

Comparison of Energy Absorption of Tube with Asymmetric Triggers when Impacted from Different Sides

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ABSTRACT: Over the past several decades increasing focus has been paid to the use of impact energy absorbers, devices designed to dissipate energy during an impact event and hence protect the structure and occupants under consideration. Thin-walled columns have a high energy absorption capability and therefore have played an important role in vehicle crashes. The absorption of energy is controlled by the plastic work in the crash box. Both less weight and the good crushing performance have to be established from the demand of energy saving and safety. In this research work, a rectangular tube of hot rolled mild steel with 2.5 mm thickness is subjected to axial and oblique impacts. Quasi-static analysis is done for axial loading. Mean load is taken as a parameter for validation of model. Modeling and meshing is done in HYPERWORKS software while LS-DYNA is used as a solver. The energy absorbing capability of obliquely loaded rectangular tube for 15 m/s with asymmetric triggers and a plane impacting from different sides for different loading angles is studied. Different parameters of energy absorption are observed during analysis.

KEYWORDS: Energy absorption, Oblique loading, Triggers, Mean load, Peak Load.

I. INTRODUCTION

Nowadays, vehicles are used extensively and a large number of horrible accidents related to them occur widely. Increasing the safety for passengers is a valuable aim and a lot of investigations are carried out in this region. Using energy absorbers is an appropriate option for this purpose. These parts have different shapes and are made from low density materials. In designing these parts, investigation of their collapse behavior and energy absorption capacity is necessary and a wide variety of studies is done about these structures, especially about thin walled tubes.

The use of thin-walled tubes collapsing plastically in axial compression is considered one of the most efficient means of energy absorption. These tubes are light in volume and weight, easy to fabricate and cheap, and stable during crushing. Crashworthiness studies devote a great deal of attention to the behavior of thin-walled structures, which have been widely used as load bearing structures as well as energy absorbers. One type of energy absorber is the crash box or crush tubes or energy absorbing tubes, which is connected to the bumpers, situated in the front and rear end of the body structure. Fig. 1 shows the position of crash box and bumper. The crash box is designed to absorb energy at low speed impacts.

There are different types of loading conditions they are (a) Axial loading (b) Oblique loading (c) Lateral loading. More realistic condition is oblique in nature. Fig. 2 shows the. In oblique collapse of the tube, there are three typical regions of oblique load angle. The first is the axial collapse dominant region, the second is bending collapse dominant region and the last is the transition region from axial collapse to bending collapse [7].

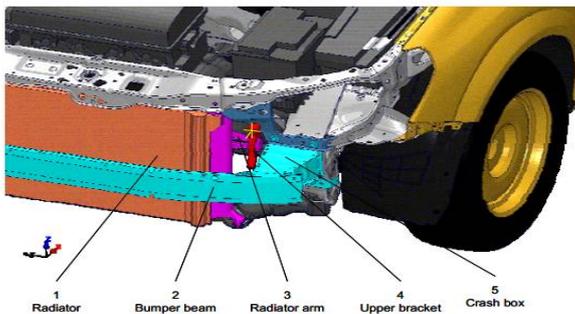


Fig. 1: Positions of Crash box and Bumper beam

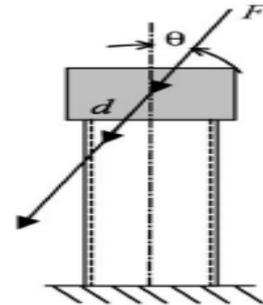


Fig. 2: Oblique loading of column [9]

Triggers: Triggers or buckling initiators are nothing but weak areas created in the tube in order to make the progressive folding of the tube. There are various types of triggers they are 1) Hole type rectangular shape 2) Diamond notch 3) Circular notch 4) Spheres etc. According to location of trigger they are classified as a) Edge triggers b) Side triggers. It is concluded that edge triggers are more effective as compared to side triggers. According to the position of the triggers they are classified as (a) Symmetric (b) Asymmetric. Sym-2 type refers to a specimen with two pairs of opposite triggers. Asym-3-R-type refers to a specimen with three asymmetric triggers in which the upper one is located at the right [8]. Fig. 3 shows square column with edge and side triggers. Fig. 4 shows specimens with symmetric and asymmetric triggers.

