

# Dynamic blast response of diagonally biased stiffened steel plate under confinement

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**Abstract:** The explosion rate is increasing in marine and industrial field. This paper investigates the confined blast response of steel square plates stiffened with diagonally biased plate stiffeners. ANSYS Autodyn was used to conduct the parametric study and to analyze the effect of these diagonally biased stiffener plates on structural response and failure of these plates. Furthermore, a study on the plastic behavior and failure of these high strength steel plates due to the impact of blast waves were conducted. Among the explosives available, TNT is used as the charge mass.

**Keywords:** TNT, Stiffeners, Finite Element, dynamic response,

## 1. Introduction

Due to the increase in different accidental or the intentional events like terrorist attack or gas leakage etc. hence the behavior of the structural components that are subjected to different kind of blast loadings has become an important subject for the research in recent years. These structures occasionally are subjected to different kinds of blast loading such as air blast, surface blast, gas explosion, confined blast during terrorist attack or during combat environment. The blast hazards in these structures will lead to the collapse of entire structure or will reduce the structural safety. The research in this field are mainly focused on two important aspects that are to determine the blast load from the explosions and to predict the dynamic response of stiffened steel plates using experimental, analytical, numerical approaches [1-8].

The rigid perfectly elastic methods which are used to estimate the residual deformation of the metal plate were first developed by Jones [9-11]. The yield line which are formed in the plate plays an important role in the deflection of the plate. Yield lines are considered for the analytical model of stiffened plates.[10,14] The rectangular plate where modeled with segments interconnected by yield line. It yields a roof shaped displacement in most of the analytical models. This method gives accurate results when initial kinetic energy to the maximum possible elastic strain energy was about to be larger than about 10 and the load pulse duration was short with respect to the fundamental natural period of elastic vibration[15,16].

When an explosion occurs in a confined environment the characteristics of the blast loads are different from open blast. A quasi static pressure load with a large duration is generated after the initial and reflected shock wave. [5] when the pulse duration was large or the structure is relatively stiff the rigid plastic solution is non conservative compared with the elastic plastic solution [7]. The dynamic response of various stiffener configuration, considering the mesh dependency, loading

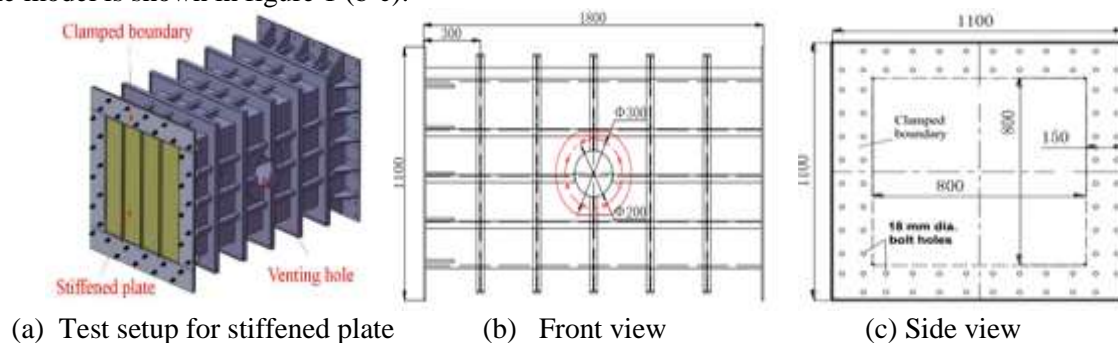


duration, strain- rate sensitivity by means of numerical analysis it is seen that the time duration and the stiffener configuration has greater effect on the overall Behaviour of the plate, stiffener response with the strain rate effect have higher stiffener response with increase in the value of  $t_d$  [3,2]. Under accidental fire the initial behavior of the stiffener plate alters, Repeated buckling caused by the travelling of fire causes alternating tension and compression which has grater implication on the integrity of welded connections [12]. The obtained result is valid only wen used with specified mesh, the mesh near the crack should be refined to ensure acceptable resolution and the broad range of mesh should satisfies the criteria and the yield acceptable predictive capability [17] .

