Blast Response Studies on Metallic Tube Core Sandwich Panels

S. Chaithanya Raja#1, Dr. J. Rajasankar*2, Dr. J. Guru Jawahar#3

[1](Master of Technology, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati, Jawaharlal Nehru Technological University, Anantapur - 515002, Andhra Pradesh, India.#1 Corresponding author)
[2](Chief Scientist, Shock and Vibration Department, SIR-SERC, Taramani, Chennai - 600113,Tamil Nadu, India)
[3](Head of the Department, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati, Jawaharlal Nehru Technological University, Anantapur - 515002, Andhra Pradesh,India.)

ABSTARCT-*Blast loading produces enormous amount of energy. It causes devastation effect to the structure that is subjecting to loading. It is essential to mitigate the blast load to make the structure sustainable and safe. Research has been carried out from decades to design protective structural member for mitigating blast loading. Sandwich panels are found out be one of such efficient structural component to be installed for periphery of structure on which blast loading is acting. In the present work effort is made in designing sandwich panel with top and bottom plates. The dimensions of 150 mm×150 mm with 4 square tubes of 12.5 mm×12.5 mm and thickness of tube of 0.6 mm in 2×2 matrix in core portion are provided. Impulse of 55 Ns is applied for duration of 17.32 μs normal to the top plate of sandwich panel. Suitability of the sandwich panel model for the present loading condition is checked. Finite element (FEM) model of the panel is modelled in FEM based software ABAQUS/CAE and analysis is done. Parametric studies are carried out by varying the thickness of square tube and spacing between the square tubes. The efficiency of sandwich panels are checked in terms of Reaction force per unit area (kN/mm^2) and Energy (kJ) absorbed by top plate and core portion. An important conclusion from the parametric studies is drawn i.e., increase in the tube spacing beyond an optimum value results in excessive deformation without progressive lobe formation. From conclusions the model that is capable of taking load effectively is finalized.*

Keywords—*Blast protection, Tube core claddings, Blast load, Thickness, Spacing, Energy absorption, Reactions.*

I. Introduction

Blast loading is an instantaneous fission reaction of the explosive materials like Cyclo Trimethylene Trinitramine (RDX), Compound B (60 % RDX and 40 % TNT), Tri Nitro Toluene (TNT) and Cyclonite etc. These explosive materials cause potential damage to the structures thereby causing damage to the residents. So, in order to protect the structure from blast loading protective structural component should be designed. It should be fixed to periphery of the structure without adding much weight to the foundation as structure is designed for certain live loads and dead loads [1]. With increase in loads on foundation by adding weight to the structure cause major damage to the structure. Tube core sandwich panel is one of such structural component with minimum weight of tubular material in core portion. These are also called as sacrificial claddings [2] that mitigate the dynamic loading due to blast effect thereby keeping structure in safe condition. The optimum design [3], [4] for metallic corrugated core sandwich panel for blast loading is essential. Tube core panels with core component of tubular material [5], [6] are effective protective system for blast loading. The square steel tubes in core portion are subjected to compression. The sandwich panel subjects to axial crushing [7], [8]. Response of sandwich panels with thin walled tubes subjected to axial load [9], [10] should be known to determine its performance ability. The factors like influence of plate thickness and core height [11] determines the behaviour of tube core panel for the load applied. Finite element modelling is the effective method for modelling the sandwich panel [12]. The Finite element model is modelled and analysed in FEM based software ABAQUS/CAE. The obtained results from the model are validated with the results available in the literature (Theobald et al., 2007) and the results are found coinciding. Parametric studies by varying the thickness of square tube in core portion and spacing between the tubes are carried out. The response of panel is studied based on Reaction force per unit area (kN/mm^2) and Energy (kJ) absorbed by tubes is studied.

II. Blast Loading

The instantaneous fission reaction of the explosive materials causes blast loading as shown in Fig.1. Propagation of explosive materials mainly takes place through air and ground. The propagation of reaction is considerably fast in air when compared to that of ground with speed of supersonic wave. The explosive material gets converted to high pressure gas. This high pressure gas causes devastation effects when encountered with structure. Then the structure will receive peak over pressure due to sudden encounter of fast moving shock wave that got push and pull action. The radiated overpressure propagating from point of explosion subjects to exponential decay with time from source. It encounters with structure and eventually becomes negative subjecting the building surfaces to suction forces as vacuum is created by the shock wave. The pressure created will be negative when compared to atmospheric pressure and is called negative pressure. It is as shown in Fig.2.