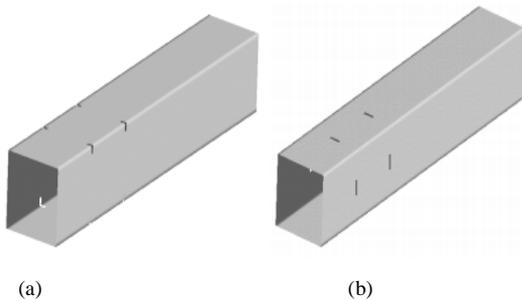


Fig. 3: Square column with (a) Edge triggers (b) Side triggers [7]

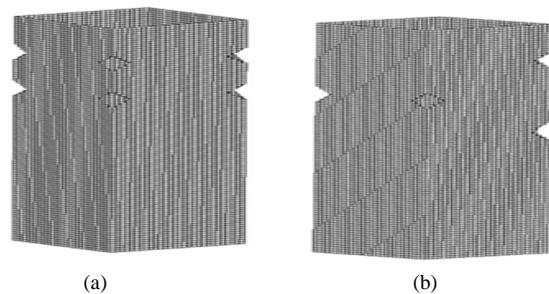


Figure 4: Specimens with triggers (a) Sym-2-type (b) Asym-3-R-type [8]

Terms related to Energy Absorption

Peak load (P_{max}): Peak load is the maximum force required for the loading and occurs when first folding occurs.

Mean crushing load (P_{mean}): Mean load is obtained by dividing the measured absorbed energy to the total crushing distance.

Crush force efficiency (CFE): Crush force efficiency is the ratio of mean load to peak load.

Energy absorption (E_{abs}): Energy absorbed is nothing but the area under the load -deflection curve.

II. LITERATURE REVIEW

A. Siva Kumar et al. [1] studied crush box components having different cross sections. Firstly experimental tests and numerical analysis were carried out on the crush box in order to better understand their behavior and model them properly. Secondly, some additional reinforcement and foam types were added in order to satisfy different segments of car. Difference between the segments was taken as mass. The simulation of the crush itself was done by means of the LS-DYNA. Results showed that square and rectangular profile have significant lower energy absorption than the other profiles. The bead initiator must be preferred as most suitable trigger form with good efficiency. Crush box with foam material and additional parts can be used with cars with high mass and without foam and additional parts can be used in small cars.

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Minoru Yamashita et al. [2] axially compressed the aluminum tubular structure with hat-shaped cross-section and buckling initiator using inertia force under the dynamic or quasi-static condition. The tubular structure was assembled with two parts using the blind rivet or the epoxide adhesive. Results showed that the predicted crush strength is about 35% greater than that in the experiment for the riveted tubular structure and it is only 10% smaller for the bonded structure. Buckling initiator worked successfully without decreasing the energy absorption efficiency of the structure also the damaged or plastically deformed region except for the lobes becomes narrower.

X.W. Zhang et al. [3] studied axial crushing of the circular tubes with buckling initiators which is installed near the impact end of the circular tube. The buckling initiator consists of a pre-hit column and several pulling strips uniformly distributed around the top edge of the tube. By using two kinds of aluminum-alloy circular tubes, a series of quasi-static compression tests were conducted. The results showed that the buckling initiator could effectively reduce the initial peak force and retain the excellent energy absorption of the circular tube also the deformation mode of the axial crushed circular tube switches from ring mode or mixed mode to diamond mode. The initial peak force could be reduced by more than 30%.