## 2. Methodology

### 2.1 Experimental setup

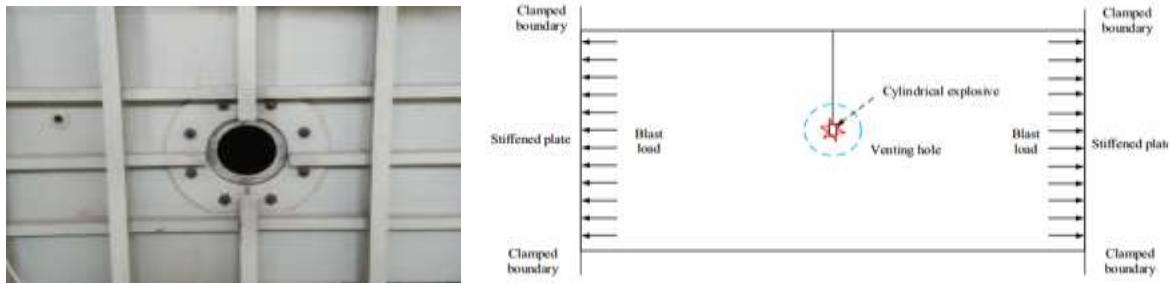
The experimental setup was designed to carry out confined blast acting in a stiffened plate. The set up has a structural chamber made from high strength steel as shown in figure 1 (a). The dimensions and the model is shown in figure 1 (b-c).



**Figure 1:** The dimensions of experimental setup. [1]

The length of the chamber is 11800mm and the square plate is 1100 x 1100 mm. plates were made with low carbon steel. The chamber was designed to be strong to withstand the load and to minimize the deformation of walls under confined blasting. A vent hole is provided at the center of the front wall as shown in figure 2(a). The area of the vent hole can be changed by installing different hollow flange plate to change the blast load acting on the test specimen. The specimens were fixed at both end on the support plate by means of 36M16 bolt. After the test plates were clamped the TNT charge in the middle of the test ring were initiated to produce blast load as shown in figure 2(b)

The plate which is used in the experiment are one way stiffened with two or three flats as shown in figure 1. The effective loading area is 800 x 800 mm as shown in Figure 2. The clamping frame was provided with rotational and translational restraints through the support plate which is located against the test plate by bolt. The diameter of the bolt hole in the test plate and the clamp frame are 2mm larger than the bolt. The stiffened plates were manufactured by welding steel flats to the plates using carbon dioxide welding method. Stitch welding technique was used for the manufacturing of the stiffened plates .This confined explosion test was funded as a part of National Defense Fundamental Research Project (B1420133057), National Natural Science Foundation of China (51409202 and 11502180) and the Fundamental Research Funds for the Central Universities (2015-yb-005) and experiment was conducted by Cheng Zheng, Xiang-shao Kong et al( 2016) Wuhan University of Technology, Wuhan 430063, China



**Figure 2** (a) Adjustable vent hole in the front wall [1] (b) schematic diagram of the test ring [1]

The square stiffened plates were tested with different thickness and loading conditions. Before the dynamic test ultrasonic thickness gauge was used for the accurate measurement of the plate and the stiffeners. a cases was studied the corresponding geometry of the stiffened plate and the loading condition and the TNT mass were shown in the table 1.

**Table 1:** dimensions of stiffener plates and loading conditions

late ref.	Plate thickness $\delta$ (mm)	Number of ribs	Length of stiffeners (mm)	Thickness Of stiffeners $b$ (mm)	Height of stiffeners $h$ (mm)	Radius of Venting hole (mm)	Mass of TNT
5	2.3	3	800	2.3	30	50	55

## 2.2 Finite element modeling

Stiffened plate of size 1100 x 1100 were made with low carbon steel with different thickness. The effective loading area is 800 x 800 mm. The diameter of the bolt hole in the test plate and the clamp frame are 2 mm larger than the bolt. The thickness of the plate is 2.3mm. the square steel plate is stiffened using stiffener plates which are placed diagonal to the effective area .thickness 1.6 mm and the mechanical properties of low carbon steel Q235 is shown in table 2, 0.5mm mesh with hard behaviour is used the mesh convergence is performed.

