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Study On Dynamic Crushing Behaviour of Collapsible Steel Tube Energy Absorbers with Cutout

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Abstract: Energy absorbing structures are gaining its own importance in engineering field now a days. These plays a vital role in safe design of structures during impact accidents. Thin walled members are commonly used as energy absorbers. Thus these have a wide variety of applications in offshore structure, automobile engineering, aircraft fuselage designs, crash barrier designs in bridge structures, etc. These structures often have geometric discontinuities like cutouts. Many researchers have considered different parametric studies on this topic. The studies based on the size of a square cutout is less. This project work aims on the numerical study on the crushing behaviour of thin walled cylindrical steel tube type collapsible impact energy absorbers with square cutout. A systematic parametric study is performed in this work, considering two parameters, size of cutout and location of cutout. Analysis results shows the strong influence of size and location of cutout on its crushing behaviour, when it is subjected to impact loading. The results will contribute a better solution for the design of thin walled energy absorbing structures in future.

Keywords: collapsible energy absorbers; square cutout; progressive crushing; global buckling

I. INTRODUCTION

The word impact reminds us accidents, natural collisions, and may more. Accidents are frequently occurring incidents in day to day life, but the least desirable ones. Impact accidents occurs in all fields of engineering, Civil engineering, auto mobile, offshore structures, nuclear reactor structures, etc. accidents causes loss of human life and also creates financial burden on society. So people are becoming aware about the safety of human life and structures. These created greater demand on engineers, and they have to design in view of safety of structures during impact accidents and to minimize the financial burden on society. Here the energy absorbers plays a vital role. Thin walled tubes are generally used as energy absorbers in structures, to make it safe from the impacts. These tubes generally have some geometric discontinuities in order to connect it with stiffeners and other members. So it is important to have a sound knowledge on the crushing behaviour of these thin walled energy absorbers. To analyse the effect of cut-out in steel tubes, when it is subjected to axial impact loading. Specimens having square cutouts with different dimensions and at different locations in the tubes are considered for the dynamic analysis. Objective of the study is to determine the influence of cutout on the crushing behaviour of steel cylindrical type collapsible impact energy absorbers. Cylindrical steel tubes are now being widely used for various structural engineering purpose. These shell structures often contain complex stiffeners and geometric discontinuities like cutouts, as a result of practical needs. These geometric discontinuities can cause a stress concentration response near the cutout and this will influence the deformation mode of structure. Scope of the project is to analyse the effect of cutout with different dimensions, located at different locations, when it is subjected to axial impact loading. Latest trends in the usage of light structures made more aspects of design critical. Which creates greater demand on engineers. Since thin walled structures are having less weight compared with the conventional type structures, and these are widely used as the impact energy absorbers, this study is having its own importance and contributes to the future design of these impact energy absorbers.

II. LITERATURE REVIEW

M.Y. Huang, et.al. (2010)[1] Describes well about the influence of elliptical cutout in steel cylindrical tubes. Thin-walled members are commonly used as energy absorbers in engineering structures and often contain cutouts. This study performed numerical simulations of high strength steel cylindrical shells with elliptical cutouts subjected to dynamic axial impact. The LS-DYNA code was the primary analytical tool used to analyse the influence of cutout locations, cutout shapes and symmetry of cutout on the energy absorption capabilities and the crush characteristics of tubes with a cutout. For high strength steel tubes made from a rate sensitive material, the stress strain curves of different strain rates were used to elucidate the effect of dynamic impact on the strain rate. Our results show that collapse crushing behaviour is strongly influenced by the location and symmetry of cutouts and the variation of major axis influences the peak crush load. Inference from the journal is that the location and size of opening significantly influence the buckling behaviour of steel tube energy absorbers

A.G. Olabi, et.al. (2007)[2] Presents an overview of energy absorbers in the form of tubes in which the material used is predominantly mild steel and aluminium. A brief summary is also given of frusta type energy absorbers. The common modes of deformation such as lateral and axial compression, indentation and inversion are reviewed. Tubes of different cross sections as well as the tapering tubes are considered in this paper. The deformation pattern of all the considered tubes are well explained. Theoretical, numerical and experimental methods which help to understand the behaviour of such devices under various loading conditions are outlined.