Recep Gumruk et al. [4] carried out the numerical investigation to study the effect of the geometrical features of bump type trigger on the crush behavior of an energy absorbing member subjected to axial impact loading. The finite element solver, LS-DYNA was used in all crush simulations. The result showed that trigger mechanism can be used to control the crush response of the member and the right combinations of the size, location and the number of triggers is critical to have a controllable, stable and predictable crash response. The peak load decreases with the introduction of a trigger also the peak crush force decreases with the increase in the height of the trigger. The fillet and trigger radii have no appreciable influence on peak crush force.

S. J. Hosseinipour et al. [5] studied axial compression of thin-walled steel tubes containing annular grooves. Quasi-static axial crushed tests were performed and the load-displacement curves were studied. A groove-less specimen tube was taken into account for comparison purposes. Results showed that the quality and the quantity of the load-displacement curve and energy absorbed by the axial crushing of tubes could be controlled by the introduction of grooves with different distances and for controlled behavior of energy absorption device, grooved tubes would be a favorable choice. The theoretical formulations showed good agreement with the experimental findings indicating that strain hardening has important effect on the results.

III. VALIDATION OF FINITE ELEMENT MODEL

A) Mean Load

W.Abramowicz and N.Jones proposed the expression for quasi-static mean load (P_m) for rectangular tube. The equation which is applicable to square tube produced reasonable results for the validation of analysis of the rectangular tube. Here perimeter of rectangular and square tube is same. Many of the researchers have used for rectangular tube. Mean load is an appropriate criterion to find energy absorption capacity of an absorber.

$$P_m / M_o = 52.22 \times (c/h)^{1/3}$$

Here,

c= side lengths of tube = (110 + 60)/2 =85 mm &

h= thickness of tube = 2.5 mm

M_o = fully plastic bending moment per unit length for sheet metal

$M_o = (\sigma_0 \times h^2)/4$ Here σ_0 is yield stress of the material

Thus,

$$\sigma_0 = (\sigma_{0 \text{ yield}}) = 293.8 \text{ MPa}$$

$$M_o = (293.8 \times h^2) / 4$$

$$= (293.8 \times (2.5)^2) / 4$$

$$= 459 \text{ MPa}$$

$$P_m / M_o = 52.22 \times (c/h)^{1/3}$$

$$P_m = 459 \times 52.22 \times (85/2.5)^{1/3}$$

$$P_m = 77650.190 \text{ N} = 77.65 \text{ KN}$$

Mean load for Quasi-static loading = 77.65 KN

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B) Finite Element analysis

Finite Element analysis is carried out using nonlinear explicit software LS-DYNA

Modeling and Meshing: The rectangular tube and the rigid plate are modeled with 2D shell elements using HYPERWORKS software. Meshing is done using Belytschko Tsay shell element. Material used for tube is mild steel of 2.5 mm thickness. The length, width and height of the tube are taken as 250mm, 60mm and 110mm respectively. Fig. 5 shows meshed model of the tube for quasi-static loading.

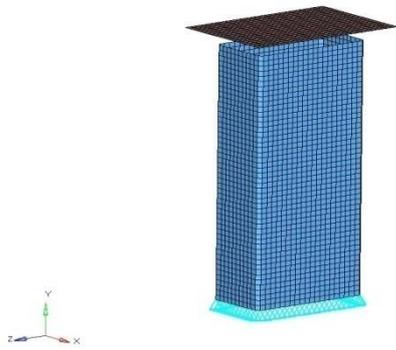


Fig. 5: Meshed model of the tube for quasi-static loading

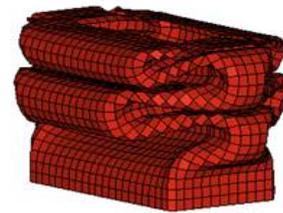


Fig. 6: Deformed shape of the crash box for quasi-static loading

The element size used is 5mm x 5mm [6] and a fillet of 3mm is given at the corners of the model. Number of elements and number of nodes generated are 3760 and 3873 respectively.

