The energy-absorbing capability of obliquely loaded circular thin-walled structural steel tube is studied with different loading angles and geometric parameters using ANSYS-14. The collapse behavior of tubes is investigated at loading angles of 00, 50, 100 and 150 with respect to the longitudinal direction of the tube. Parametric studies are carried out in order to assess the effect of load angle, wall thickness, height and the hole with varying position on energy absorbing capacity of obliquely loaded steel tubes.

I. INTRODUCTION

Thin-walled columns have a high energy-absorption capability and therefore have played an important role in vehicle crashes. Most of the frames in modern vehicles are made from thin-walled sections. Tubes absorb the impact energy through material deformation during crushing. The collapse of a tube has two primary modes, axial and bending, but during an actual crash event, the tube is subjected to either pure axial or bending collapse, but rather a combination of the two modes. If the tube experiences global bending instead of axial crushing, the energy absorption will be lower, and both moments and axial forces will be transferred to the rest of the structure. It is therefore, important to understand what happens to the tube when subjected to oblique load. Reyes, et al. [1] studied the behavior and energy-absorbing capability of obliquely loaded square thin-walled aluminum columns experimentally & FEM analysis by LS-DYNA. Reyes, et al. [2] performed the oblique loading through quasi-static experiments and numerical simulations. Li et al [3] quantify the energy absorption of empty and foam-filled tubes under oblique loading with different loading angles and geometry parameters. Reyes, et al. [4] examined the behavior of empty and foam-filled square thin-walled aluminum column subjected to quasi-static oblique loading. J. Song [5] studied windowed square tubes subject to oblique impact numerically, with variable being load angle, width and height of window and impact velocity. Nia, et al. [6] studied quasi-static oblique loading of aluminum thin-walled tubes with buckling initiators both experimentally and numerically. Buckling initiators, which are made in the form of cuttings at the specimen corners when inserted at angles 70, 140 and 210 and the effects of load angle are studied. This is due to the different collapse modes, as the progressive buckling of axial crushing is a much more energy-absorbing process than bending. In the present work, the effect of tube thickness, length and effect of hole on peak load and energy absorbing capacity of steel tube under oblique loading is investigated numerically.

II. METHODOLOGY

Numerical simulations of tubes subjected to axial crushing are carried out, using quadratic hexahedron elements in ANSYS-14 Workbench. The tube is meshed by triangular surface mesher, the support conditions to the tube is constrained at one end and other translate vertically over a pre-defined displacement such that the free end of the tube was axially crushed onto a fully fixed end. The material used is structural steel with following material properties.

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>7850</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>200</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Yield Strength (MPa)</td>
<td>250</td>
</tr>
<tr>
<td>Tangent Modulus (GPa)</td>
<td>1.45</td>
</tr>
</tbody>
</table>

III. RESULTS & DISCUSSION

(a) Effect of Length

Figs. 1 and 2 shows the effect of length on peak load and energy absorption capacity under quasi-static crushing. From the above result the peak load is higher for longer tube, i.e. as the length of the tube increases the peak load also increases. And for the energy absorption capacity from Fig. 2 it is clear that the longer tube absorbs much energy as compared to shorter tubes for tube at 00.
(b) Effect of Inclination
When subjected to small angle loading, overall buckling occurred after folds were formed in the axial direction, hence the plastic deformation of structures became easier and more energy was absorbed. However, if the load angle is too large, the crushing force may decrease. When subjected to small-angle oblique loading, the specific energy absorption of tubes remain nearly unchanged, but the energy absorption decreases slightly when the load angle is too large. From Fig. 2 it has been seen that for tube of length L = 200 mm the energy absorption decreases with the increases in tube inclination.

Fig. 1. Peak load variation with angle ? for different length L for t = 1mm

Fig. 2. Effect on energy absorbed for different lengths at various inclination angles for thickness t = 1 mm

(c) Effect of Thickness
The deformation mode depends on thickness of the tube whether the deformation takes place in progressive manner with symmetric mode or asymmetric mode. However, when the wall thickness is increased, the shape of the force-displacement curves changes. From the below Fig. 3 it has been concluded that thicker the higher will be its energy absorption capacity at the cost of weight. From Fig. 3, for t = 2 mm the energy absorbing capacity increases upto 50 than decreases whereas for tube with 1mm thickness the energy absorbing capacity decreases as the inclination increases.

Fig. 3. Effect on energy absorbed for different thickness at various inclination angles for L = 200 mm

(d) Effect of Hole
As per from above study is has been observed that tube with higher length has higher energy absorbing capacity. Now based on that another effect is taking into account i.e. effect of hole on energy absorbing capacity. Hole at different position is done and its dia. is also varied. Fig. 4 shows the comparison between hole at different position at different inclination and also the comparison between tube with and without hole on energy absorbed due to quasi static crushing. And Fig. 5 shows the effect of hole dia. on energy absorbed at different inclination and the comparison between the tube with and without hole. Fig. 6 has shown the effect of hole position from the base at 50 mm, the hole is done at inclined surface on both tension side and compression side and also the through hole is being done to observe the effect of it on energy absorbing capacity. It has been clear from the Fig. 6 that when hole is done on compressive side it increases the energy absorbing capacity as compared to all other conditions.

Fig. 4. Effect of hole on energy absorbed various inclination angles for L = 200 mm
IV. SUMMARY

In this paper the behaviour of the tubes subjected to oblique load is studied and the response is analyzed at various lengths, thicknesses, inclinations and effect of hole on it. Paper gives a subsequent steps has taken to see understand all the possible effects on tube when loaded obliquely under certain defined conditions. Initially the tube length effect, thickness and inclination effect has been observed. Than the effect of hole as a buckling initiator is also presented. And finally the best position of the hole to get the higher energy absorbing capacity is concluded.

REFERENCES