0.0125	51.8140	281.0800	0.0363	65.4138	226.5200	0.0053
0.27	50.7770	209.5800	0.0469	60.6214	209.5800	0.0054	65.5770	103.4600	0.0121	51.9380	275.1400	0.0361	65.3973	228.1800	0.0054
0.28	50.3270	211.8100	0.0489	60.9078	211.8100	0.0056	65.4370	114.3900	0.0119	51.8950	269.7100	0.0359	65.3826	230.2200	0.0056
0.29	50.5120	210.2500	0.0488	61.3951	210.2500	0.0057	64.9330	90.0870	0.0117	51.8420	264.7700	0.0358	65.3688	232.4900	0.0057
0.30	50.5180	211.3900	0.0485	60.5260	211.3900	0.0058	65.1900	86.9050	0.0117	51.6920	260.2200	0.0357	65.3559	234.9100	0.0058
0.30	50.5540	213.3400	0.0483	61.3730	213.3400	0.0059	65.4780	90.1320	0.0118	51.4160	255.6100	0.0356	65.3448	237.3300	0.0059
0.31	50.5660	213.8700	0.0487	61.3628	213.8700	0.0060	65.0830	128.9700	0.0122	51.2700	250.8800	0.0354	65.3338	239.6000	0.0060
0.32	50.5410	212.8600	0.0491	60.8534	212.8600	0.0061	65.3610	135.4900	0.0122	51.0910	246.0100	0.0352	65.3237	241.6900	0.0061
0.33	50.4850	212.2100	0.0492	60.6799	212.2100	0.0061	65.5300	115.1400	0.0120	51.2300	241.3700	0.0350	65.3163	243.4900	0.0061
0.34	50.4070	211.6900	0.0491	61.3407	211.6900	0.0062	65.4650	109.5400	0.0119	51.2610	238.3800	0.0348	65.3099	245.0100	0.0062
0.34	50.2990	211.9600	0.0490	60.5839	211.9600	0.0062	65.4450	105.6100	0.0120	51.2980	236.2600	0.0346	65.3025	246.1500	0.0062
0.35	50.2750	212.8100	0.0490	60.5262	212.8100	0.0063	65.4610	101.1100	0.0119	51.2880	234.3700	0.0343	65.2942	246.8700	0.0063
0.36	50.3480	213.3300	0.0496	61.3186	213.3300	0.0063	65.5030	98.2050	0.0119	51.2970	232.6300	0.0340	65.2860	247.0800	0.0063
0.37	50.4180	215.0200	0.0496	61.3118	215.0200	0.0064	65.5340	96.5540	0.0119	51.3250	230.9000	0.0336	65.2786	246.6900	0.0064
0.38	50.4410	217.0700	0.0499	60.4716	217.0700	0.0064	65.5490	95.8650	0.0119	51.3230	229.3800	0.0332	65.2712	245.6000	0.0064
0.38	50.4300	218.5700	0.0509	60.7990	218.5700	0.0064	65.5540	95.6630	0.0118	51.2990	228.1900	0.0327	65.2648	243.6900	0.0064
0.39	50.4470	219.3500	0.0522	60.6255	219.3500	0.0064	65.5510	95.6600	0.0118	51.2650	227.1600	0.0325	65.2574	240.9600	0.0064
0.40	50.4480	218.4600	0.0529	60.5354	218.4600	0.0064	65.5400	95.6920	0.0118	51.2270	225.9300	0.0325	65.2501	237.4600	0.0064