Boundary conditions and Load conditions: The tube is constrained at the bottom in all translational and rotational directions. The Rigid plate is given prescribed velocity of 10mm per minute in vertically downward direction of rectangular tube. For quasi-static analysis no mass is considered for plate.

Energy absorption and mean load: Fig. 6 shows deformed shape of the crash box for quasi-static loading. It is observed that for quasi-static loading the tube gets deformed in regular pattern. Energy absorption takes place during progressive folding.

From the data points load-deflection curve is obtained. Load vs. Deflection curve is as shown in the figure 7. Area under the curve is the energy absorbed by the tube which is determined using Microsoft Excel software. The energy absorbed by the tube under quasi-static impact loading is 14358.04 J.

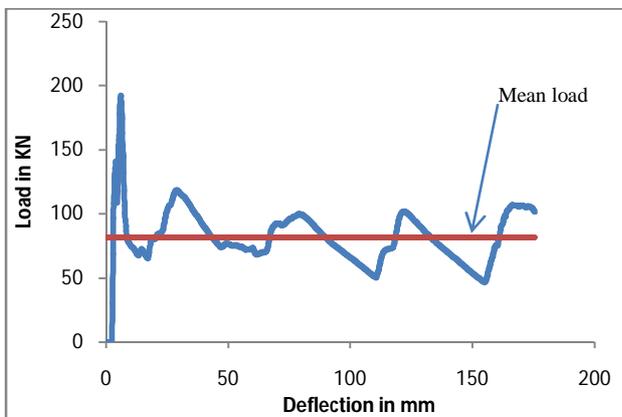


Fig. 7: Load vs. Deflection curve of quasi-static analysis

Table 1: Comparison of Mean load values

Type of analysis	Mean crushing load		
	Analytical (for square tube) (KN)	F.E.A. (for rectangular tube) (KN)	Difference %
Quasi-static	77.65	81.83	4.18

C) Comparison of Results: Analytical solution of square tube is validated with F.E.A. of rectangular tube and it gives reasonably good results. Table 1 indicates the comparison of analytical results and F.E.A. results.

IV. ENERGY ABSORPTION OF TUBE WHEN IMPACTED FROM FIRST (TOP) TRIGGER SIDE

Model consists of two parts the tube and rigid plate. The rectangular plate with asymmetric triggers and the rigid plate are modeled with 2D shell elements. The rigid plate is impacted from first (top) trigger side. The element size used is 5mm x 5mm [6] and Belytschko Tsay shell type of element is used. The tube is constrained at the bottom in all translational and rotational directions. A coefficient of friction $\mu=0.1$ is considered between the rigid plate and tube and also between the tube surfaces. The rigid plate is given initial velocity of 15m/s in vertically downward direction and mass applied to the plate is 125kgs. The rigid plate is inclined at various loading angles from 0° to 30° in the steps of 5° and both inertia and strain hardening effect is considered. Number of elements and nodes generated are 3715 and 3864 respectively.

The position and location of the triggers for the tube when impacted from different sides is as shown in the fig. 8. In the figure case1 means rigid plate impacted from first (top) trigger side and case 2 means rigid plate impacted from opposite to first (top) trigger side.

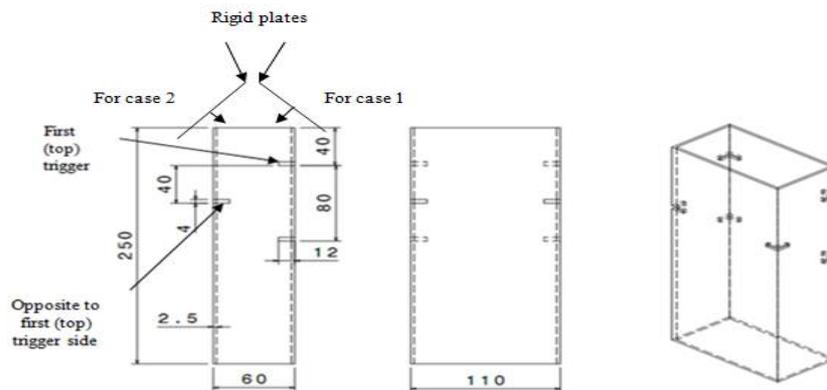


Fig. 8: Position of the triggers in the model impacted from different sides

Fig. 9 shows model of the tube when impacted from first (top) trigger side. From the data points obtained load deflection curves for different loading angles is plotted for the tube with triggers and impacted from first (top) trigger side is as shown in the fig. 10.