III. ANALYSIS

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, impact accidents and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used. FEA software ANSYS has been used in this study.

A. Methodology

The methodology of the work involves various steps included in the study. The first stage of study was literature survey on the concerned topic. Then studied the basics of FEA software, ANSYS. Then the dynamic crushing behaviour of these collapsible cylindrical tube type energy absorbers when it is subject to impact loading with a constant velocity is done with the help of Explicit Dynamics module of ANSYS software. Before conducting the FEA analysis with the help of software, validation of the same was done.

- Cylindrical tube type steel specimens with geometric discontinuity, square cutout, is considered
- Determination of effect of cutouts in their dynamic crushing behaviour was studied
- Square cutouts of three different sizes placed at three different locations were modelled
- Analysis of all the modelled specimens were carried out
- Graphs of reaction load versus deflection were prepared for each specimen
- Effect of size of cutouts and their location on the crushing behaviour of these impact energy absorbing tubes were determined with the help of prepared graphs

B. Material properties

- Steel-High Strength Steel, Elastic Modulus=2×10^5 MPa, Poisson ratio=0.30

B. Elements used

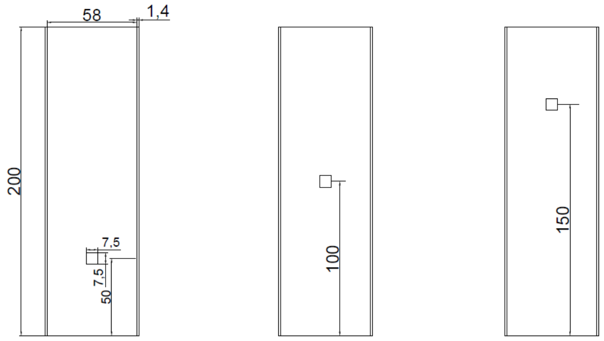
SHELL163 is a 4 noded element with both bending and membrane capabilities. Both in plane and normal loads are permitted. The element has 12 degrees of freedom at each node: translations, accelerations, and velocities in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. This element is used in explicit dynamic analyses only.

C. Parameters considered for the study

Specimens having square cutouts of size 7.5mm, 8.5mm, 9.5mm, located at 0.25L, 0.50L, and 0.75L from bottom, were modelled and analysed.

D. Geometry

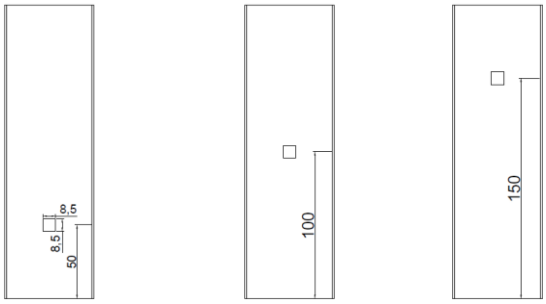
The CAD drawing for all the models considers in the study is given below. All these specimens were modelled in ANSYS software and analysed using the same.



cutout = 7.5mm x 7.5mm
location=0.25L=50mm

cutout = 7.5mm x 7.5mm
location=0.50L=100mm

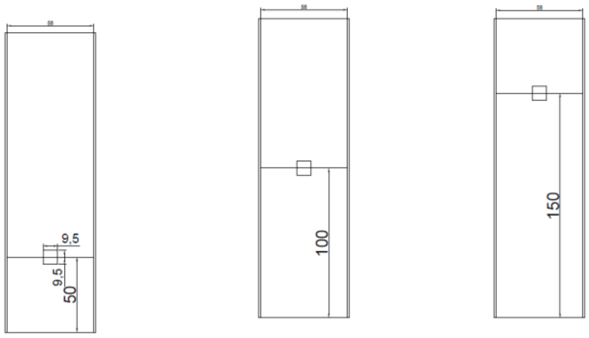
cutout = 7.5mm x 7.5mm
location=0.75L=150mm



cutout = 8.5mm x 8.5mm
location=0.25L=50mm

cutout = 8.5mm x 8.5mm
location=0.50L=100mm

cutout = 8.5mm x 8.5mm
location=0.75L=150mm



cutout = 9.5mm x 9.5mm
location=0.25L=50mm

cutout = 9.5mm x 9.5mm
location=0.50L=100mm

cutout = 9.5mm x 9.5mm
location=0.75L=150mm

Fig 1: CAD drawings of the Geometry of specimens

E. Boundary and load conditions

Displacement boundary conditions were needed to constrain the model to get a unique solution. To ensure that the model acts in the same way as the experimental conditions, got from literature survey, boundary conditions are applied. The loading end of tube was set free. End opposite to the loading end, was made fixed.