c. 200 ms blast duration

Time	PLATE			CONFIG T GEOM STRIPE			CONFIG PARALLEL GEOM STRIPE			CONFIG X GEOM STRIPE			CONFIG T GEOM T		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	37.517	347.13	0.0011	7.6795	121.0500	0.0007	19.2360	302.9100	0.0378	10.6450	221.7000	0.0011	7.2841	69.4240	0.0003
0.02	38.534	303.59	0.0012	10.2920	202.2400	0.0011	19.8560	333.8300	0.0390	14.4320	221.7000	0.0011	10.1610	176.3700	0.0009
0.02	40.184	326.18	0.0014	13.4890	221.0500	0.0011	23.6020	344.0300	0.0345	18.0040	225.6700	0.0011	12.2780	216.9100	0.0011
0.03	42.454	342.4	0.0018	17.8510	240.0700	0.0012	30.0620	341.9400	0.0342	21.8860	231.6500	0.0012	15.6740	221.9200	0.0011
0.04	43.142	344.5	0.0031	24.4380	274.5900	0.0016	36.9620	342.6500	0.0286	26.6900	244.1500	0.0012	20.6750	245.8800	0.0013
0.05	43.986	343.44	0.0049	31.3600	315.0000	0.0023	41.8470	344.7000	0.0278	33.6290	267.3500	0.0014	27.1460	269.3900	0.0016
0.06	45.997	342.93	0.0059	37.5820	330.8500	0.0032	45.3160	345.9200	0.0296	40.5820	293.7000	0.0017	33.3520	296.1200	0.0021
0.06	49.342	344.48	0.0064	42.7430	341.8400	0.0041	47.8490	346.4700	0.0307	47.3260	318.2800	0.0022	39.0320	325.6500	0.0030
0.07	53.544	345.21	0.0064	47.9940	345.7300	0.0052	49.9590	346.7400	0.0323	53.5990	342.3600	0.0032	44.2410	339.8300	0.0042
0.08	58.333	346.09	0.0063	53.2260	345.6900	0.0070	51.9790	347.1600	0.0369	59.5610	347.7700	0.0044	49.1210	345.9100	0.0056
0.09	63.396	346.27	0.0060	58.1960	345.7000	0.0092	54.4290	347.2100	0.0412	65.3220	347.7700	0.0058	53.9490	346.5100	0.0073
0.10	78.999	348	0.0057	62.9720	347.5700	0.0123	57.7900	347.3200	0.0449	70.7750	347.7700	0.0074	58.8360	346.6500	0.0095
0.10	82.306	335.16	0.0053	65.6860	326.7900	0.0144	60.0730	338.2900	0.0476	74.1420	347.7700	0.0088	61.7240	335.0700	0.0111
0.11	88.095	314.84	0.0051	65.4740	292.6900	0.0144	59.7210	331.3100	0.0480	74.0220	347.7700	0.0096	61.4540	330.2600	0.0111
0.12	91.801	297	0.0049	65.2440	262.6100	0.0142	59.3520	319.3500	0.0483	73.9580	347.7700	0.0100	61.6360	331.2700	0.0111
0.13	93.495	279.04	0.0050	65.0080	236.6800	0.0140	58.9740	306.5200	0.0485	74.1980	347.7700	0.0102	62.6940	322.9800	0.0112
0.14	91.212	261.2	0.0050	64.7680	211.9500	0.0137	58.5970	293.1500	0.0487	74.8970	347.7700	0.0104	63.2950	307.6700	0.0115
0.14	90.925	243.44	0.0050	64.5250	188.5200	0.0134	58.1870	278.7800	0.0488	75.4070	347.7700	0.0105	63.5430	284.7400	0.0116
0.15	89.634	225.92	0.0051	64.2810	165.9200	0.0130	57.7750	257.8300	0.0490	75.7790	347.7700	0.0106	63.9220	281.4900	0.0112
0.16	88.341	208.81	0.0051	64.0340	144.5500	0.0126	57.3460	242.4000	0.0491	73.3940	347.7700	0.0106	64.0550	229.3700	0.0112
0.17	88.044	192.4	0.0051	63.7850	127.5200	0.0121	56.9010	236.2100	0.0492	73.1780	347.7700	0.0105	64.0250	225.9800	0.0114
0.18	87.741	177.08	0.0051	63.5320	140.0300	0.0116	56.4380	231.1400	0.0494	72.9400	347.7700	0.0104	63.5270	195.5500	0.0110

