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Numerical Analysis of Dynamic Responses of the Plate Subjected to Impulsive Loads

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Abstract**—**Plate is one of the popular structural elements used in a wide range of industries and structures. They may be subjected to blast loads during explosion events, missile attacks or aircraft attacks. This study is to investigate dynamic responses of the rectangular plate subjected to explosive loads. The effects of material properties and plate thickness on responses of the plate are to be investigated. The compressive pressure is applied to the surface of the plate. Different amounts of thickness in the range from 1mm to 30mm are considered for the plate to evaluate the changes in responses of the plate with respect to plate thickness. Two different properties are considered for the steel. First, the analysis is performed by considering only the elastic-plastic properties for the steel plate. Later on damping is considered to investigate its effects on the responses of the plate. To do analysis, numerical method using a finite element based package ABAQUS is applied. Finally, dynamic responses and graphs showing the relation between maximum displacement of the plate and aim parameters are provided.

Keywords**—**Impulsive loaded plates, dynamic analysis, abaqus, material nonlinearity.

I. Introduction

PLATES are widely used as one of key components in the various structures. Structures such as containment buildings, high rise buildings, power plants and other important structures may be subjected to loads due to explosion events, missile attacks, aircrafts attacks so that they need to be designed such that they can resist against those loads and impacts.

Blast loads, nowadays, are taken into account during design procedure because of the hazards faced to the important structures [6]. In recent years, many research works have been performed on the explosion from different points of view. Authors performed explosive related researches to investigate explosion process, behavior of the structures subjected to blast loadings, the behavior of the materials of aim structures, obtaining the parameters of burst events and finding out the way through which the explosive loads are applied to the structures [2], [3], [5], [7].

Rapid and intense release of energy due to detonation, convert the explosive to the high pressure gas having high temperature. The wave front expanded into surrounding air radially [6]. The wave front which is called blast pressure suddenly arises from open air pressure, P_0 to incident pressure, P_s^+. Wave front moves radially from the explosion point to the surroundings with decreasing speed U which always is higher than speed of sound. As the wave front spreads in to the greater volumes of surroundings, the maximum event pressure decreases while the duration period increases [6], [8]. The shape of the blast wave, in the explosion path, is totally as the shape given in Fig. 1. As can be seen from Fig. 1, the blast wave front, having the pressureP_a(pressure of atmosphere), move from the point of explosion to a specific point during the time t_a. Then, at time t_a, the pressure increases up to maximum pressure P_s^+. The pressure gradually decreases from P_s^+ to P_a during time t_0. The time duration of t_0 is called positive phase duration. Then the pressure of blast wave decreases to maximum negative pressure P_s^- which is a pressure below P_a then finally it returns to P_a. This part, below the P_a, is called negative phase for which the time duration is shown by $t_0{}^-$. The positive phase, for design purpose, is more important than negative phase. The area under curve of pressure-time is called event impulse which i_s^+ shows it for positive phase and i_s^- shows it for negative phase.

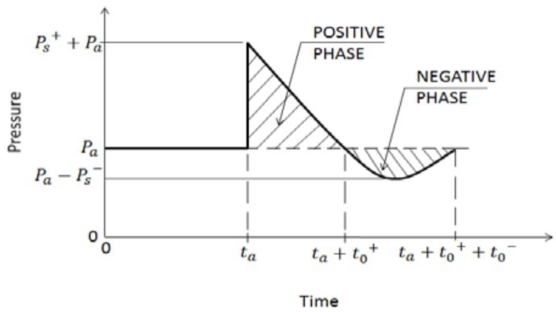

Fig. 1 Ordinary Shape of Blast Wave

The explosion events are categorized in deferent batches with respect to the charge confinement as well as position of the event to the ground and aim structures. They are batched, from viewpoint of confinement, in two main groups of confined explosions and unconfined explosions. Each main category is also divided in three groups. Each type of explosion leads to specific pressure load. Indeed depending on the conditions of the explosion, the resulting loads have different quiddity. Table I shows the different types of the burst phenomenon and the type of corresponding loads which will be applied to the structures [6].

In design of structures resistant against blast, the free air burst and air burst are rarely taken into account. Other types of explosions, surface burst and confined explosions are considered for design purpose. This study is to investigate the plate subjected to surface burst.