Impact loading is applied to the specimen, in order to get the dynamic crushing behaviour of specimen, when it is having geometric discontinuity, a square cutout. For that, a rectangular block is modelled and assigned weight of 117 kg and a constant velocity of 12.14m/sec. ANSYS model for the loading plate is shown in below figure.

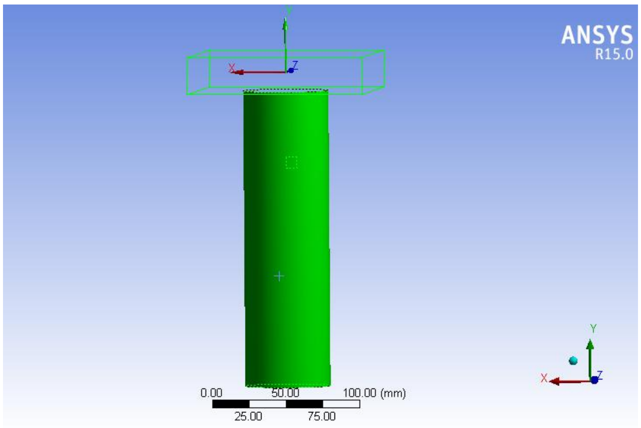


Fig 2: Loading Plate on the Specimen

G. Results and discussions

(a.) Results

Numerical simulations were carried out for determining the crushing behaviour of thin walled steel tubes. Circular tubes with a diameter of 58mm, length of 200mm and a thickness of 1.4mm was considered. Three different square cutout sizes, 7.50mm, 8.50mm, 9.50mm were used. And three different locations of these cutouts in the tube were also considered. Analysis of tube without cutout was carried out for the validation study. Shell 163 used only for the analysis of structures in explicit dynamics were used as element type for the specimen. Load deflection graphs got from the software are shown in following figures.

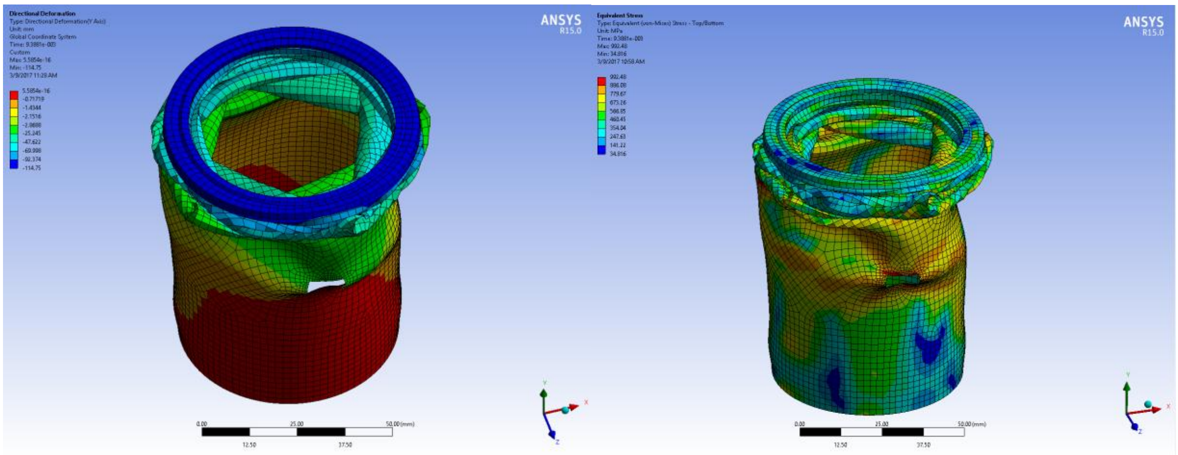


Fig 3: Directional Deformation Diagram and Stress Diagram of Specimen Having Square Cutout Size 7.5mm Located At 0.25L