0.18	87.741	168.28	0.0051	63.2730	178.5200	0.0116	55.9470	227.3700	0.0496	72.6740	347.7700	0.0102	63.0300	168.4800	0.0108
0.19	87.741	166.58	0.0052	63.0060	218.5000	0.0116	55.4030	224.9900	0.0502	72.3710	347.7700	0.0100	62.9680	148.2900	0.0111
0.20	87.741	166.46	0.0052	62.7280	259.1300	0.0116	54.5610	219.4800	0.0527	72.0130	347.7700	0.0098	63.0190	151.8100	0.0108
0.21	87.741	108.32	0.0052	62.6960	256.6100	0.0117	53.3260	210.9600	0.0598	71.8410	347.7700	0.0097	63.1820	144.6900	0.0108
0.22	87.741	84.941	0.0052	62.6740	255.3500	0.0118	52.8540	194.2400	0.0626	71.7410	347.7700	0.0096	63.2960	140.0100	0.0103
0.22	87.741	84.291	0.0053	62.6590	254.1400	0.0119	52.6580	189.2500	0.0631	71.6970	347.7700	0.0096	63.3930	138.8600	0.0104
0.23	87.741	83.651	0.0053	62.6480	253.0600	0.0119	52.5170	197.4100	0.0632	71.6760	347.7700	0.0095	63.3300	159.1300	0.0105
0.24	87.741	83.172	0.0053	62.6390	251.9000	0.0120	52.3900	221.0400	0.0636	71.6610	347.7700	0.0095	63.2120	150.6100	0.0106
0.25	87.741	82.803	0.0053	62.6330	250.6400	0.0120	52.2460	234.4900	0.0645	71.6380	347.7700	0.0095	63.0470	153.7000	0.0106
0.26	87.741	82.553	0.0053	62.6300	249.4000	0.0121	52.1490	237.7000	0.0655	71.6280	347.7700	0.0095	62.9690	169.7400	0.0108
0.26	87.741	82.337	0.0053	62.6270	248.2100	0.0121	52.1610	235.3700	0.0660	71.6140	347.7700	0.0094	63.0240	173.3400	0.0108
0.27	87.741	82.146	0.0054	62.6250	247.1400	0.0122	52.1560	231.9400	0.0662	71.5630	347.7700	0.0094	63.0380	174.5800	0.0107
0.28	87.741	81.991	0.0056	62.6220	246.0900	0.0122	52.1370	228.3700	0.0661	71.4760	347.7700	0.0093	63.2330	169.4900	0.0106
0.29	87.741	81.867	0.0057	62.6200	245.0700	0.0122	52.1110	225.0800	0.0660	71.3890	347.7700	0.0097	63.2130	186.2800	0.0106
0.30	87.741	81.711	0.0058	62.6170	244.0700	0.0123	52.0780	222.7300	0.0659	71.3560	347.7700	0.0101	62.9650	218.4000	0.0106
0.30	87.741	81.954	0.0059	62.6140	243.0800	0.0123	52.0340	224.2100	0.0658	71.3610	347.7700	0.0107	62.7360	207.4800	0.0106
0.31	87.741	82.151	0.0060	62.6110	242.1300	0.0123	51.9760	225.8700	0.0657	71.3570	347.7700	0.0112	62.8930	166.7500	0.0105
0.32	87.741	82.244	0.0061	62.6090	241.2400	0.0123	51.9050	227.7300	0.0656	71.3440	347.7700	0.0114	63.0000	164.5900	0.0103
0.33	87.741	82.274	0.0061	62.6080	240.4100	0.0123	51.8270	229.7500	0.0656	71.3190	347.7700	0.0116	62.9790	166.8200	0.0103
0.34	87.741	82.224	0.0062	62.6070	239.6500	0.0124	51.7450	231.9000	0.0656	71.2760	347.7700	0.0117	62.7410	185.6700	0.0105
0.34	87.741	82.139	0.0062	62.6070	238.9400	0.0124	51.6600	234.2400	0.0657	71.2320	347.7700	0.0117	62.6410	195.2300	0.0106
0.35	87.741	82.025	0.0063	62.6070	238.2400	0.0124	51.5780	236.9400	0.0659	71.2710	347.7700	0.0117	62.7330	197.6300	0.0106
0.36	87.741	81.908	0.0063	62.6070	237.5700	0.0124	51.4970	239.8200	0.0662	71.3130	347.7700	0.0117	62.7240	217.3700	0.0106
0.37	87.741	81.813	0.0064	62.6080	236.9300	0.0124	51.4140	242.8200	0.0666	71.3480	347.7700	0.0117	62.7080	258.5900	0.0103
0.38	87.741	81.669	0.0064	62.6080	236.3100	0.0124	51.3100	245.9500	0.0670	71.3770	347.7700	0.0117	62.7720	237.4200	0.0100
0.38	87.741	81.43	0.0064	62.6090	235.7100	0.0124	51.1760	249.0600	0.0679	71.4080	347.7700	0.0118	62.8640	175.8900	0.0103