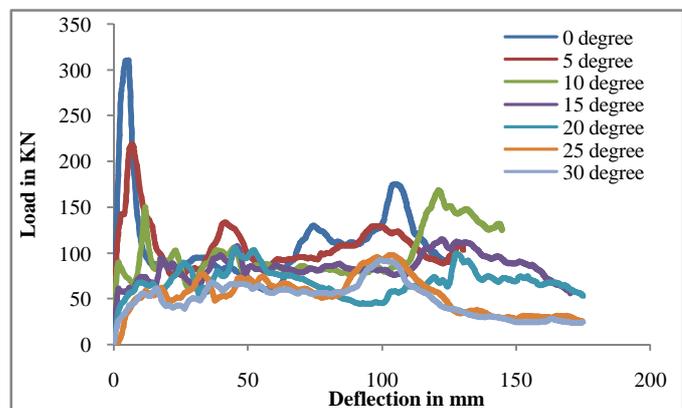
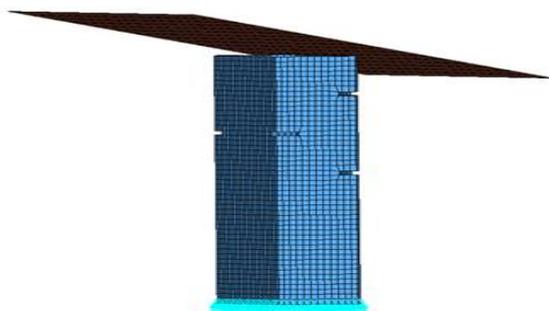


Fig. 9: Model of the tube when impacted from first (top) trigger side

Fig. 10: Load vs. Deflection curve for tube impacted from first trigger side

International Journal of Innovative Research in Science, Engineering and Technology

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It is observed that as the load angle increases the peak load decreases and at the end for 25° and 30° it remains constant. Deflection of the tube is restricted up to 70% of the total length of the tube. There is very large reduction in peak load for increasing load angles. The results are shown in the table 2

V. ENERGY ABSORPTION OF TUBE WHEN IMPACTED FROM OPPOSITE TO FIRST (TOP) TRIGGER SIDE

Model consists of two the tube and the rigid surface representing the crushing surface. The rectangular tube with asymmetric triggers and the rigid plate are modeled with 2D shell elements. The rigid plate is impacted from opposite to first (top) trigger side. The element size used is 5mm x 5mm [6]. The tube is constrained at the bottom in all translational and rotational directions. For both the components, no. of integration points is used as 5 and Belytschko Tsay shell type of element is used. A coefficient of friction $\mu=0.1$ is considered between rigid plate and tube also same value incorporates between the tube surfaces. The rigid plate is given initial velocity of 15m/s in vertically downward direction and mass applied to the plate is 125kgs. The rigid plate is inclined at various loading angles from 0° to 30° in the steps of 5° and both inertia effect and strain hardening effect is considered. Figure 8 shows the position and location of the triggers for the tube when impacted from opposite to first (top) trigger side. Fig. 11 shows model of the tube when impacted from opposite to first (top) trigger side.