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TABLE I
CATEGORIES OF EXPLOSION EVENT AND CORRESPONDING LOADING

Charge Confinement	Category	Pressure Loads
Unconfined Explosions	Free Air Burst	Unreflected
	Air Burst	Reflected
	Surface Burst	Reflected
Confined Explosion	Fully Vented	Internal Shock
		Leakage
	Partially Confined	Internal Shock
		Internal Gas
		Leakage
	Fully Confined	Internal Shock
		Internal Gas

Two types of material properties including material nonlinearity are considered for the steel plate to investigate the responses of the plate with respect to its material properties. Table II shows the elastic properties of steel while Table III shows the nonlinear properties of two types of steel. Likewise, when the responses of the plate subjected to blast loads are investigated with respect to plate thickness, one batch of material properties is considered for the all the cases of plate thickness. The original plate has the length 1000mm width of 500mm and the thickness of 15mm.

The blast load is applied to the plate as pressure. In order to define it in ABAQUS, the amount of 10MPa is given as its magnitude. Then, amplitude should be added to the applied load to complete the loading pattern [4]. Fig. 2 shows the blast load which is applied to plate through the analysis.

For the boundary conditions, in this study, it is appropriate to note that all the edges of the plate are constrained for all the degrees of freedom i.e., four edges of the plate are constrained for all displacement and rotations in X, Y and Z directions.

To mesh the plate to be ready for doing analyses, the element type and family are needed to be specified as well as the mesh size. The element type, in this study, is considered to be quad while the mesh technique is structured [1].

Element library is explicit while the geometric order is linear for the element family of shell. The S4R element is chosen for the model to do analyze the plate subjected to blast loading. The approximate global size of mesh is considered to be 0.02.

A. Investigation into the Material Properties

The aim is to investigate the effects of change in material properties on the dynamic responses of the plate subjected to blast loading. At the first step the elastic-plastic behavior is considered for the plate. The elastic properties of the steel plate are given in Table II. The stresses and corresponding plastic strains of to two batches of material properties are given in Table III. Through the second step, damping is also considered to investigate its effects on the responses of plate subjected to blast loading.

TABLE II
ELASTIC PROPERTIES OF STEEL

Density (Kg/m^3)	Elastic Modulus(Pa)	Poisson's ratio
7800	210×10^9	0.3

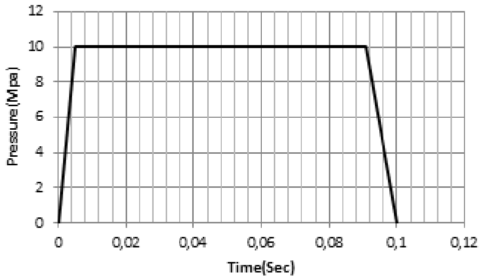

Fig. 2 Applied Blast Loading

TABLE III
PLASTIC PROPERTIES OF STEEL

Case I		Case II	
Yield Stress(Pa)	Plastic Strain	Yield Stress(Pa)	Plastic Strain
300×10^6	0.00	400×10^6	0.00
350×10^6	0.025	440×10^6	0.02095
375×10^6	0.10	500×10^6	0.10352
394×10^6	0.20	692×10^6	0.13524
400×10^6	0.35	566×10^6	0.24571

B. Damping Effects on the Plate Responses

Not considering damping effects, the structure continues oscillating when the excitement applied to the structure. The energy dissipation occurs due to friction at supports and damping. So the need for considering damping gains its importance. To define damping the parameter of Bulk Viscosity Damping, which affects the dynamic responses of the high velocity dynamic problems like burst, is needed to be defined. In this study as the model is shell, the linear damping is considered for the model. Since the bulk viscosity coefficient is very small, a long time is needed for oscillations to be damped so the amplitude going to be zero gradually. To add damping to the material properties in ABAQUS, three parameters are needed to be defined as given in Table IV.