0.39	87.741	81.059	0.0064	62.6110	235.1600	0.0124	51.0110	252.0000	0.0690	71.4450	347.7700	0.0121	63.4580	197.9200	0.0106
0.40	87.741	80.539	0.0064	62.6120	234.6700	0.0125	50.8120	255.2500	0.0703	71.4930	347.7700	0.0124	62.0620	194.1200	0.0110

200 ms blast duration

Time	CONFIG PARALLEL GEOM T			CONFIG X GEOM T			CONFIG T GEOM L			CONFIG PARALLEL GEOM L			CONFIG X GEOM L		
	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)	Deformation (mm)	Stress (MPa)	Strain (mm/mm)
0.00	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.01	18.2060	345.5200	0.0218	9.0483	55.4020	0.0003	7.2914	55.4020	0.0003	1.2592	283.4100	0.0253	9.7934	69.4240	0.0003
0.02	19.0740	308.6900	0.0204	12.2672	185.0800	0.0009	10.5990	185.0800	0.0009	9.7527	315.3400	0.0244	13.2774	176.3700	0.0009
0.02	21.7090	324.7700	0.0180	15.3034	218.4600	0.0011	14.2740	218.4600	0.0011	22.0970	336.3700	0.0239	16.5637	216.9100	0.0011
0.03	26.5810	333.2300	0.0148	18.6031	226.0700	0.0011	19.0590	226.0700	0.0012	20.3880	339.2900	0.0211	20.1351	221.9200	0.0011
0.04	31.6920	342.4400	0.0145	22.6865	238.1100	0.0013	24.7280	238.1100	0.0013	21.4160	341.3200	0.0205	24.5548	245.8800	0.0013
0.05	35.8860	343.6300	0.0164	28.5847	249.9400	0.0016	30.9570	249.9400	0.0015	22.6710	341.6200	0.0229	30.9387	269.3900	0.0016
0.06	39.0290	344.5900	0.0206	34.4947	265.9400	0.0021	37.5150	265.9400	0.0021	24.1510	341.7500	0.0245	37.3354	296.1200	0.0021
0.06	41.5450	345.0600	0.0243	40.2271	283.2400	0.0030	43.6480	283.2400	0.0029	28.2750	342.3400	0.0258	43.5399	325.6500	0.0030
0.07	43.7800	346.2100	0.0272	45.5592	301.6200	0.0042	49.4490	301.6200	0.0042	32.0240	343.8200	0.0272	49.3111	339.8300	0.0042
0.08	46.1170	346.5900	0.0300	50.6269	320.6000	0.0056	54.8190	320.6000	0.0058	34.5640	343.7300	0.0291	54.7961	345.9100	0.0056
0.09	49.0930	347.1200	0.0330	55.5237	335.9700	0.0073	62.3710	335.9700	0.0082	35.8380	344.9000	0.0313	60.0962	346.5100	0.0073
0.10	53.2040	347.1200	0.0363	60.1588	347.8000	0.0095	67.4020	347.7890	0.0107	37.4360	348.0000	0.0337	65.1130	347.9500	0.0095
0.10	59.0990	338.5300	0.0383	63.0207	339.7900	0.0111	70.1310	339.7900	0.0124	39.5000	334.4600	0.0351	68.2106	335.0700	0.0111
0.11	57.6890	321.6700	0.0381	62.9187	332.4300	0.0111	69.9480	332.4300	0.0123	40.4400	326.4800	0.0350	68.1002	330.2600	0.0111
0.12	55.3350	309.4900	0.0379	62.8643	318.2200	0.0111	70.2170	318.2200	0.0126	41.2360	299.3800	0.0347	68.0414	331.2700	0.0111
0.13	55.0530	299.2200	0.0378	63.0683	311.3900	0.0112	70.0600	311.3900	0.0127	42.8210	287.2600	0.0345	68.2622	322.9800	0.0112
0.14	54.6700	288.5300	0.0376	63.6625	279.6900	0.0115	69.6500	279.6900	0.0133	43.6490	276.2100	0.0342	68.9052	307.6700	0.0115