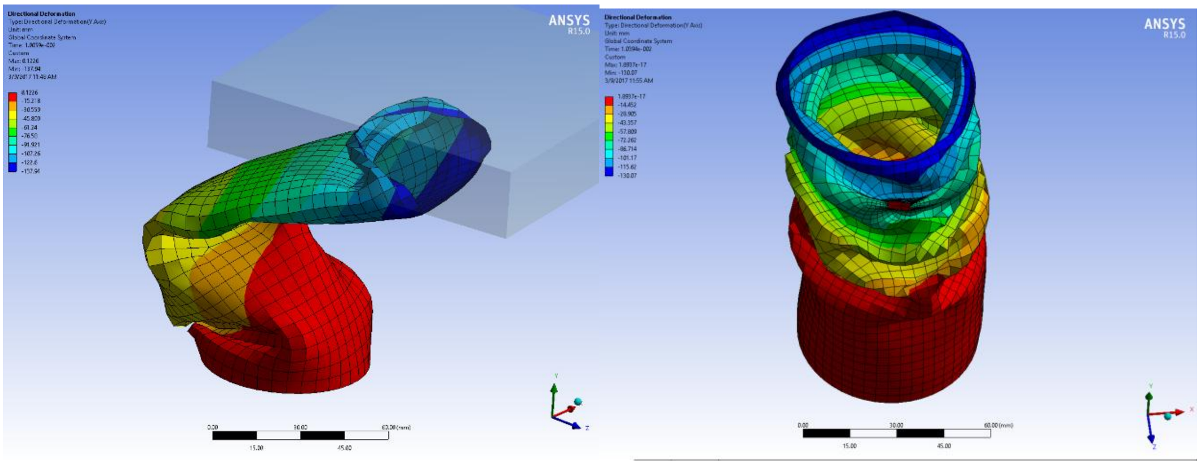


Fig 4: Directional Deformation Diagram of Specimen Having Square Cutout Size 8.5 mm Located At 0.50L and 0.75L

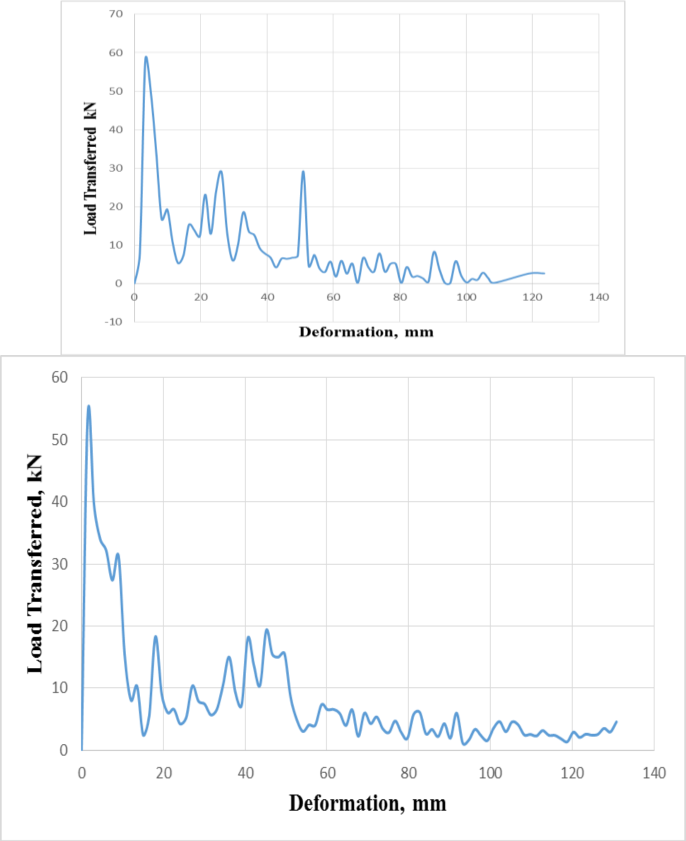


Fig 5: Load Deformation Curve for Specimen Having Cutout Size 7.5mm Located At 0.25L and 0.50L Respectively