The numerical modeling is performed with ANSYS AUTODYN. In the numerical model, the stiffener, the plate are discretized by bilinear four-node quadrature shell elements having one quadrature point and fully coupled Eulerian lagrangian approaches are used to simulate the coupling interaction between the blast load and the stiffened plate. The structural chamber is treated as a rigid boundary of air fixed support is provided along the boundary that is the rotational and translation of all nodes of the clamp are restrained and flow out boundary is applied to the zone where vent hole is provide and also to the area behind the plate. The FE model of air is shown in Figure 3 (d). bonded body interaction is provided between the stiffeners and the steel plate. The square plate is stiffened using diagonally biased stiffeners 10 models were modeled the dimensional details is shown in table 3. Geometrical models are shown in figure 3 the finite element model for air is shown in figure 8

**Table 2:** mechanical properties of material

Mass density	= 7850 kg/m <sup>3</sup>	Strain hardening modulus B	= $275 \times 106$ Pa
Poisson ratio	= 0.28	Strain hardening index $n$	= 0.36
Young's modulus $E$	= $2.06 \times 10^{11}$ Pa	Strain rate hardening index $C$	= 0.022
Yielding stress $A$	= $270 \times 106$ Pa	Temperature softening parameter $m$	= 1.03
Johnson–Cook constitutive relation		Melting temp 800 'C	

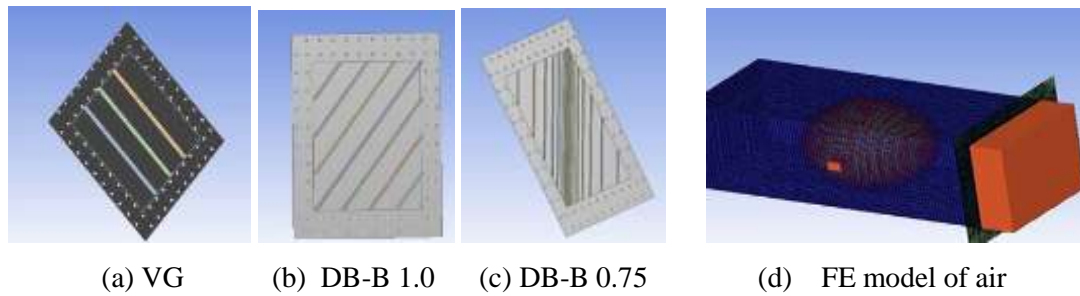
**Figure 3:** FE Model of stiffened plate and fluid**Table 3:** Dimensions of stiffened plates

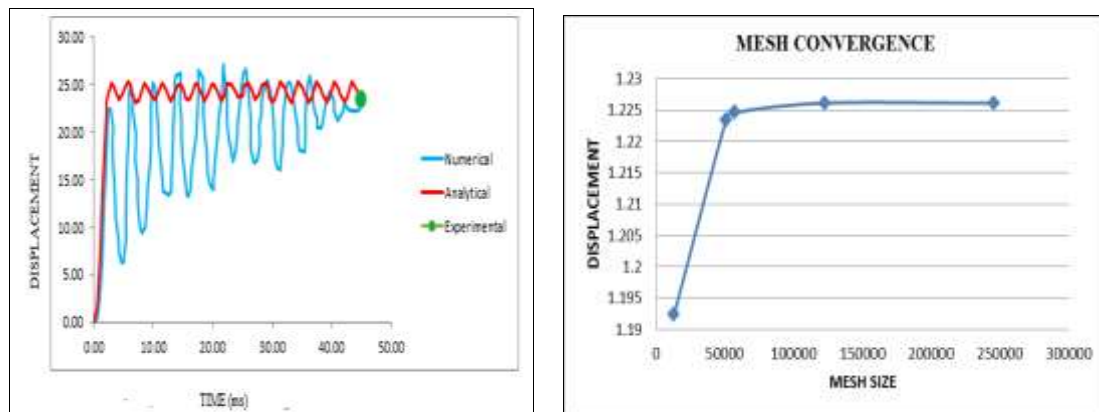
Plate ref.	Designation	Plate thickness $\delta$ (mm)	Biase ratio	Thickness of stiffeners $b$ (mm)	Height of stiffeners $h$ (mm)	Radius of venting hole (mm)	Mass of TNT (g)
1	WS	2.3	0	0	0	50	55
2	DB-B 1.0	2.3	1.0	1.6	25	50	55
3	DB-B 0.9	2.3	0.9	1.6	20	50	55
4	DB-B 0.8	2.3	0.8	1.6	16	50	55
5	DB-B 0.75	2.3	0.75	1.6	10	50	55
6	DB-B 0.7	2.3	0.7	1.6	8	50	55
7	DBC-B 1.0	2.3	1.0	1.6	30	50	55
8	DBC-B 0.9	2.3	0.9	1.6	30	50	55
9	DBC-B 0.8	2.3	0.8	1.6	30	50	55
10	DBC-B 0.75	2.3	0.75	1.6	30	50	55
10	DBC-B 0.7	2.3	0.7	1.6	30	50	55
12	VG	2.3	0	2.3	30	50	55