0.14	54.3500	278.9500	0.0374	64.0960	272.7700	0.0116	69.4400	272.7700	0.0137	44.6410	268.8000	0.0338	69.3744	284.7400	0.0116
0.15	54.0030	269.8400	0.0372	64.4122	257.6300	0.0112	69.2950	257.6300	0.0134	46.2770	261.1500	0.0333	69.7167	281.4900	0.0112
0.16	53.6480	261.4100	0.0370	62.3849	222.9400	0.0112	69.0990	222.9400	0.0132	47.6730	249.2700	0.0334	67.5225	229.3700	0.0112
0.17	53.3080	254.0900	0.0367	62.2013	173.6000	0.0114	68.6670	173.6000	0.0132	49.6180	242.0200	0.0328	67.3238	225.9800	0.0114
0.18	52.9590	248.0400	0.0365	61.9990	164.9700	0.0110	69.0100	164.9700	0.0132	51.9380	239.0400	0.0321	67.1048	195.5500	0.0110
0.18	52.6070	243.3100	0.0362	61.7729	91.6060	0.0108	68.4260	91.6060	0.0125	53.9460	235.4900	0.0313	66.8601	168.4800	0.0108
0.19	52.2470	239.0800	0.0362	61.5154	91.0350	0.0111	68.0540	91.0350	0.0120	56.1790	233.0500	0.0300	66.5813	148.2900	0.0111
0.20	51.5320	227.2300	0.0389	61.2111	286.6500	0.0108	68.6060	286.6500	0.0112	58.8010	266.8500	0.0336	66.2520	151.8100	0.0108
0.21	51.1850	218.7900	0.0440	61.0649	120.0500	0.0108	67.6610	120.0500	0.0111	59.5770	297.9700	0.0394	66.0937	144.6900	0.0108
0.22	50.5370	212.2700	0.0462	60.9799	125.8900	0.0103	67.6360	125.8900	0.0111	59.5050	311.6500	0.0404	66.0017	140.0100	0.0103
0.22	49.4420	208.6600	0.0479	60.9425	127.8600	0.0104	67.5630	127.8600	0.0111	59.4200	312.2900	0.0413	65.9612	138.8600	0.0104
0.23	48.7130	208.8500	0.0489	60.9246	128.6300	0.0105	67.4970	128.6300	0.0111	59.3050	310.6600	0.0416	65.9419	159.1300	0.0105
0.24	48.3530	207.7500	0.0495	60.9119	128.5900	0.0106	67.4360	128.5900	0.0111	59.1420	289.4700	0.0421	65.9281	150.6100	0.0106
0.25	48.2720	206.9300	0.0492	60.8923	127.7700	0.0106	67.3800	127.7700	0.0111	58.9220	298.0800	0.0425	65.9070	153.7000	0.0106
0.26	47.9680	206.7600	0.0507	60.8838	126.4500	0.0108	67.3560	126.4500	0.0111	58.6630	300.2500	0.0425	65.8978	169.7400	0.0108
0.26	47.7610	205.2600	0.0507	60.8719	123.3700	0.0108	67.3680	123.3700	0.0111	58.3990	297.9300	0.0434	65.8849	173.3400	0.0108
0.27	47.7770	207.0600	0.0504	60.8286	120.7400	0.0107	67.3600	120.7400	0.0111	58.1620	295.8100	0.0437	65.8380	174.5800	0.0107
0.28	47.7660	209.8400	0.0505	60.7546	119.1000	0.0106	67.3790	119.1000	0.0111	57.9730	286.4800	0.0444	65.7579	169.4900	0.0106
0.29	47.6730	211.2900	0.0502	60.6807	118.6100	0.0106	67.3980	118.6100	0.0110	57.8280	290.6900	0.0453	65.6779	186.2800	0.0106
0.30	47.6770	210.2500	0.0497	60.6526	118.7300	0.0106	67.4060	118.7300	0.0110	57.7020	297.5100	0.0460	65.6475	218.4000	0.0106
0.30	47.6770	264.3000	0.0502	60.6569	119.1600	0.0106	67.4370	119.1600	0.0110	57.5570	298.9200	0.0478	65.6521	207.4800	0.0106
0.31	46.9820	256.4500	0.0495	60.6535	120.1600	0.0105	67.4820	120.1600	0.0110	57.3710	301.5900	0.0492	65.6484	166.7500	0.0105
0.32	46.4610	250.9000	0.0506	60.6424	121.1500	0.0103	67.5280	121.1500	0.0109	57.1500	301.5000	0.0498	65.6365	164.5900	0.0103
0.33	46.8130	234.0000	0.0514	60.6212	121.8800	0.0103	67.5720	121.8800	0.0109	56.9230	300.0000	0.0499	65.6135	166.8200	0.0103
0.34	46.7690	223.4800	0.0517	60.5846	120.6600	0.0105	67.6170	120.6600	0.0108	56.7160	299.7700	0.0501	65.5739	185.6700	0.0105
0.34	46.7550	220.8200	0.0519	60.5472	122.0700	0.0106	67.6670	122.0700	0.0109	56.5340	298.8200	0.0503	65.5334	195.2300	0.0106

