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Numerical Investigations on Blast Protection System with Metallic Tube Core Sandwich Panels

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Abstract: - **Effect of blast loads from explosion can be mitigated by using thick armor systems that are often heavy and significantly increase the self-weight of the structure. In the design of structure for blast protection, sacrificial claddings which consist of high energy absorbing elements are used. A sandwich type protective structure consists of light weight core which is often used for blast mitigation. The choice of core type has an influence on the performance of sandwich panel. The cores can be of wood, foam material and tubular elements. In this study, behavior of sandwich panel with square tubular core is investigated through numerical studies. Panel is made of mild steel having top plate dimension of 150 mm x 150 mm x 2.5 mm; bottom plate of 150 mm x 150 mm x 5 mm and square tube core of 12.5 mm x 12.5 mm with 0.6 mm thickness. A finite element model is developed and validated using experimental results in literature. Parametric studies are carried out using the validated finite element model. By varying the tube length of the core, the responses of the panels in terms of energy absorption and reaction forces are compared.**

KEYWORDS: - **Blast loading, Reaction forces, Tube core sandwich panel, Energy absorption.**

I. INTRODUCTION

The analysis and design of structures subjected to blast loads require understanding of blast phenomena and dynamic response of structural elements [1]. For blast resistant structures efficient energy absorbing material/structural configuration is preferred Sandwich panel with honey comb, square, folded plate, pyramidal, corrugated and diamond cores are commonly used as energy absorbers. Sacrificial cladding layers are used for blast mitigation [2]. They have investigated both experimental and analytically the sacrificial layered structure with mild steel web plates. The cladding structures are mainly designed in such a way that the forces transferred are controlled to an extent in the protective structure. Core height and face plate thickness influences the response of honeycomb sandwich panel [3]. Optimum mass distributions for blast mitigation through sandwich plates are investigated by maximizing the impulse capacity while limiting the back face acceleration. Constraints in development of protection system for existing structure should not produce additional weight to the foundation [4]. By varying the mass ratio between the face sheets and the core, it influences the behavior of the sandwich panel [5]. Due to increase in absorption capacity of the protective layer, the forces on the main structure may be reduced. Protective layers with a large absorption capacity which transfer forces less than the elastic limit of the primary structures are preferred. In blast applications, buckling of a tube core will limit the energy absorption capacity; the structural integrity of primary structure may be compromised. Thus square tubes are used as effective energy absorber. In this study, numerical investigations are carried out by using the metallic tubular elements in sandwich panel against blast loads. The main objective of this investigation is to reduce the energy transmission to the protected structure.

II. PROPERTIES

2.1 MATERIAL PROPERTIES

Mild steel is used for all the elements of the sandwich panel. The stress strain data used in the simulation is obtained from uni-axial tensile tests. The Young’s modulus is taken as 210 GPa and initial yield stress of the steel used in this study is 259 MPa. Mild steel exhibits linear elastic and strain hardening behavior, subjected to plastic deformations. According to Cowper-Symonds, the strain rate effect on mild steel is obtained by Eqn (1).

$$\frac{\sigma}{\sigma o} = \left[1 + \left(\frac{\varepsilon}{D}\right)^{1/q}\right] \qquad (1)$$

where σ_d – Dynamic yield stress
σ_o – Static yield stress
$\acute{\varepsilon}$ – Strain rate

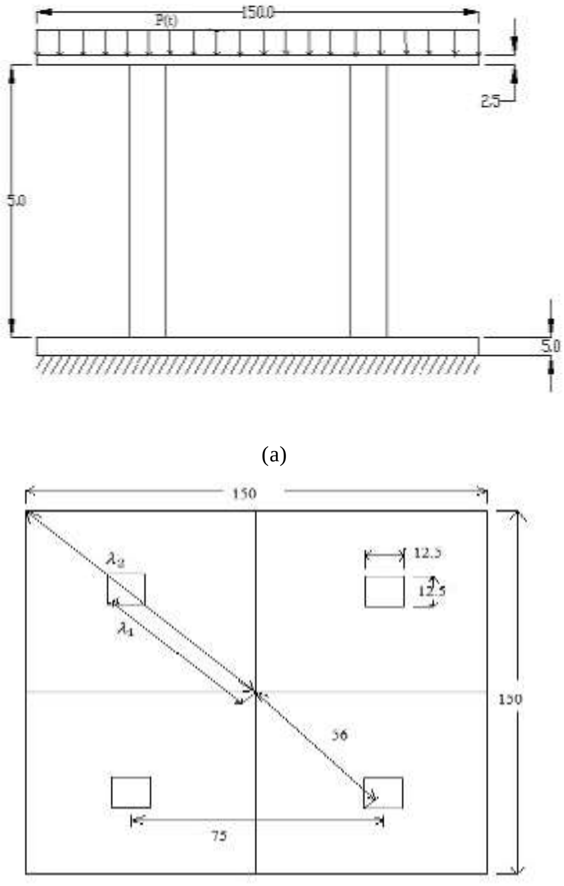
D & q are material parameter where $D = 844\ s^{-1}$ and $q = 2.207$ which are found to be experimentally using locally available steel [6].

