PREDICTION OF BLAST LOADING AND ITS IMPACT ON THE STIFFENED DOOR STRUCTURE

(SC-118)

S. Lakshmi Shireen Banu[1*] and N.V. Ramana Rao[2]

[1]*Department of Civil Engg., MCET, Siddipet, Medak District-502372, A.P, India.*
[2]*Department of Civil Engg. JNTUH College of Engg., Kukatpally, Hyderabad- 500085, A.P, India.*
**e-mail: vlsbanu@yahoo.co.in*

ABSTRACT

An unexpected bomb explosion within or in the near vicinity of a commercial or military structures can cause severe damage on the building's external and internal structural frames. Generally, these external structures can be strengthened using reinforced concrete walls. However, the entrances cannot be completely sealed off under consideration of free pass. Thus, a variety of blast resistant doors that withstand explosion impact were designed for various applications. Such a blast resistant door could be constructed as stiffened steel plate. The objective of this paper is to study the extent of damage that can be caused due to a blast load on stiffened steel plate designed to withstand blast load using computational methods. In this paper, panels with different stiffeners are considered for numerical study. Two types of stiffeners, T and HAT shaped stiffeners are considered. The thickness of these stiffeners is varied to study the effect of damage caused due to blast load. Special emphasis is focused on evaluation of mid-point displacements and strain energy. The finite element package ABAQUS is used for modeling the plate, with two different stiffeners separately having constant height and different thickness. The boundary conditions are assumed to be fixed on all sides and meshed using the S4R type shell element. For the response calculations, a fixed blast load is applied in all the cases of the stiffened steel plate of the door structure considered. The blast response of stiffened blast doors with two different stiffeners subjected to constant blast load was examined. The present analysis gives a comprehensive insight into the effects of explosion on blast door structures. The results of blast load analysis for stress, mid-point displacements and strain energy for T and HAT stiffeners were compared against each other and found that HAT stiffener performs better.

Keywords: Blast, Impact, Stiffener.

1. INTRODUCTION

The blast problem is rather new; information about the development in this field is made available mostly through publication of the Department of Defense, U.S. Air Force and other governmental offices and public institutes.

1.1. Blast Door

The design and analysis of steel plate with stiffeners subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. For the design work of blast resistance structure, it is well recognized that two important technologies, including structural dynamic analysis and blast aerodynamics, are involved. Especially, the dynamic response to explosive loading should be taken into consideration during design stage. On the other hand, the identification of the explosive loading characteristics such as peak pressure and loading duration of blast wave is a prerequisite prior to mechanical analysis. Although some studies on blast loading model are available in literatures, quantification of the blast parameters has been a highly complicated task with advanced techniques.

Accordingly, most of the blast door structures were designed as per the guidelines provided in the military technical manual TM5-1300, NAVFAC P-397, and the analysis work was performed following the official design criteria. Essentially, the structural stiffness of blast door was estimated under different blast loads and then the blast resistance was evaluated according to the material strength, making sure whether the structure could meet the requirement in explosion capacity. As to the dynamic analysis presented in TM5-1300, a simplified single-degree-of-freedom system was usually employed to simulate the dynamic response of the whole structure under the blast shock wave, by which the maximum distortion, time-history of acceleration can then be investigated.

1.2. The Explosion Process

The explosion is a rapid chemical reaction in a substance, which converts the original material into a gas at very high temperature and pressure evolving large amount of heat (4389 kJ/kg of trinitrotoluene (TNT) explosive). The explosion process is divided into two parts: (1) the detonation process and (2) the interaction process between the product gases and the surrounding medium (air in atmosphere and water in underwater). During the detonation process, a detonation wave is generated and propagates in the explosive.

Once the process of detonation is completed, the interaction of the product gases with the surrounding medium takes place. The product gases with high pressure and temperature expand outward by generating a pressure wave. The gaseous products are assumed to be inviscid at this high temperature and thus the viscous forces are not considered for the explosive modeling.

AIR BLAST: A schematic of the blast wave is shown in figure.1; the shock wave has an instantaneous rise and an exponential fall. The parameters of interest for the damage process are the peak overpressure (that is the pressure above the atmospheric pressure), the positive duration and impulse with respect to the scaled distance. The negative phase of the blast wave is generally ignored.