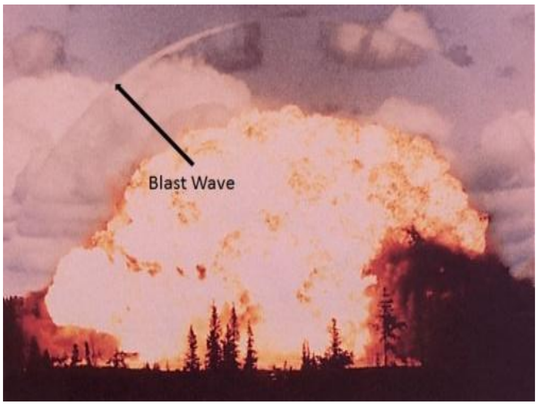

Fig. 1 Blast wave and its propagation

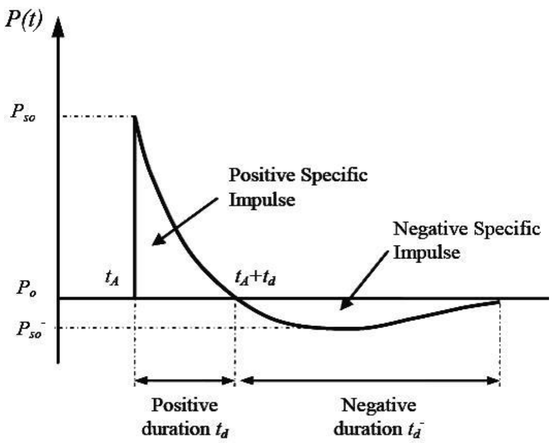

Fig. 2 Blast wave pressure – Time history

P_o = Ambient atmospheric pressure.

P_{so} = Stagnation overpressure.

t_A = Blast wave arrival time.

t_d = Duration of impulse.

Wind plays a major role in increasing the velocity of propagation of wave that accompanies with blast wave and this causes dynamic pressure P_d. It is proportional to the square of the wind velocity and density of the air behind the shock front. The relation of dynamic pressure is shown in Eqn (1) [13].

$$P_d = 0.5\rho u^2 \qquad (1)$$

u = Velocity of the air particle

ρ = Air density.

The intensity of dynamic pressure will be more as it is equal to the square of velocity of air particle. The factors that are determining the intensity of destruction are charge weight Wand standoff distance R from the point of explosion.

III. FINITE ELEMENT METHOD

Finite element method (FEM) is the process of dividing the given structural member in to numerous individual components by discretization. The Finite element method will yield better results by solving complex object to simple geometrical objects [14]. The members' top and bottom plate is discretised to geometrical objects like 8 nodedrectangular solid elements. The hollow square tubes in core portion are discretised to 4 noded shell elements. Based on this displacements and rotations at different nodes of individual elements are obtained from geometrical deformation of the whole sandwich panel. Hence FEM based software ABAQUS/CAE is used in modelling the sandwich panel.

IV. NUMERICAL ANALYSIS

A. DESCRIPTION OF PROBLEM:

To determine the efficiency of the tube core sandwich panel a model is considered with different dimensions of top plate, bottom plate and square tubes in core portion. Material is taken as steel that can effectively withstand the applied pressure and transfer to the core. The top plate and bottom plate are considered of 150 mm × 150 mm with top plate of 2.5 mm thick and bottom plate of 5 mm thick. Square tube is taken as 75 mm long and thickness is taken as 0.6 mm and the blast load is characterized using a rectangular pressure pulse relation described in Eqn (2).

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

Where P_0 is the applied peak pressure and t_0 is the blast duration. Impulse is taken as I = 55 Ns for an impulse duration of t_0 = 17.32μs and A is the area of top plate of 150 mm × 150 mm. The applied pressure is computed using the relation as shown in Eqn (3).

$$P_0 = \frac{I}{At_0} \qquad (3)$$

The top plate is free in all degrees of freedom while the bottom plate is fixed. Both the ends of square tubes are fixed to the top and bottom plate with nodal rotations arrested for tube plate bonding. The model is validated with that of same model available in literature (Theobald et al., 2007);parametric studies by varying the thickness of the square tube to 0.5 mm, 0.625 mm and 1 mm and the spacing between the square tubes to 37.5 mm and 100 mm are carried out. Response of different tube core sandwich panels to the applied impulse of 55 Ns is studied. The plan and elevation of Sandwich panel is as shown in Fig. 3.