0.35	46.6770	222.6100	0.0522	60.5804	128.7500	0.0106	67.7080	128.7500	0.0109	56.3560	297.9500	0.0505	65.5693	197.6300	0.0106
0.36	46.7080	244.5600	0.0520	60.6161	142.0000	0.0106	67.6010	142.0000	0.0111	56.1600	298.0300	0.0507	65.6080	217.3700	0.0106
0.37	47.1570	264.8500	0.0515	60.6458	140.3200	0.0103	67.3780	140.3200	0.0114	55.9450	298.1100	0.0509	65.6402	258.5900	0.0103
0.38	47.7950	251.5000	0.0510	60.6705	148.3700	0.0100	67.1930	148.3700	0.0110	55.7250	298.7600	0.0511	65.6668	237.4200	0.0100
0.38	47.9950	220.8800	0.0521	60.6968	158.3600	0.0103	66.7510	158.3600	0.0112	55.5110	299.3800	0.0513	65.6954	175.8900	0.0103
0.39	47.6050	214.3400	0.0512	60.7283	163.8200	0.0106	66.8820	163.8200	0.0113	55.2920	299.8500	0.0515	65.7294	197.9200	0.0106
0.40	47.4120	216.4700	0.0506	60.7691	163.2500	0.0110	66.9580	163.2500	0.0113	55.0420	300.2600	0.0516	65.7736	194.1200	0.0110