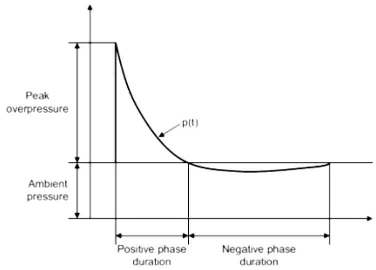


Figure 1. A schematic of the blast wave

The peak overpressure P_s and duration of positive pressure t_d can be expressed as a function of the scaled distance Z and explosive charge weight W, respectively. i.e,

$$\frac{P_s}{P_o} = \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{0.048}\right)^2}\cdot\sqrt{1+\left(\frac{Z}{0.32}\right)^2}\cdot\sqrt{1+\left(\frac{Z}{1.35}\right)^2}} \quad (1)$$

$$\frac{t_s}{W^{\frac{1}{3}}} = \frac{980\left[1+\left(\frac{Z}{0.54}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{0.002}\right)^3}\cdot\sqrt{1+\left(\frac{Z}{0.74}\right)^6}\cdot\sqrt{1+\left(\frac{Z}{6.9}\right)^2}} \quad (2)$$

The equation $P(t)$ is often simplified with a triangular pressure-time curve Bulson (1997) [2],

$$P(t) = P_{max}\left(1-\frac{t}{t_d}\right) \quad (3)$$

Conventional high explosives tend to produce different magnitudes of peak pressure. As a result, the environment produced by these chemicals will be different from each other. In order to have a basis for comparison, various explosives are compared to equivalent TNT values. With a scaling parameter, it is possible to calculate the effect of an explosion as long as the equivalent weight of charge in TNT is known,

$$Z = \frac{R}{W^{\frac{1}{3}}} \quad (4)$$

Where R is the distance from the detonation and W is the equivalent weight TNT.

These computationally intensive effects are difficult to simulate in real time, so we use a simple model that propagates blast waves outwards as if they were in the open air and not being affected by surrounding objects. As a result, object damage that occurs may not be identical to real-life explosion.

2. PROBLEM DEFINITION

The schematic diagram of the cover plate used for blast load analysis is shown in figure 2. The weight of the TNT (explosive) applied is 200 kg at a stand-off distance 10 m. It should be noted that plate is fully fixed in all directions. The basic problem addressed in the work may be stated as follows: ASTM A515 GRADE 50 MATERIAL FOR COVER PLATE- Young's Modulus, E = 200 x 10^9 N/m^2, Poisson ratio, ν = 0.3, Density, ρ = 7830 kg/m^3, Static yield, σ_{yield} = 265 x 10^6 N/m^2, Ultimate Tensile strength, σ_{ut} = 492 x 10^6 N/m^2.

Blast door with dimensions 5.142 x 2.56 m with thickness 30 mm is taken and two different stiffeners T and HAT are chosen for stiffening of the cover plate of the door structure. Two separate materials for cover plate and stiffeners are chosen from Ming-Wei Hsieh *et al.* [1], in which the materials are chosen from a manual which is specially designed by Department of the Army, "Structures to resist the effects of accidental explosive," *TM5-1300,* Washington, D.C. (1990) [3]. The FEM analysis is carried-out in ABAQUS 6.6-3. ASTM A36 STEEL MATERIAL FOR STIFFENER- Young's Modulus, E = 200 x 10^9 N/m^2, Poisson ratio, ν = 0.26, Density, ρ = 7800 kg/m^3, Static yield, σ_{yield} = 248 x 10^6 N/m^2**,** Ultimate Tensile strength, σ_{ut} = 400 x 10^6 N/m^2**.**