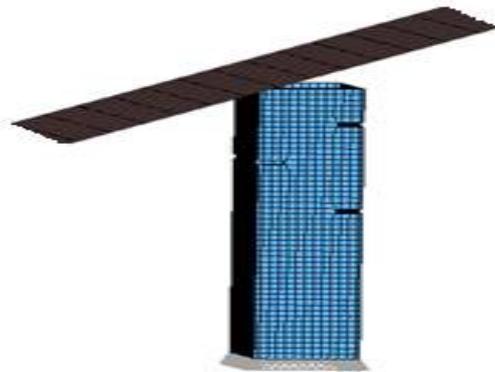


Fig. 11: Model of the tube when impacted from opposite to first (top) trigger side

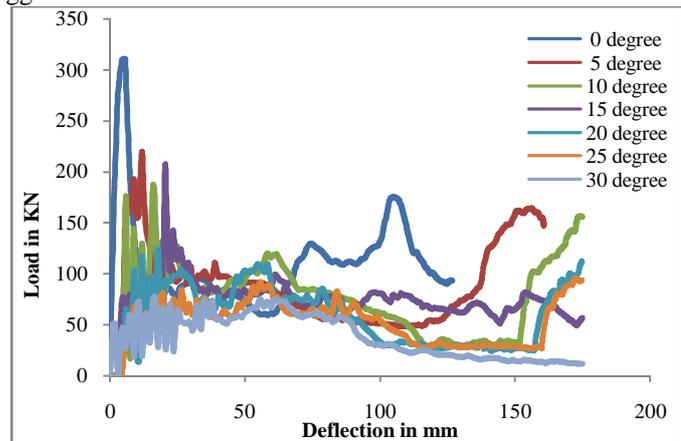


Fig. 12: Load vs. Deflection curve for tube impacted from opposite to first (top) trigger side

From the data points obtained load deflection curves for different loading angles is plotted for the tube with triggers and impacted from opposite to first (top) trigger side is as shown in the fig. 12.

It is observed that as the load angle increases the peak load decreases and at the end for 30° it remains constant. Deflection of the tube is restricted up to 70% of the total length of the tube. There is very large reduction in peak load for increasing load angles. The results are shown in the table 2.

The deformed shapes of the tube for the tube without trigger, for the tube with trigger when impacted from first (top) trigger side and for the tube with trigger when impacted from opposite to first (top) trigger side is as shown in the fig. 13.

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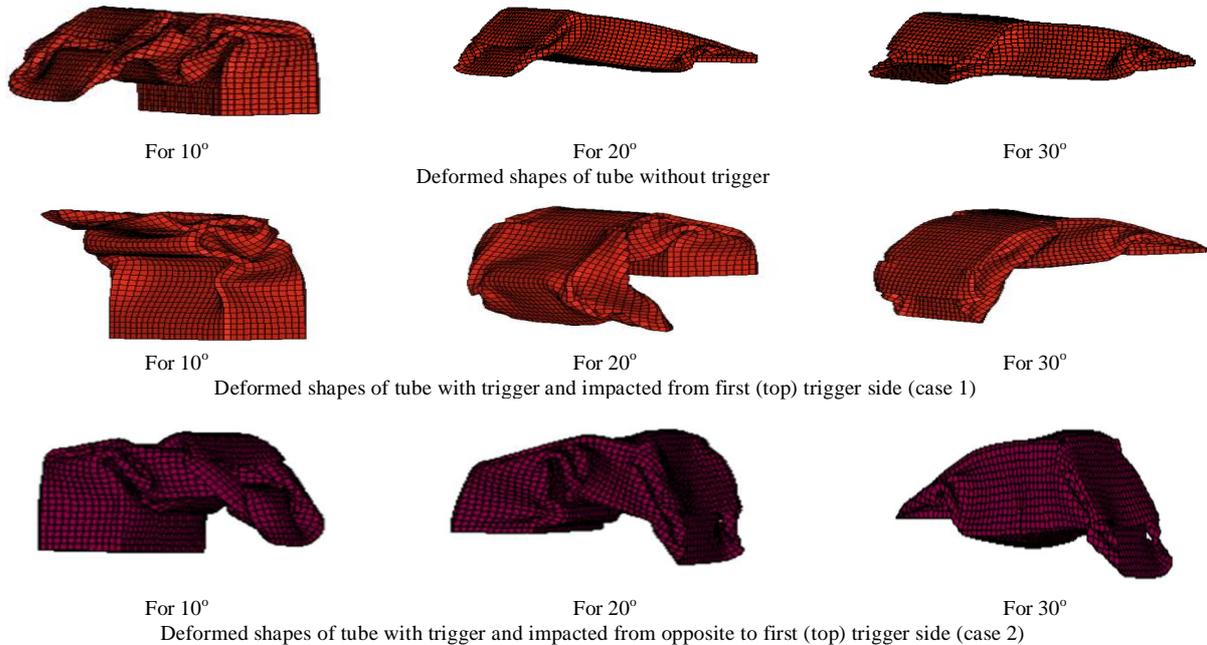