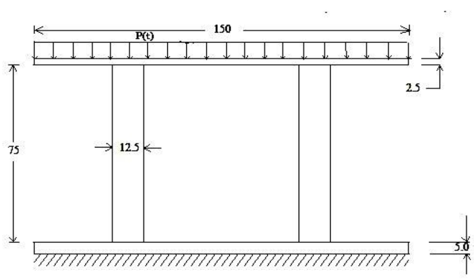

Fig. 3. a. Elevation of tube core sandwich panel

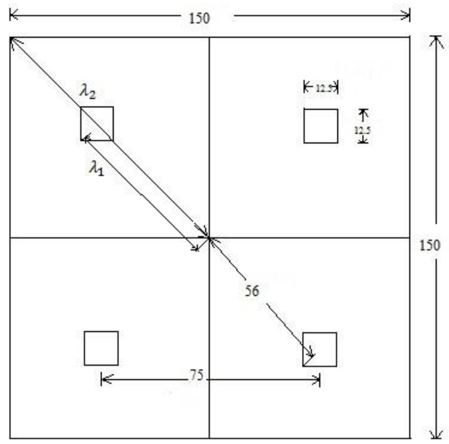

Fig. 3. b. Plan of tube core sandwich panel

Fig. 3 Schematic diagram of tube core sandwich panel

V. FEM SIMULATION

A. ABAQUS/CAE MODELING:

Finite Element Software ABAQUS/CAE is used in modelling tube core sandwich panel. The description of modelling is given here under

B. MODULES AND THEIR USE:

ABAQUS/CAE is divided in to different modules to carry out the function of modelling. Each module concerns to specific function that is assigned. Different modules used in ABAQUS/CAE are:

*1) **Part:***Top and bottom plates are modelled with dimensions of 150 mm × 150 mm and top plate thickness of 2.5 mm and bottom plate thickness of 5 mm. Tubes are modelled with length of 75 mm and thickness of 0.6 mm.

*2)**Property:***Mild steel properties are assigned to the parts modelled. Mass density, Elastic property, Plastic property andSpecific heat property are assigned to the parts. Plastic properties are assigned as per Cowper – Symonds relation as shown in Eqn (4). The properties assigned to the parts are:

Young's modulus, E = 2.07 × 10^5 MPa, Yield stress,σ_y = 259 MPa, Poisson's ratio = 0.3, Density ρ = 7850 kg/m^3, Specific heat = 452 J/kg$^\circ$ C.

$$\frac{\sigma_d}{\sigma_0} = \left[1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{q}}\right] \qquad (4)$$

Where D and q are material properties and they are given as D = 844 s^{-1} and q = 2.207 [15]. The tangential friction is given as μ_k = 0.3 [16] and the properties are, σ_d = dynamic yield stress, σ_0 = static yield stress, $\dot{\varepsilon}$ = strain rate. These properties are mainly used in carrying out the analysis for concerned sandwich panel. The parts due to assigning property are shown in Fig. 4.

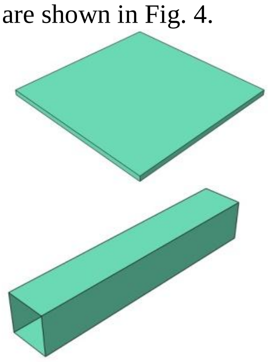

Fig. 4. a. Plate Fig. 4. b. Tube

Fig. 4 Isometric view of plate and tube section due to assigning property

*3) **Assembly:***Assembly module is mainly used for assembling multiple parts created to form Single structural component. The square tubes should be placed in core portion between top and bottom plate in 2 × 2 matrix form as shown in Fig. 5.

*4) **Step:***Dynamic/ Explicit step is created. So that nonlinear analysis takes place with a time period of 0.002 sec.

*5) **Interaction:***Interaction module is mainly used to assign self contact property to square tubes in core portion. The lobe formation in square tubes is made possible due to interaction module as shown in Fig. 5.

*6) **Load:***The pressure loading of 141.32 N/mm^2 should be applied by creating amplitude table for time period of 17.32 μs [17] as shown in Table 1. The pressure should be applied in rectangular pulse mode to create blast loading effect as shown in Fig. 6.