TABLE IV
DAMPING PARAMETERS FOR STEEL PLATE

Alpha(α)	Beta(β)	Composite
50	0	0

C. Investigation into the Plate Thickness

To evaluate the dynamic responses of the plate subjected to burst loads with respect to plate thickness, a range of thickness from 1mm to 30mm is considered for the plate. The values of 1mm, 2.5mm, 5mm, 7.5mm, 10mm, 15mm, 20mm, 25mm and 30mm are considered to be specified to the plate thickness. The load pattern, in this section, is the same as already used. The elastic properties of the steel are the same as before while the case II is considered for the plastic behavior of the steel. For the boundary conditions, it can be mentioned that four edges of the plate are constrained for all the degrees of freedom. The mesh pattern and element type are applied as already explained.

II. RESULTS

Dynamic responses of the plate subjected to explosive loads are obtained by application of numerical tool, ABAQUS. This problem is considered to be investigated from different points of view. The results of inspecting the effects of material properties on the dynamic responses of the plate are provided. To investigate the effects of damping on the plate responses, comparative graphs including both with and without damping are provided. The results of investigation into the plate thickness effects on the responses of steel plate are provided, as well. Changes in maximum displacement of the plate with respect to plate thickness are also given as graphs.

A. Material Properties and Damping

To evaluate the effects of material properties on the dynamic responses of the plate two batches of material properties are specified to the plate. The damping effects are also considered to be investigated. Fig. 3 shows the comparative graph of the dynamic responses of the plate for both cases of material properties. As can be seen from Fig. 3, the graph corresponding to material properties of case II shows lower amounts of displacement. It is may already expected as the steel plate manufactured by material of case II has more strength than plate created by material of case I.

Fig. 4 shows the comparative graphs regarding to material properties of case I in which the damping effects on the dynamic responses of the plate are shown. Fig. 5 shows the comparative graphs for material properties of case II for both with and with damping effects.

As can be seen from Figs. 4 and 5, by considering damping for the material properties the oscillations of the plate are damped. However, there is no change in maximum displacement of the plate.

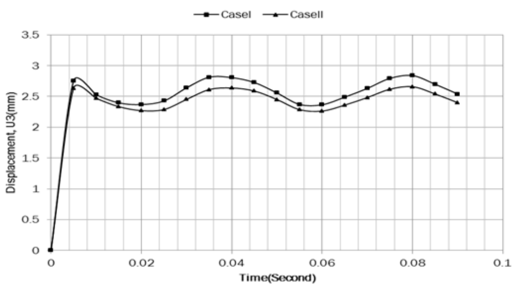

Fig. 3 Comparative Graphs for Both Material Properties

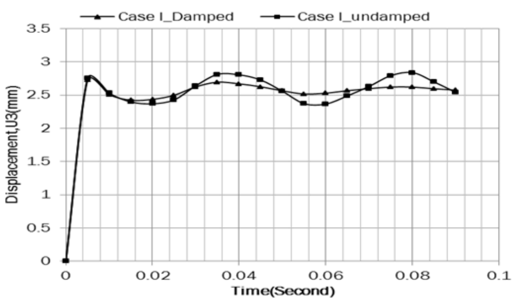

Fig. 4 Comparative graphs for material properties of case I with and without damping

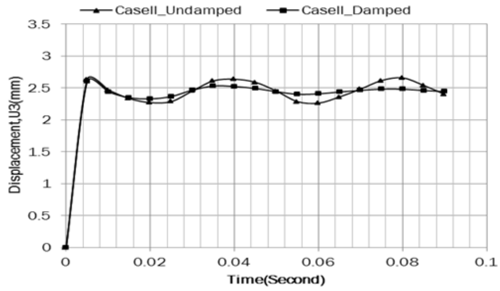

Fig. 5 Comparative graphs for material properties of case II with and without damping

B. Effects of Plate Thickness on Dynamic Responses

In order to investigate the responses of the plate with respect to the plate thickness, this study considered to specify values from 1mm to 30mm to the plate thickness. The loading pattern and boundary conditions are the same as already used while it is preferred to use the material properties corresponding to case II. Damping is also considered for these analyses. To clarify the results they are given in two different graphs. Fig. 6 shows the dynamic responses of the plates having the thickness values from 1mm to 10 mm while Fig. 7 shows those corresponding to the values from 15mm to 30mm.