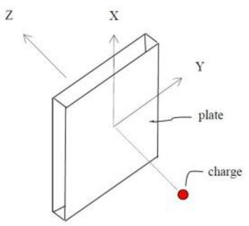


Figure 2: Basic Structural Model

Table 1: The cover plate with different stiffener

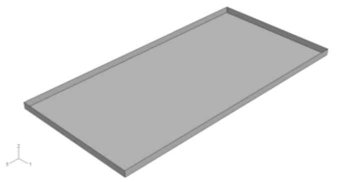
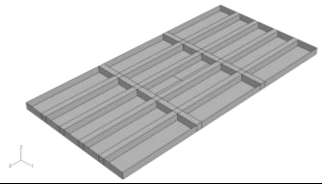
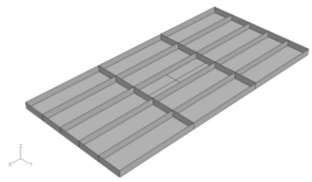
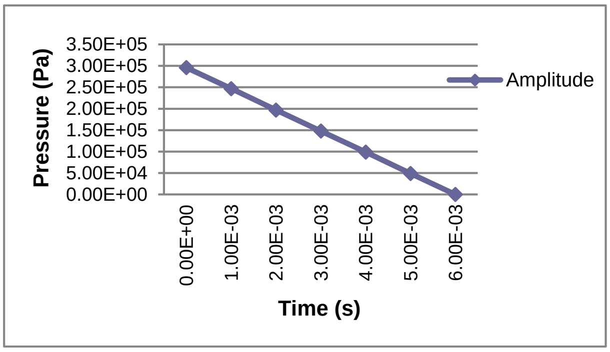
Cover plate without stiffeners	Cover plate with HAT shaped stiffener	Cover plate with T shaped stiffener
		

Table 2: Shows the varying pressure with respect to time

P(t) (Pa) (x 10e5)	ts (milli sec)
2.96	0
2.47	1
1.97	2
1.48	3
0.99	4
0.49	5
0	6



Graph 1: Shows the positive duration of load with respect to time

The plate will be subjected to a load that varies with time and the graph 1 shows only the positive peak overpressure and its decline with respect to time. This is because the positive phase is more important in studies of blast wave effects on structures due to its high amplitude of the overpressure and the concentrated impulse.

Table 3: Characteristics of blast wave with different W-R combinations

TNT explosive charge (kg)	Stand-off distance (m)	Scaled distance	Peak overpressure (bar)	Positive duration (ms)
100	10	2.15	1.74	6
200	10	1.71	2.96	6
300	10	1.49	4.07	6
400	10	1.36	5.01	6
500	10	1.26	5.96	6

The pressure is applied against the top of the plate (where as the stiffeners are on the bottom of the plate). Such a pressure load will place the outer fibers of the stiffeners in tension.

3. RESULTS AND DISCUSSIONS

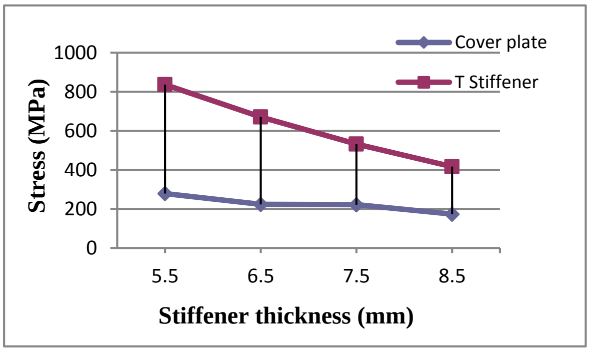
The duration of the positive phase of the blast is 6 milliseconds. The 3D model of the cover plate with stiffeners was modeled and the effects of blast loading in the dynamic-explicit analysis to obtain the deflection time-history of the cover plate, using ABAQUS.

2.1. Maximum Principal Stress

The maximum principal stress in MPa at highly stressed regions are tabulated and shown in Table 4 and Table 5 for T and HAT stiffeners respectively.

Table 4. Results for T shape stiffener

Results for T stiffener Height=140mm, Plate thickness=30mm			
Sl. No.	Stiffener thickness (mm)	T stiffener Maximum principal stress (MPa)	
		Cover plate	Stiffener
1	5.5	278.8	836.3
2	6.5	223.6	670.9
3	7.5	221.7	532.1
4	8.5	173.6	416.7



Graph 2: Stress variation in cover plate and T stiffener

The values presented in the table. 4 are taken from the contour plots presented below form Fig 3 to Fig 6.