Strain rates are taken based on the theoretical approximations of the strain rate in the folding of square tubes. Density and Poisson’s ratio of mild steel are taken as 7850 kg/m^3 and 0.3 respectively. Specific heat of the panel is taken to be 452 J/kg° C. Tangential friction is given as $\mu_k = 0.3$[7].

2.2 GEOMETRICAL PROPERTIES

Panel geometry has a significant effect in energy absorbing properties. The behavior of sandwich panel using square tubes has been investigated in the presence of circular cutout in the tube face. The cutout diameter is taken as the 1/4th of the mean width of the tube. These studies investigate the response of panel structure by modifying the critical variables [8].

In this study, the top and bottom plate area is 150 mm x 150 mm. Tube size of 12.5 mm x 12.5 mm with thickness of 0.6 mm [9]. The variable $\lambda = \lambda_1 / \lambda_2$, where λ_1 & λ_2 are as shown in Fig. 1, that defines position of the tube in the panel. Top plate thickness of the panel is of 2.5 mm and bottom plate thickness of panel is 5 mm. Fig. 1 shows the typical cross section of the sandwich panel.



(a)

(b)

Fig. 1 Schematic diagram the sandwich panel (a) Elevation (b) Plan view

III. FINITE ELEMENT MODELLING

3.1 LOADING CONDITIONS

The modelling has been done in ABAQUS/CAE. The characterization of blast load is defined using Eqn (2). The equation represents the rectangular pressure pulse.

$$P(t) = \begin{cases} P_0, & 0 \le t \le t_0 \\ 0, & t > t_0 \end{cases} \qquad (2)$$

where P_0 is the peak pressure of the applied load and t_0 is the pulse duration.

Impulse is assumed to be I= 55Ns. The blast load applied is to distribute uniformly in the form of pressure. The pulse duration depends on the pressure exerted and the face plate area and the corresponding setup is described in [8]. Pulse duration t_0 is calculated as 17.32μs [8]. The applied pressure is calculated using the formulae $P_0 = I/At_0$. Fig. 2 shows the loading pattern on the panel in the simulation.

3.2 BOUNDARY CONDITIONS

Boundary conditions of the panel have significant effect on behavior of plates and tubes regarding buckling. Top plate is free for all degrees of freedom and bottom plate is fixed in space. The ends of the tube are clamped with both the plates as in Fig. 2.

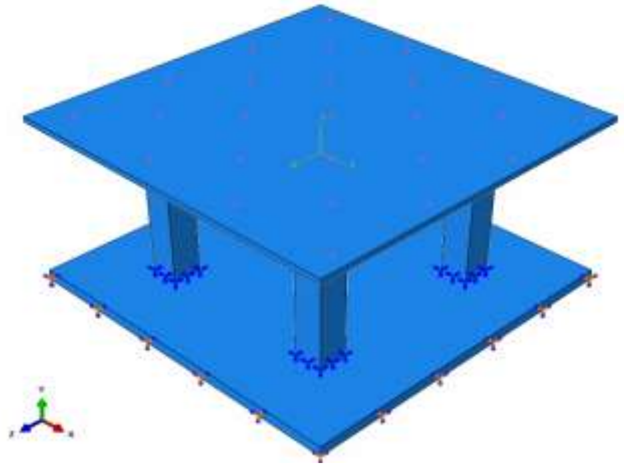


Fig. 2 Loading and Boundary conditions

3.3 MESHING

The panel is modeled using mesh elements in ABAQUS/CAE. Bottom plate is fixed rigid. Top plate is meshed using 8 noded brick element (C3D8R) and tube core is meshed using 4 noded shell elements (S4R). Finite element model of the panel is shown in Fig. 3.