Fig. 13: Deformed shapes of the tube

VI. COMPARISON OF ENERGY ABSORPTION OF TUBE WITH ASYMMETRIC TRIGGERS WHEN IMPACTED FROM DIFFERENT SIDES

The comparison of the results of the tube without trigger and with asymmetric triggers impacted from different sides is shown in the table 2.

Table 2: Comparison of results of tube without triggers and with asymmetric triggers impacted from different sides

Angle	Mean load in KN		
	Tube without trigger	Tube with trigger & impacted from first (top) trigger side	Tube with trigger & impacted from opposite to first (top) trigger side
0°	145.64	110.33	110.33
5°	99.84	107.82	87.83
10°	82.93	97.78	76.21
15°	60.27	84.35	74.89
20°	53.61	68.29	58.90
25°	42.20	54.29	52.75
30°	34.75	49.93	38.86

Fig. 14 shows the graph of mean load vs. load angles for the tube without trigger, for tube with trigger impacted from first (top) trigger side and for the tube impacted from opposite to first (top) trigger side.

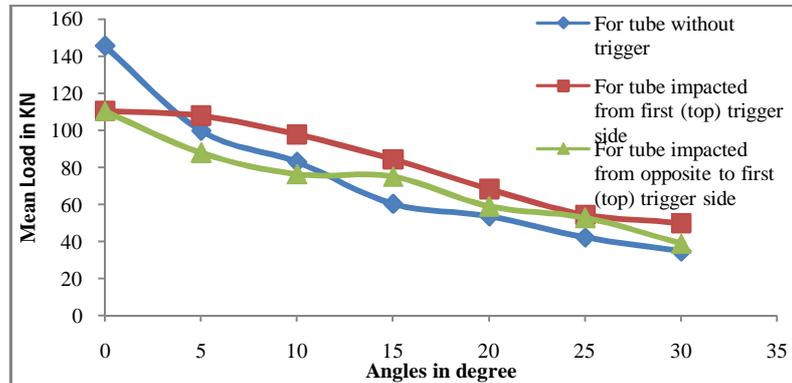


Fig. 14: Mean load vs. Impact angles for tube without triggers and with asymmetric triggers impacted from different sides

From graph it is observed that for the tube without triggers the mean load decreases as impact angle increases and there is more reduction in mean load at 5° load angle. For the tube with triggers impacting from first (top) trigger side there is gradual decrease in mean load and peak load is reduced as compared to tube without trigger. For the tube with triggers impacting from opposite to first (top) trigger side there is decrease in mean load up to 10° also there is increase in mean load at 15° & further it decreases.

VII. CONCLUSIONS

During oblique loading energy absorption is less as compared to that of axial loading. By using triggers energy absorption can be increased during oblique loading. For lower loading angles energy absorption increases for tube when impacted from opposite to first (top) trigger side as compared to tube impacted from first (top) trigger side. By using triggers peak load is reduced. First (top) trigger should be placed at the contacting side of the plate for efficient energy absorption.

VIII. ACKNOWLEDGEMENT

We are thankful to the Principal and Management of Walchand Institute of Technology, Solapur for supporting us during this study.

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