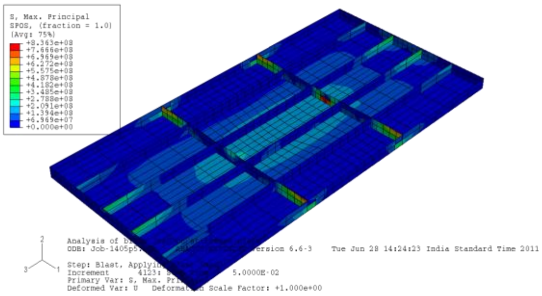


Figure 3: Results of T stiffener thickness of 5.5 mm

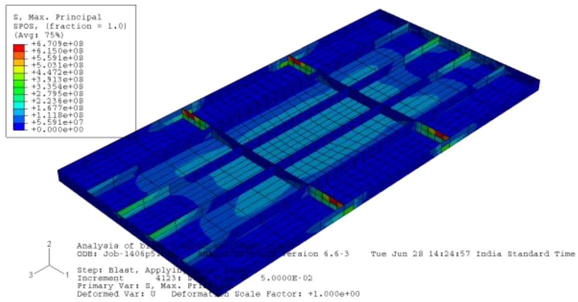


Figure 4: Results of T stiffener thickness of 6.5 mm

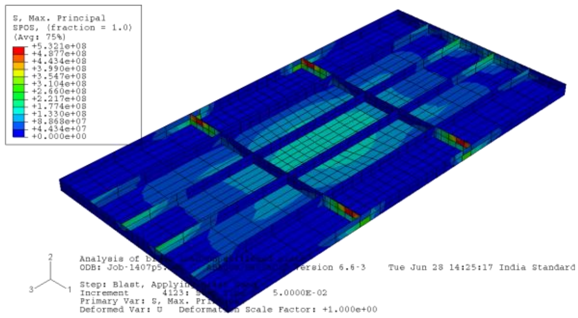


Figure 5: Results of T stiffener thickness of 7.5 mm

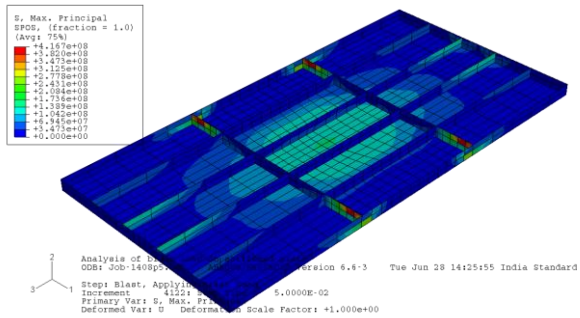
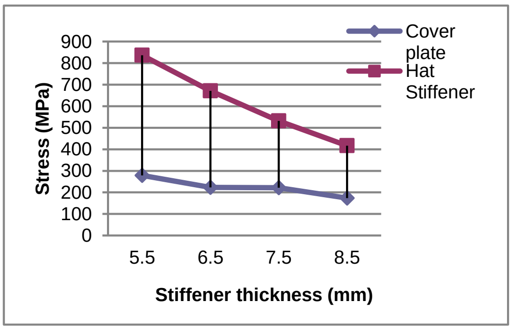


Figure 6: Results of T stiffener thickness of 8.5 mm

Table 5. Results for H shape stiffener

Results for HAT stiffener Height=140mm, Plate thickness=30mm			
Sl. No.	Stiffener thickness (mm)	HAT stiffener Maximum principal stress (MPa)	
		Cover plate	Stiffener
1	5.5	263.1	631.5
2	6.5	218.4	524.2
3	7.5	155.6	391.2
4	8.5	105.8	221.2



Graph 3: Stress variation in cover plate and HAT stiffener

The values presented in table 5 are taken from the contour plots presented below form Fig 7 to Fig 10.