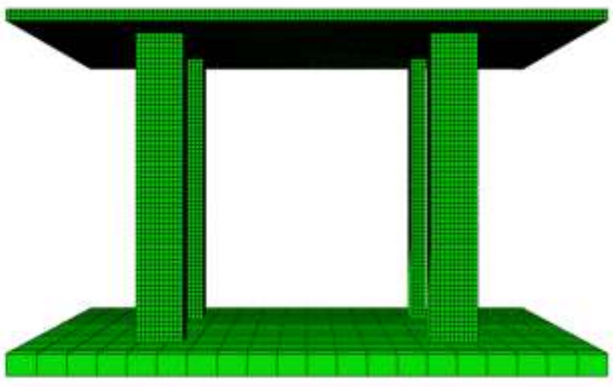


Fig. 3 Finite element meshing of the sandwich panel

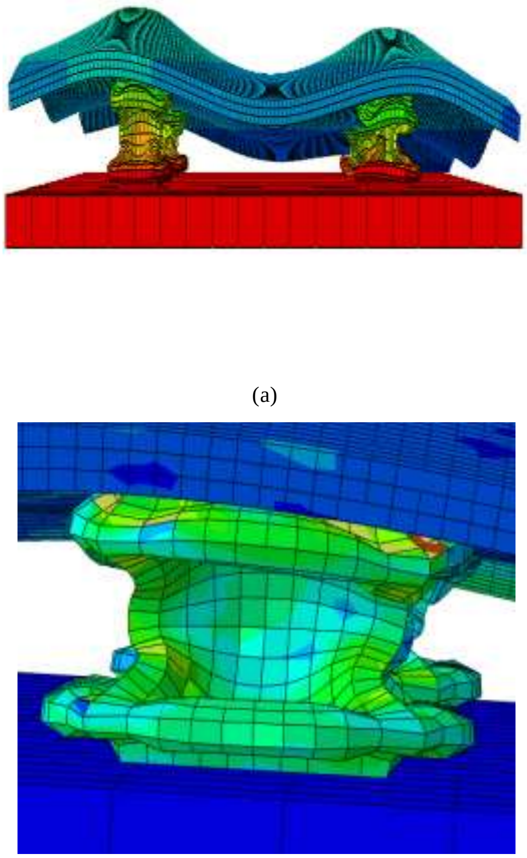
IV. VALIDATION OF RESULTS USING LITERATURE

Numerical model is validated with the response of the panel available in literature [8] for blast load. The deformation pattern of tube length of 50mm, 75mm, 100mm is shown in Fig.4,5 & 6 respectively.

Deformation of the tube is 12% less when compared to that in literature. By varying the tube length of the validated model it is concluded that lesser the tube length more the deformation. Energy absorption of the plate is predicted to be 10.58% more when compared to that in literature and for tube it is predicted that energy absorbed is approximately same.

Table 1 Results obtained from FEA

Description	Tube deformation, mm	Energy Absorption, J	
		Plate	Tube
Reference(Theobald et al., 2007)	58.25	482	2700
Tube length of 75 mm	50.91	431.00	2722.26


(a)

(b)

Fig. 4 Deformation of 50mm tube length (a) Overall view (b) Closed view of the tube

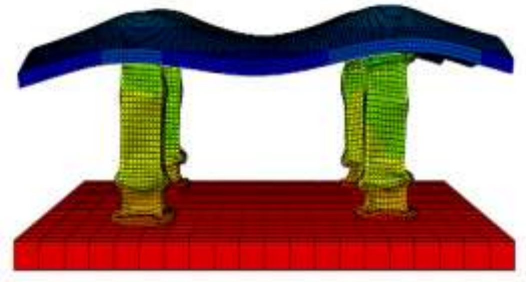


Fig. 5 Deformation of 75mm tube length

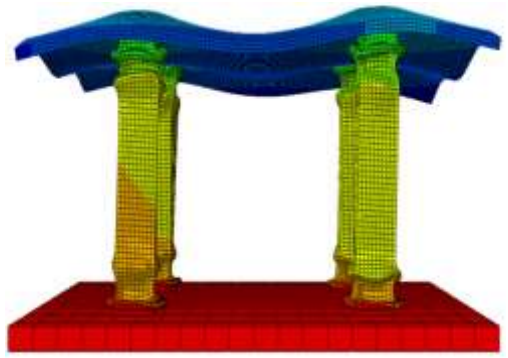


Fig. 6 Deformation of 100mm tube length

V. PARAMETRIC STUDIES

Parametric study is carried out varying the tube length to 50mm and 100mm. Variation of tube length is based on the ratio of tube length to width ratio. This tube aspect ratio ranges between 4 and 6. The geometric parameters used in the study are chosen based on reasonable manufacturing and experimental constraints.