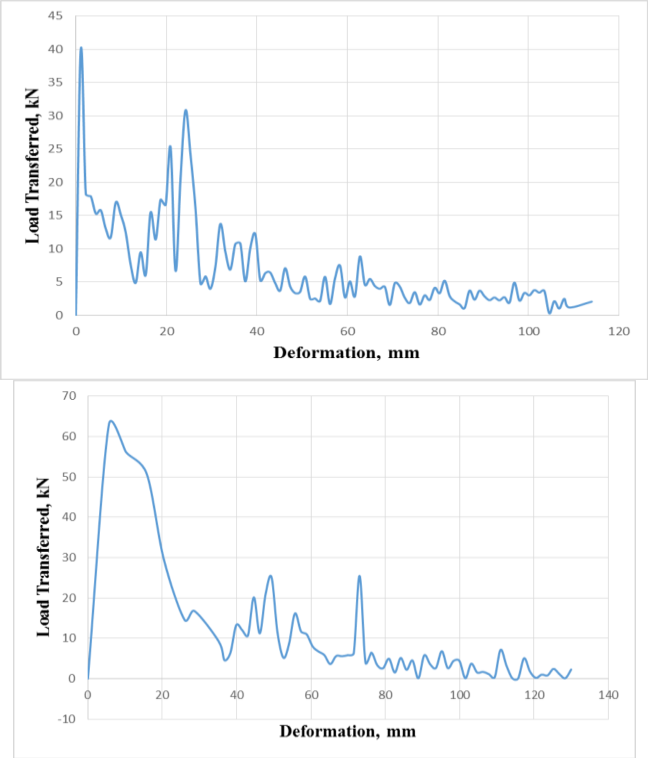


Fig. 6 Load Deformation Curve for Specimen Having Cutout Size 7.5mm and 8.5mm Located At 0.75L and 0.25L Respectively

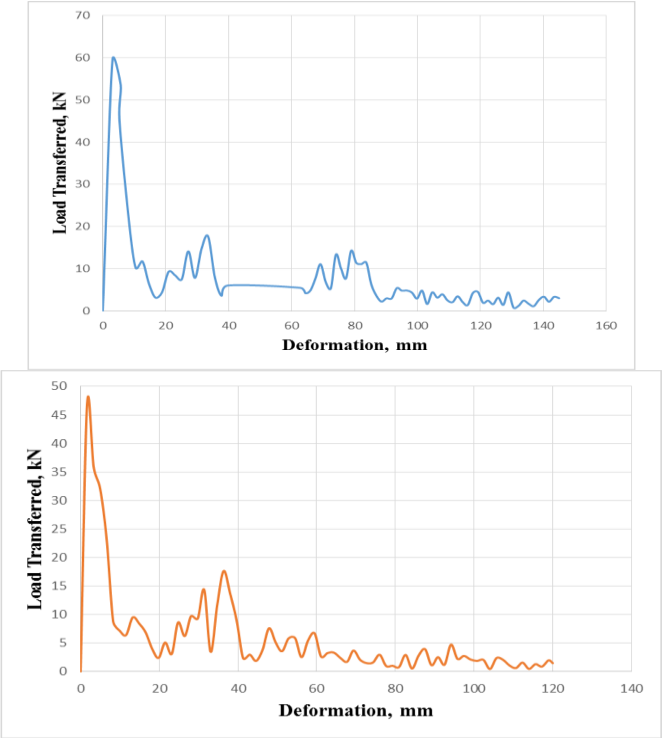


Fig. 7 Load Deformation Curve for Specimen Having Cutout Size 8.5mm Located At 0.50L and 0.75L Respectively