Taking look into the graphs it is observed that by increasing in thickness of the plate the amounts of displacements decreased. From plate having the thickness of 1mm to plate of 2.5mm thickness there is a large decrease in displacement. By investigating the other graphs it can be inferred that by increasing in plate thickness the amounts of change in displacement decreased. In the other word, the plates of larger values of thickness can carry larger blast loads, as they have more stiffness. As the thickness increased its effects on the plate responses decreased.

The other result which can be observed from the graphs is oscillation. As can be seen thicker plates show more oscillation than thin plates. It is standing in the range of thickness from 5mm to 20mm. But by increasing in the plate thickness more than 20mm, i.e., plates of 25mm and 30mm thicknesses, the oscillations decreased.

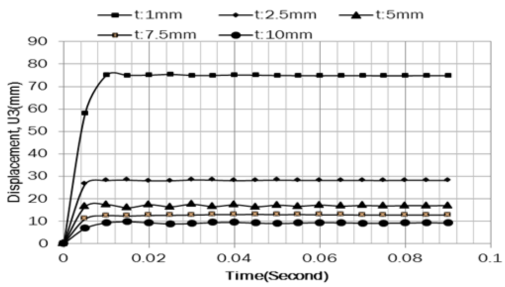

Fig. 6 Comparative graphs of dynamic responses of plate for the plate thickness from 1mm to 10mm

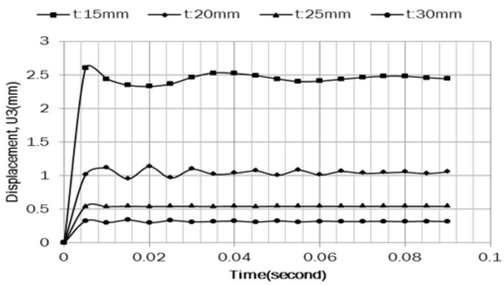

Fig. 7 Comparative graphs of dynamic responses of plate for the plate thickness from 15mm to 30mm

Fig. 8 shows the maximum displacement of the plate versus thickness. As can be seen from the graph shown in Fig. 8, as the thickness of the plate decreased the amounts of displacement increased. From the plate of 2.5mm thickness to 1mm there is a sudden increase in maximum displacement. It gains the importance in design procedure for the plate to resist against blast load. There is also a sudden decrease in maximum displacement in range of thickness from 15mm to 17.5mm. Between two sudden descend in graph the trend of decrease in plate deflection is linear.

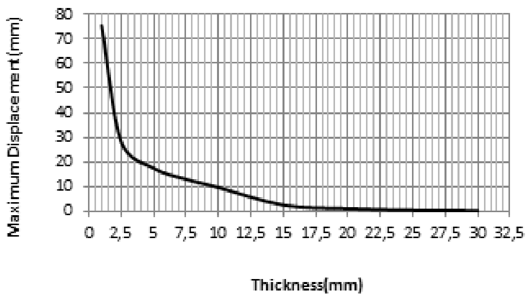

Fig. 8 Maximum displacement of plate with respect to the plate thickness

The total trend of change in maximum displacement, which occurs at the center of plate, with respect to plate thickness is exponential and given as graph. To estimate the amount of maximum displacement of the plate subjected to blast load equation (1) is suggested for the condition of this study. It is appropriate to note that more investigations are needed to present more accurate equation including all the effective parameters. Equation (1) can be expressed as:

$$U = 52.819e^{0.18t} \quad (1)$$

where U is the maximum displacement of the plate along with plate thickness, z-direction, and t is the thickness of the plate.

III. Conclusions

Investigation of the plate subjected to blast loading is performed in this study. The aim was to evaluate the dynamic responses of the plate with respect to some important parameters which affect the plate responses. In the first step, to investigate the effects of material properties, two different plastic behaviors were considered to be specified to the steel plate materials while the elastic properties considered as the same. Steel plate of material properties of case II showed lower amounts of displacements. Then, damping also was defined for the steel plate to observe the change in dynamic responses of the plate. As may already expected the oscillations were damped.

This study also investigated the responses of the plate with respect to its thickness. The results showed that as the thickness decreases the amount of displacement exponentially increases. Through this study an equation was presented for the estimation of the maximum displacement of the plate which occurs at the center of plate, with respect to the plate thickness. For the future study more investigations are needed to enhance the presented equation in which other important parameters effecting on the displacement of the plate included.

Acknowledgment

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