Table 1: Time vs. Amplitude table for time period of 17.32 μs

Time (seconds)	Amplitude (N / mm^2)
0	0
1E-015	141.32
1.732 E-005	141.32
1.7320000000001 E-005	0

7) ***Boundary condition:***The bottom plate is fixed i.e. displacements (U) and rotational components (UR) are constrained. The square tubes edges are constrained to top and bottom plate by keeping UR for the structure to be in fixed condition and displacements should be kept in free condition for free displacement of tube core panel as shown in Fig. 6.

8) ***Finite element mesh:***Meshing should be done to the parts created using mesh module. 8- Noded solid elements C3D8R are used for meshing of top and bottom plates. 4-Noded shell elements called S4R are used for meshing of square tubes in core portion as shown in Fig. 7.

9) ***Job:***The ABAQUS/CAE model that is created should be submitted for analysis using job module. Analysis results in obtaining stresses and displacements at various contour points of the tube core panel.

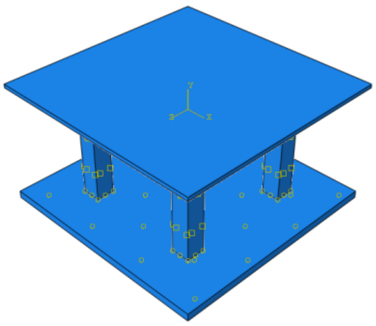

Fig. 5 Interaction property is assigned totube core sandwich panel

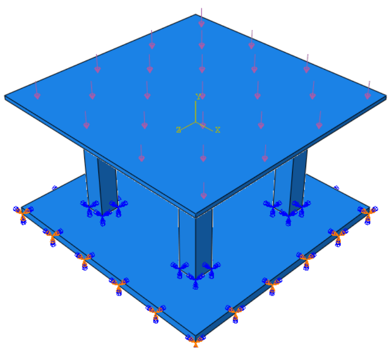

Fig. 6 Loading and Boundary condition given to tube core sandwich panel

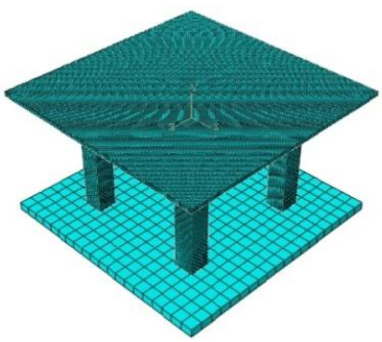

Fig. 7 Meshing assigned to tube core sandwich panel

C.DEFORMATION PATTERN OF SQUARE TUBES:

Pressure loading is applied on the top plate of the tube core panel. The load gets distributed over the entire plate and transfers to the square tubes in core portion. The square tubes reduce the intensity of loading on deformation by forming lobes on the square tubes as shown in Fig. 8. Due to this the intensity of loading transferred to the base plate is reduced and keeping the primary structure to be in safe condition.

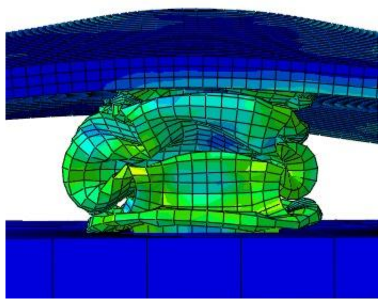

Fig. 8 Deformation pattern of the square tube

VI. NUMERICAL VALIDATION

The ABAQUS/CAE model that is modelled is analysed and is validated with that of model as given in [4](Theobald et al., 2007). The validated Energy (kJ) vs. Time (s) plot is as shown in Fig. 9.

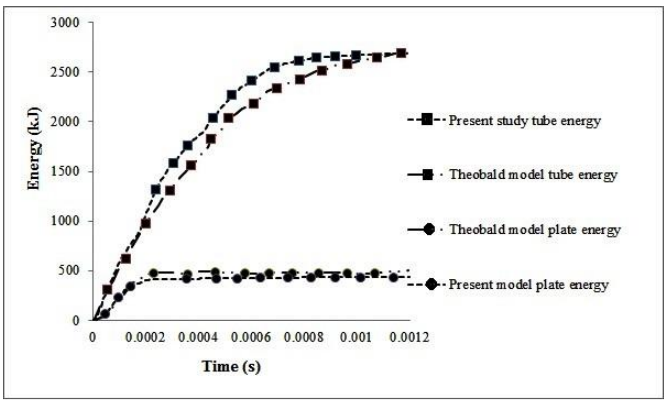

Fig. 9 Comparison of energy absorption curve

The maximum Reaction force per unit area (kN/mm^2) and Energy (kJ) absorbed by top plate and square tubes of ABAQUS/CAE model and the values obtained from the reference model in [4] are given in Table 2.