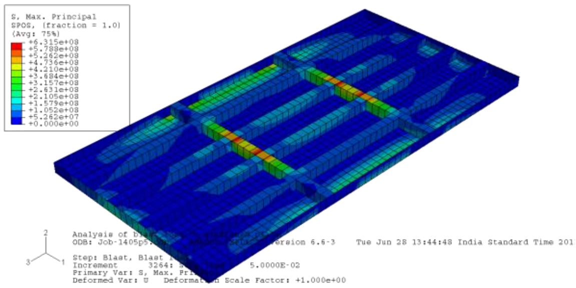


Figure 7: Results of HAT stiffener thickness of 5.5 mm

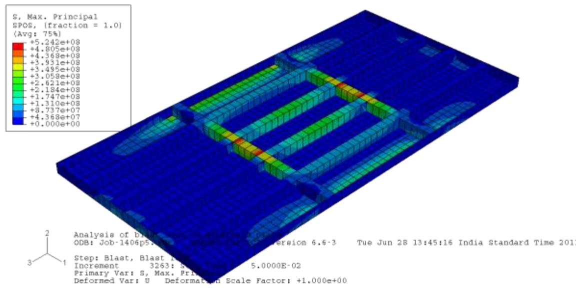


Figure 8: Results of HAT stiffener thickness of 6.5 mm

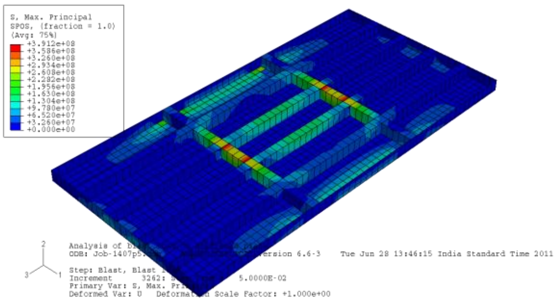


Figure 9: Results of HAT stiffener thickness of 7.5 mm

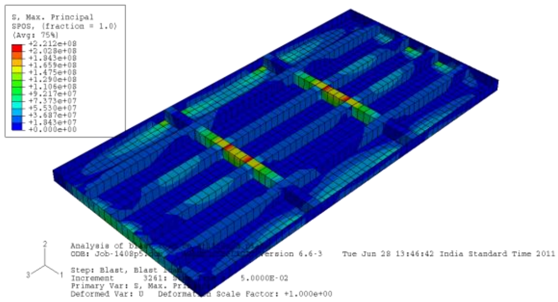


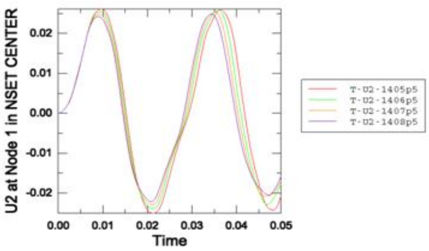
Figure 10: Results of HAT stiffener thickness of 8.5 mm

2.2. Mid-Point Displacement At Center Node

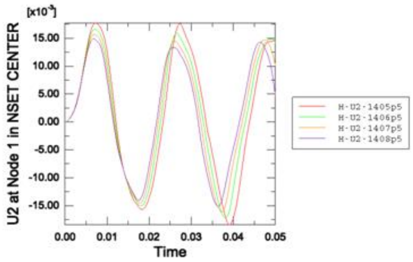
These graphs below show the maximum displacements plots at center node for T stiffener and HAT stiffener of 5.5mm, 6.5mm, 7.5mm and 8.5mm thickness.

2.2.1 Observations For Mid-Point Displacement At Center Node

The increase of thickness in both cases of cover plate with T and HAT shaped stiffener results in decrease in mid-point displacements as seen in graphs 4 and 5. It is observed that the displacement in T shaped stiffener is 20 x 10^{-3} m and in HAT shaped stiffener is 17.5 x 10^{-3} m. Hence, it is observed from graphs that HAT shaped stiffener shows less mid-point displacement than T shaped stiffener.



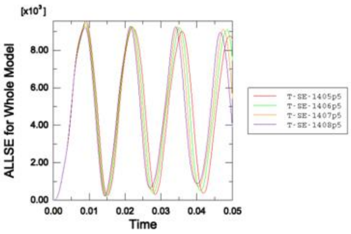
Graph 4: Deflection (m) vs Time (s) for T stiffener with varying thickness



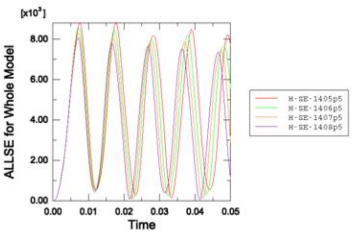
Graph 5: Deflection (m) vs Time (s) for HAT stiffener with varying thickness

2.2.2 Strain Energy

The graphs (6 to 7) below show the strain energy plots for T stiffener and HAT stiffener of 5.5mm, 6.5mm, 7.5mm, and 8.5mm thickness.