### 2.3 Calibration

The result obtained from the base journal is similar to that obtained from software analysis. The result is obtained by plotting displacement versus time graph it is seen that the end moment and the maximum deflection of the experimental value and also the analytical value obtained from the base journal is approximately equal to the value that we obtained during our validation procedure. the obtained result is plot on table 4 and the graph is shown in figure 4(a). Mesh convergence is shown in figure 4(b) The obtained error percentage is 3.4% which is less than 5% hence numerical validation is considered to be acceptable

**Table 4:** validation result

	Analytical	Experimental	Numerical	Analytical Error	Experimental Error
Maximum Deflection	25.47		26.57	4.1%	
End Deflection	23.27	23.502	22.7	2.4%	3.4%

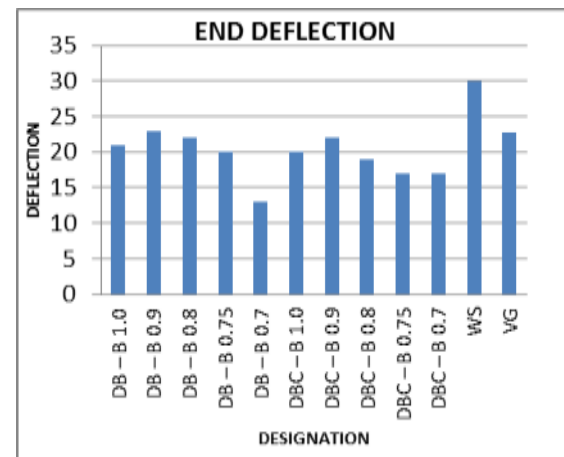
**Figure 4 :** (a) Validation curve**(b)** Mesh convergence

### 3. Result and discussion

The displacement and strain history at the center of the plate is taken as the output in the numerical solution the numerical result of the parameters are shown in table 4 and the bar chart showing the deflection is shown in figure 5

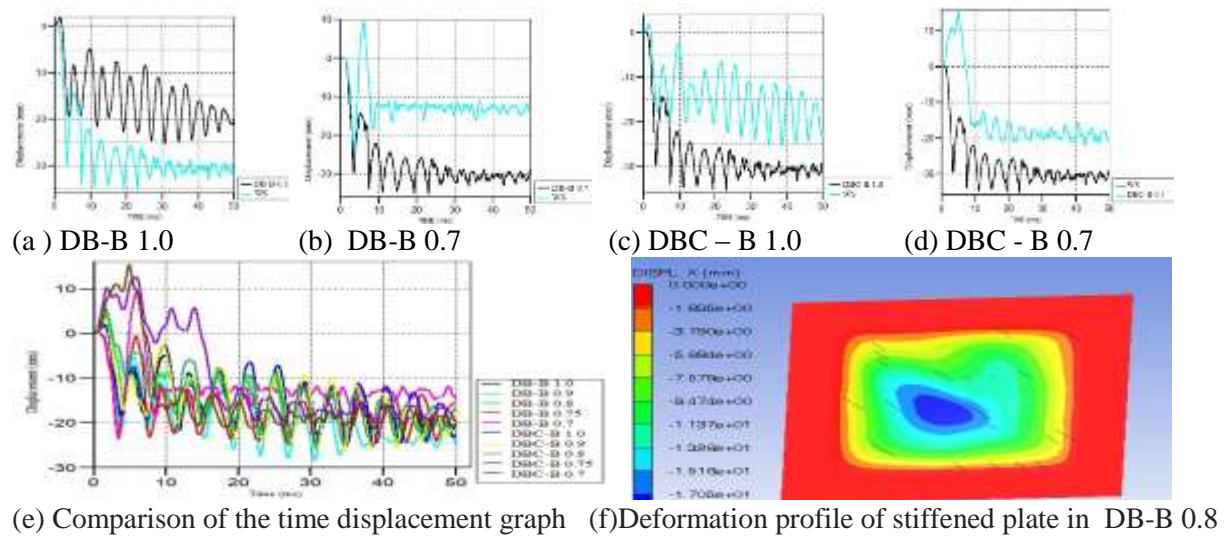
**Table 5:** Displacement at the center of the plate