Table 2. Comparison table of Reaction force (kN) and Energy (kJ)

Description of the study	Maximum Reaction Force (kN)	Energy absorbed (kJ)	
		Top Plate	Square tube
Theobald and Nurick (2007)	99.54	487.12	2690.04

Present study	112.19	442.84	2678.89

VII. PARAMETRIC STUDIES

Parametric studies are carried out by varying the thickness of square tubes and the spacing between the square tubes in core portion. The results corresponding to Reaction force per unit area (kN/mm^2) and Energy (kJ) taken by square tubes in core portion are obtained.

A. VARIATION OF THICKNESS OF SQUARE TUBES IN CORE PORTION:

Different tube core sandwich panel are modeled by varying the thickness of square tubes to 0.6 mm, 0.5 mm, 0.625 mm and 1 mm in ABAQUS/CAE are analyzed. The deformation of models are obtained and are given in Fig. 10.a. to 10.d.

Fig. 10.a. Tube thickness of 0.6 mm

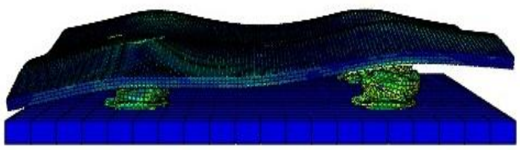

Fig. 10.b. Tube thickness of 0.5 mm

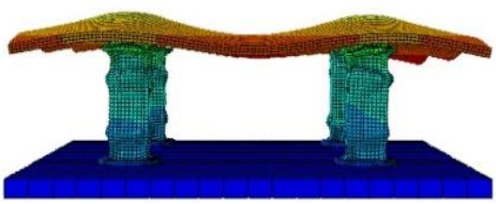

Fig. 10.c. Tube thickness of 0.625 mm

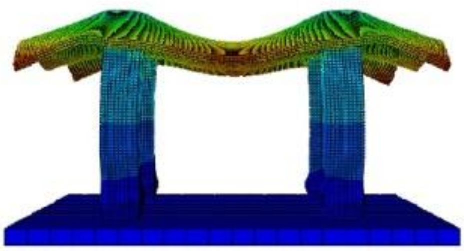

Fig. 10.d. Tube thickness of 1.0 mm

Fig.10 Deformation of sandwich panel with square tubes of various thicknesses

The tube with a thickness of 0.5 mm is undergoing more deformation when compared to the tube with thickness of 0.6 mm and 0.625 mm. while, tube with thickness of 1 mm is undergoing firstly to compression and then it is subjecting to buckling.

B. VARIATION OF SPACING BETWEEN THE SQUARE TUBES IN CORE PORTION:

Other parametric study is also carried out by varying the spacing between the square tubes in the core portion to 37.5mm, 75 mm and 100 mm. The deformation pattern of tube core panels are as shown in Fig. 11.a. to11.c.

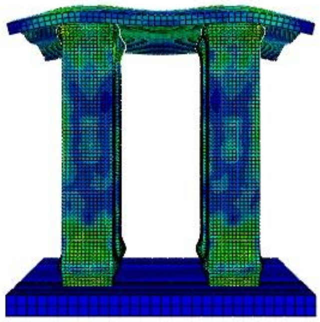

Fig. 11.a. Panel with spacing of 37.5 mm

Fig. 11.b. Panel with spacing of 75 mm

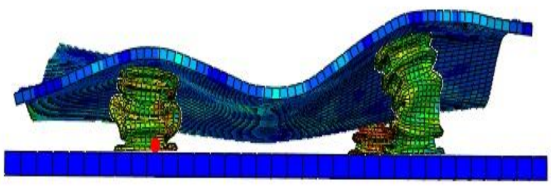

Fig. 11.c. Panel with spacing of 100 mm

Fig. 11 Deformation of sandwich panels of various spacing between square tubes in core portion

If the spacing between the tubes is 37.5 mm then tubes are giving more resistance for the applied load and the Reaction force per unit area (kN/mm^2) on the bottom plate is also more in this case. The tube core panel with spacing of 100 mm is not having progressive deformation.