Graph 6: Energy (kNm) vs Time (s) for T stiffener with varying thickness



Graph 7: Energy (kNm) vs Time (s) for HAT stiffener with varying thickness

2.2.3 Observations For Strain Energy

The strain energy of cover plate with T and HAT shaped stiffener with thickness varying from 5.5 mm to 8.5 mm at an increment of 1 mm are plotted with respect to time in graphs no. 6 to 7. It is observed from the graphs that by increasing thickness, the strain energy in cover plate, with T and HAT shape stiffener is decreasing. The increasing of thickness in both cases of cover plate T and HAT shaped stiffener results in decreasing of strain energy. From the graphs 6 and 7, it is observed that the strain energy in T shape is 9kNm and the strain energy in HAT shaped, is 8kNm. Hence it can be observed from graphs that HAT shaped stiffener shows less strain energy than T shaped stiffener.

3. SUMMARY AND CONCLUSIONS

3.1. Summary

In the present investigation, an attempt has been made to predict the failure of a fully fixed stiffened cover plate of a blast door, subjected to air blast loading. The numerical analysis has been performed using ABAQUS. In the entire analysis, a cover plate with T and HAT shaped stiffeners is considered with the thickness of the plate and height of the stiffener being constant. The thickness of the stiffeners is varied from 5.5 mm to 8.5 mm with an increment of 1 mm.

The blast load is applied based on the Friedlander equation. For the analysis, the pressure is assumed to be uniform within each finite element. However, the variation of the pressure across the length and breadth of plate is considered and is estimated based on spherical shock wave spreading pattern. With respect to time, pressure is assumed to be exponentially decaying.

3.2. Conclusions

- The maximum principal stress of the panel decreases with the increase in thickness of stiffeners in both T and HAT shaped stiffeners.
- The mid-point displacement at the center of the node is much larger in plate with T shaped stiffener than in HAT shaped stiffener.
- The strain energy is more in cover plate with T shape stiffened plate than in cover plate with HAT shape stiffened plate.
- From the present analysis, the cover plate with HAT stiffener is found to offer more resistance compared to the plate with T stiffener for blast loads.

4. REFERENCES:

[1] Ming-Wei Hsieh, Jui-Pin Hung, "INVESTIGATION ON THE BLAST RESISTANCE OF A STIFFENED DOOR STRUCTURE", Journal of Marine Science and Technology, Vol. 16, No. 2, pp. 149-157 (2008).

[2] Buslon, P.S., 1997. Explosive loading of engineering tractures, E & FN Spon, London.

[3] Brode, H. L., "Numerical solution of spherical blast waves", Journal of Applied Physics, American Institute of Physics, New York, 1955.

[4] Department of the Army, "Structures to resist the effects of accidental explosive," TM5-1300, Washington, D.C. (1990).

[5] Department of the Navy, "Structures to resist the effects of accidental explosive," NAVFAC P-397, Design Manual, Alexandria, VA. (1991).

[6] Hsin, Y. L., and Hong, H., "Reliability analysis of direct shear and flexural failure modes of RC slabs under explosive loading," Engineering Structure, Vol. 24, pp. 189-198 (2002).

[7] A. Khadid et al. (2007), " Blast loaded stiffened plates" Journal of Engineering and Applied Sciences,Vol. 2(2) pp. 456-461.

[8] Alexander M. Remennikov, (2003) "A review of methods for predicting bomb blast effects on buildings", Journal of battlefield technology, vol 6, no 3. pp 155-161.

[9] Langdon, G. S., Yueh, K., Chung, S., Nurick, G. N., "Experimental and numerical studies on the response of quadrangular stiffened plates. Part II: Localized blast loading," International Journal of Impact Engineering,

[10] Louca, L. A., Pan, Y. G., and Harding, J. E. (1998), "Response of stiffened and unstiffened plates subjected to blast loading," Engineering Structure, Vol. 20, No. 12, pp. 1076-1086.