CONCLUSION AND SUGGESTION

5.1 Conclusion

Based on the analysis performed in this project, these following conclusions can be drawn

1. The midpoint deformation responses of plate subjected to blast loading, for each stiffener geometry is occurred at 200 ms, and the result is as follows:
   a. Unstiffened plate, 93.50 mm with von mises stress 348.00 MPa
   b. Stripe Geometry, maximum response at X configuration with midpoint displacement 75.78 mm and von mises stress 347.77 MPa
   c. T Geometry, maximum response at X configuration with midpoint displacement 64.41 mm and von mises stress 347.80 MPa
   d. L Geometry, maximum response at T configuration with midpoint displacement 70.22 mm and stress 347.79 MPa
2. The investigation of the effect of stiffener geometry, stiffener configuration, and blast duration to the plate responses is as follows
   a. T geometry is the best geometry to be used. T geometry can reduce up to 33.74% of unstiffened plate deformation.
   b. Parallel Configuration is the best geometry to be used. Parallel Configuration can reduce up to 31.81% of unstiffened plate deformation.
   c. The result shows that the longer the duration, the higher the deformation responses occurred. The maximum deformation and stress responses occurred after the maximum peak overpressure happened. The time delay from maximum load to maximum response is 0.007 s, 0.0063 s, and 0.028 s for 50 ms, 100 ms, and 200 ms blast duration, respectively.
   d. There is no consistent tendency regarding the effect of mass. But from the analysis came the fact that the heavier plate not always results the better response. So that the designer should carry out the stiffness factor more closely. With the same mass, designer can provide stronger stiffener with varying the geometry.

3. The best stiffened plate against blast loads is the Parallel Configuration with T Stiffener Geometry, reducing up to 36.87% deformation of unstiffened plate. The design satisfies the response criteria so the redesigning procedures are not necessary to be conducted.

5.2 Suggestion

These following suggestions can be performed for further analysis:

1. Applying the optimization theory to create an optimum design of the stiffened plate.
2. Varying more plate configurations and geometries.
3. Applying more realistic blast loads with accounting the distance and charge mass.
4. Modelling the blast load wave so that the response is more realistic.
5. Applying the blast resistant stiffened plate to a complex structure to prove the effectivity.
6. Expanding the analysis duration time to investigate the residual stress behavior after the blast load finishes.

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Raditya Danu Riyanto, born on 25th March 1992 at Surabaya, is the author of “Design of Blast Resistant Stiffened Plate”. He finished the project for about 5 months at Laboratory of Offshore Structural Dynamics. This project is an enormous finding at newly discovered scientific field, especially in building that can resist to an explosion loads. He did it just at his undgraduate degree final project. Danu, so he called, has strong Javanese-Chinese background from his family. After graduated from SMA Taruna Dra Zulaeha at 2010, he decided to continue his study at Ocean Engineering Department ITS Surabaya by SNMPTN with NRP 4310100097. He is also former Paskibraka (Pasukan Pengibar Bendera Pusaka) for East Java Province on 2009 at Gedung Negara Grahadi Surabaya as commander of platoon 17. After finishing his duty, he then be the head of Purna Paskibraka Indonesia at Probolinggo Jawa Timur from 2010-2011. During his study, he achieved a lot of prestigious awards, including 100 ITS Super Students, 3rd Place ClassNK Award for Excellence Study and Commitment to the development of Maritime Industry. He also mastered many national level events, including OCEANO at 2012 and 2012 National Bridge and Earthquake Resistant Building Competition. Despite his business with several organizations, marked with be the head of several organizations including Purna Paskibraka Indonesia Kabupaten Probolinggo (2010-2011) and Head of Student Organization at Laboratory of Offshore Structural Dynamics (2013-2014), he still could get his degree with cum laude.