VIII. RESULTS

The Reaction force per unit area (kN/mm^2) vs. Time (s) and Energy taken by the tubes (kJ) vs. Time (s) for tube core panels of various thicknesses of tubes and various spacing between the tubes in core are plotted and the results are shown in Fig. 12.and Fig. 13.

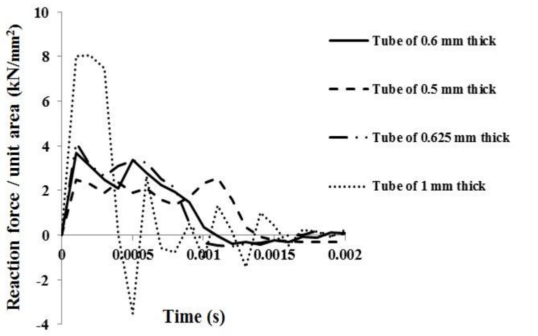

Fig. 12.a. Comparison of RF/Unit area curve

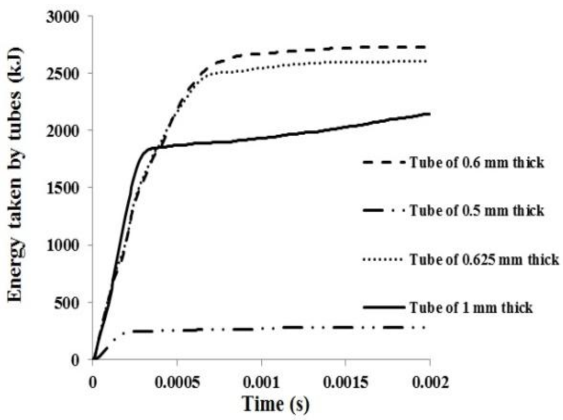

Fig. 12.b. Comparison of Energy absorption curve

Fig.12 Comparison plots of tube core sandwich panels with various tube thickness

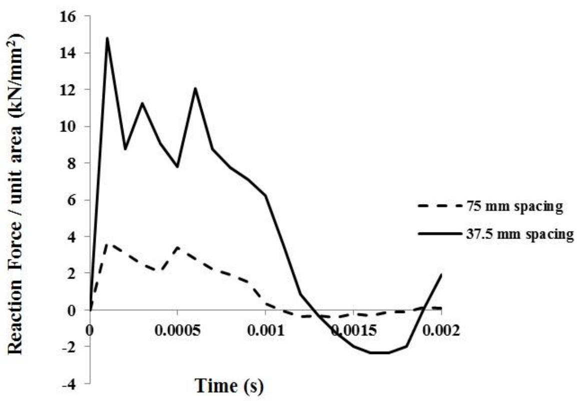

Fig. 13.a. Comparison of RF/Unit area curve

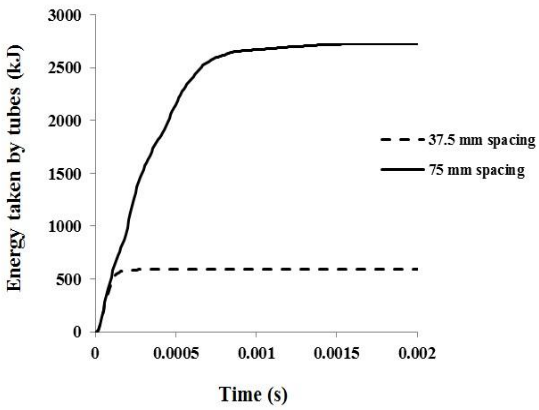

Fig. 13.b. Comparison of Energy absorption curve

Fig.13 Comparison plots of tube core sandwich panels with various spacing between the square tubes

IX. CONCLUSIONS

From the parametric study that is carried out different conclusions are drawn based on the Reaction force per unit area (kN/mm^2) and Energy taken by the tubes (kJ) with in time period of 0.0002 seconds. They are given as:

- Lateral buckling is resulted due to increase in the thickness of the square tubes with more reaction force on bottom plate.
- Decrease in thickness and spacing between the tubes results in less energy absorption of square tubes and more reaction force on bottom plate.
- Increase in spacing between the tubes beyond optimum value cause excessive deformation and no progressive mode formation.
- From the parametric study done tube core sandwich panel with a spacing of 75 mm between the square tubes and tube thickness of 0.6 mm is found to be the optimum model for applied impulse of 55Ns for duration of 17.32 µs.