Plate no	Designation	Maximum deflection	End deflection
1	DB – B 1.0	25	21
2	DB – B 0.9	28	23
3	DB – B 0.8	26	22
4	DB – B 0.75	25	20
5	DB – B 0.7	24	13
6	DBC – B 1.0	26	20
7	DBC – B 0.9	26	22
8	DBC – B 0.8	25	19
9	DBC – B 0.75	20	17
10	DBC – B 0.7	22	17
11	WS	36	30
12	VG	26.57	22.7

**Figure 5:** Displacement bar chart

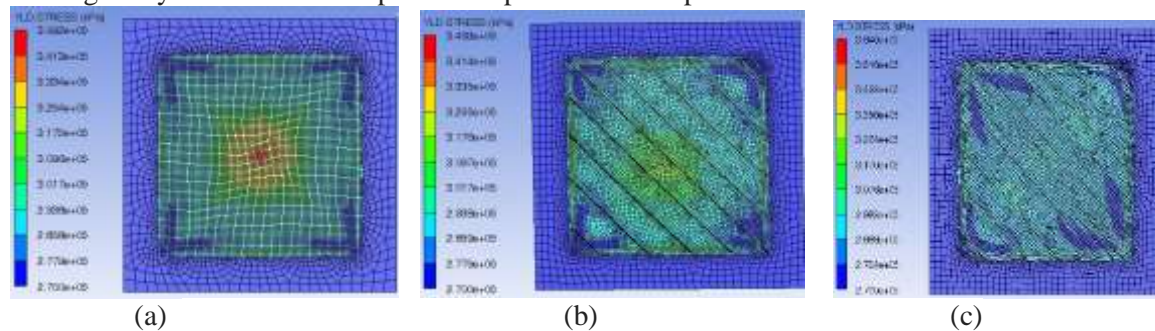
In dynamic test the confined blast wave have a long duration and relatively high peak pressure. The time displacement history graph in comparison with square plates without stiffeners is shown in figure 6. From the result, much variation in the vibration characteristics exist between the end deflections under biased specimen. The end deflection was reduced from about 30mm in the test specimen to 13mm in the biased specimen. The contour plot of DB-B-0.8 is shown in figure 6 (f)





**Figure 6:** displacement time graph

The stress acting on the plate varies with the change in the position of the yield line. With the change in the peak stress values the deformation varies. The plate without stiffeners has maximum stress concentration at the center leading to maximum deformation causing fracture. These could initiate the crack propagation along the yield lines, causing failure. Within our stiffened models, the CB-B 0.9 has maximum deformation while the stress concentration is maximum towards the center, this is due to the low bias ratio. Moreover, specimen CBC-B 0.75 has minimum deformation, and as seen from stress contours, the normalized stresses are distributed along the stiffened plates and along the edge of the plate. It has been seen that about 10% decrease in stress concentration was achieved with diagonally biased stiffeners plates compares with WS plates.



**Figure 7:** (a) Stress profile of stiffened plate in WS (b) Stress profile of stiffened plate in DB-B 0.9 (c) Stress profile of stiffened plate in CBC-B 0.7.

#### 4. Conclusion

This paper aims to investigate the behaviour of the square stiffened steel plate under confined blast loading through numerical formulation. From the results it was observed that with the increase in stiffener bias or with the reduction in the spacing between the stiffener-plates for the same volume of steel, the deflection can be reduced. In general for an unstiffened plate, the deflection is maximum at the center; by increasing the stiffeners at the center the deflection can be reduced drastically. From the results it is seen that maximum variation in the residual deflection for various bias, reduces to less than 10%. However, with reduced spacing the vibration on the plates can be damped faster and hence can give more fatigue life to the specimen plates. Conclusively, the optimum bias ratio is 0.7 and the

stresses decrease by about 10% for the diagonally biased stiffeners leading to a reduced deformation and increased vibration damping for these plates.

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