Table 2 Variation in tube length

Parameter	Tube length / Tube width	Value, mm	
		Tube length	Tube width
Tube length	4 6 8	50 75 100	12.5 12.5 12.5

Table 3 Results from tube length variation

Tube length (mm)	Tube Deformation (mm)	Energy Absorption in tube (J)	Mean Reaction Force (kN)
50	21.97	2650.12	16.44
75	50.91	2722.6	11.23
100	48.84	2878.4	13.80

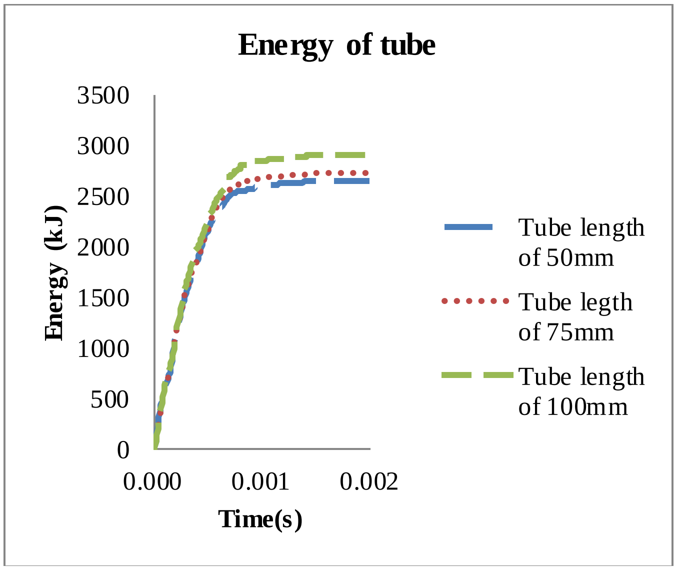


Fig.7 Time variation of energy absorption

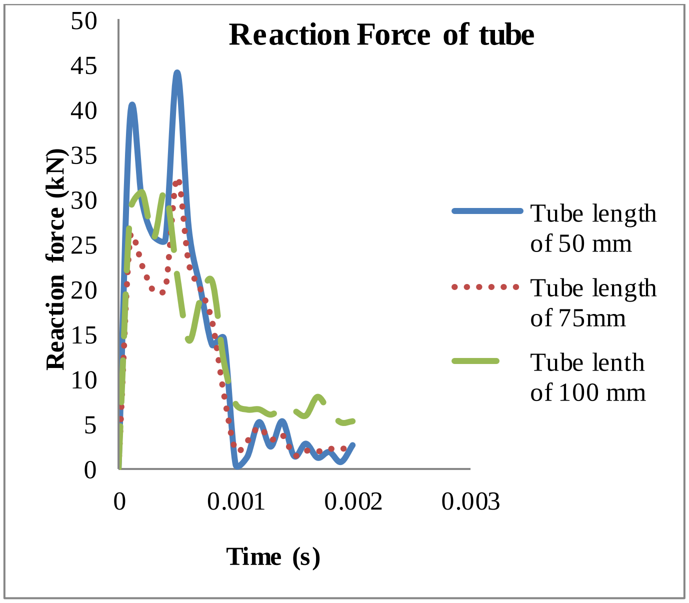


Fig.8 Time variation of reaction force at bottom plate

VI. CONCLUSION

Numerical investigations are carried out on sandwich panel with tube cores. It is observed that the tube deformation, energy absorption and reaction force at bottom plate varies with change in tube length. The reaction force and tube deformation are highly sensitive to the tube geometry. Energy absorption is found to decrease with reduction of tube length. Tube length of 100 mm shows lateral bucking instead of crushing of tube core and also the reaction force is 18.64% more when compared to 75 mm tube length. From the numerical investigations, the panel having 75 mm tube length is found to be more effective under an impulse of 55 Ns.

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