ACKNOWLEDGEMENT

It is my immense pleasure to express my gratitude to Dr.J. Rajasankar, Chief Scientist, Shock and Vibration Department, CSIR-SERC, Taramani, Chennai. For his valuable guidance to carry out the research, Dr. N. Anandavalli, Principal Scientist, Shock and Vibration Department, CSIR-SERC, For her suggestions and to Dr. J. Guru Jawahar, Head of the Department, Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati. For his supervision for completion of the work.

REFERENCES

[1] S. Bhardwaj, Q. N. Mehraj., *A Review on foundation of buildings and structures*, SSRG International Journal of Civil Engineering (SSRG – IJCE), Issue 3, Vol 2, pp. 4-9, 2015.

[2] S. Guruprasad, A. Mukherjee., *Layered sacrificial cladding under blast loading*, International journal of impact Engineering, Vol 24, pp. 957-973, 2000.

[3] W. Abramowicz, N. Jones., *Dynamic progressive buckling of circular and square tubes*, International journal of impact Engineering, Vol 4, pp. 243-270, 1986.

[4] C.C. Liang, M.F. Yang, P.W. Wu., *Optimum design of metallic corrugated core sandwich panels subjected to blast loads*, International journal of Impact Engineering, Vol 34, pp.134-156, 2007.

[5] M.D. Theobald, G.N. Nurick., *Numerical investigation of the response of sandwich-type panels using thin-walled tubes subjected to blast loads*, International journal of Impact engineering, Vol 34, pp.134-156, 2007.

[6] M.D. Theobald, G.N. Nurick., *Experimental and numerical analysis of tube core claddings under blastloads*, International journal of Impact engineering, Vol 37, pp.333-348, 2010.

[7] X. Zhang, G. Cheng, Z. You, H. Zhang., *Energy absorption of axially compressed thin-walled square tubeswith patterns*, International journal of Thin-Walled structures, Vol 45, pp. 737-746, 2007.

[8] S.R. Reid, *Plastic deformation mechanisms in axially compressed metal tubes used as impact energy absorbers*, International journal of Mechanical sciences, Vol 35, pp. 1035-1052, 1993.

[9] A.A.N. Aljawi, *Axial crushing of square steel tubes*, The 6th Saudi Engineering conference, Vol 3, pp.3-18, 2002.

[10] S. Chung Kim Yuen, G.N. Nurick and H.L. Witbeen, *The response of sandwich panels made of thin walled tubes subjected to axial load*, International journal of protective structures, Vol 2, pp. 477-498, 2011.

[11] Y. Chi, G.S. Langdon, G.N. Nurick., *The influence of Core height and face plate thickness on the response of honeycomb sandwich panels subjected to blast loading*, Materials and design, Vol 31, pp.1887-1899, 2010.

[12] M.M. Younes, *Finite Element Modeling of crushing behaviour of thin tubes with various cross sections*, 13th International conference on Aerospace sciences and aviation technology, Vol ST 34, pp. 7-19, 2009.

[13] G.F.Kinney and K.J.Graham., *Explosive shocks in air*, Springer Verlag, New York, 1985.

[14] Z. Zhang, B. Andrawes, J.R. Edwards., *Parametric study on the distribution of longitudinal load in railway track under dynamic wheel loading using finite element analysis*, SSRG International Journal of Civil Engineering (SSRG – IJCE), Issue 5, Vol 2, pp. 28-41, 2015.

[15] S.T. Marias, R.B. Tait, T.J. Cloete,G.N. Nurick., *Material testing at high strain using the split Hopkinson pressure bar* , Latin Am J Solids Struct; 1: pp. 319-39, 2004.

[16] P.Nannuci, N.S. Marshall, G.N. Nurick., *A computational investigation of the progressive buckling of square tubes with geometric imperfections*, In: Lok TS., Editors. Third Asia-Pacific conference on shock and Impact loads on structures under shock and impact, pp. 155-168, 1998.

[17] N.Anandavalli, J.Rajasankar., *Effectiveness of tube core sandwich panel in structural protection against blast loads*, 5th International Congress on Computational Mechanics & Simulation, pp. 749-759, 2014.