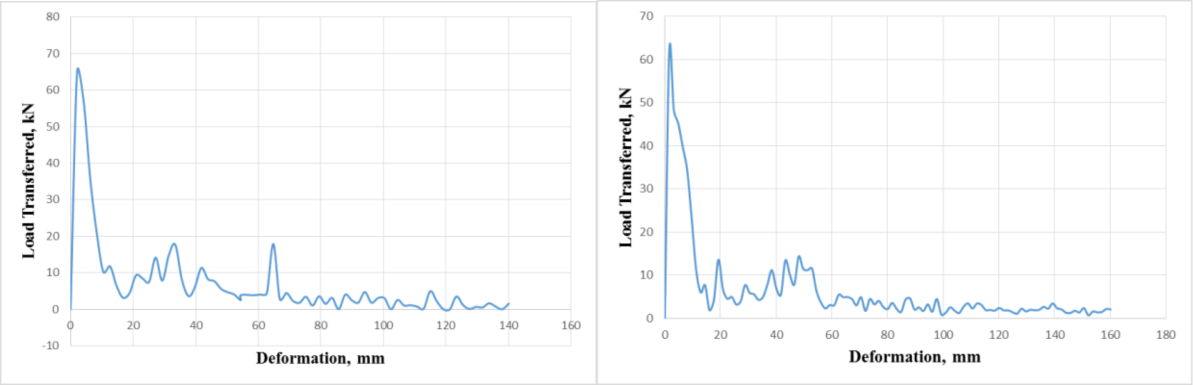


Fig. 8 Load Deformation Curve for Specimen Having Cutout Size 9.5mm Located At 0.25L and 0.50L Respectively

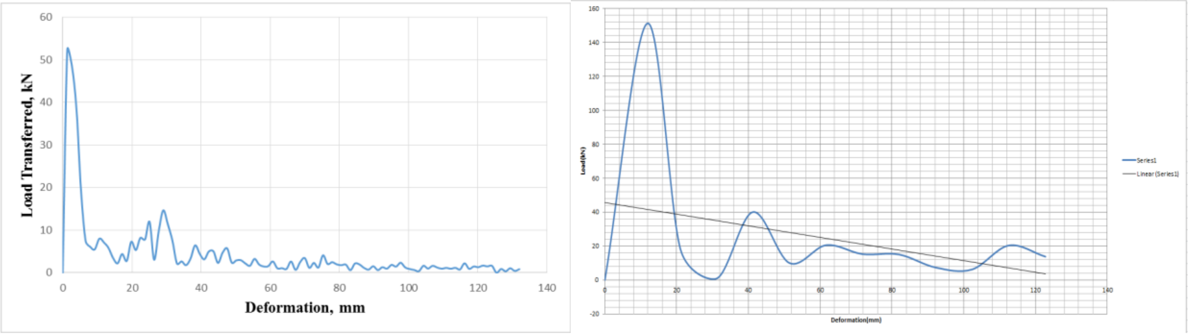


Fig. 9 Load Deformation Curve for Specimen Having Cutout Size 9.5mm Located At 0.75L and specimen without cutout Respectively

(b.) Discussion

Comparing the peak loads of each specimen, it is clear that the size of cutout and its location plays a significant role in its crushing behaviour. Comparing the load deformation graph of specimen without cutout with that of specimen with a cutout of size 9.5mm, at 25% height of specimen, a reaction force reduction of 57% is occurring. The peak reaction force for each wrinkle is less in magnitude for the specimens having cutout, with that of specimens without cutout. Comparing the deformation pattern, shown in Fig 3.3, for the specimen without cutout and the patterns for the specimens with cutout, it is clear that the irregular folding is formed due to the presence of cutout. Among the specimens with cutouts, the lesser magnitude of peak force is obtained for the specimens with cutout located at 95% height. In which the specimen with the smaller cutout size have the lowest peak force. A reduction of 25% of the peak load for the smaller size cutout specimen is clearly visible from the graphs compared with the specimen having larger cutout. This is solely due to the location of cutout. As we all know, lesser the magnitude of peak force, greater will be the energy absorption capacity of that specimen. Energy absorption capacity is inversely proportional to the peak load, which is beyond the scope of this study. All the specimens having cutouts at 25% and 75% height shows a progressive crushing behaviour and the specimens with cutout at mid height shows a global bending behaviour. So it is clear that the crushing mode depends on the location of cutout. Results shows a reduction in the magnitude of peak force of all the specimens, when the cutout was located near the loading end, the upper end. And shows a much lesser force for the specimens with small cutouts, this is indeed a preferred solution for future works.

IV. CONCLUSIONS

A systematic numerical investigation was carried out to examine the influence of high strength cylindrical tubes with square discontinuities with varying size and location. An investigation was also conducted to examine the crush performance of the size and location of cutouts along the length of the shell. The numerical simulations provided valuable information into the behavior of the shells, and enable us to understand the variations of tubes with cutouts. Results show that the location of cutout can significantly influence the buckling performances and energy absorbing capacity of the thin walled tubes. The numerical results indicated that a cutout located at the mid height of the cylindrical tube led to the collapse of global bending, whereas when the cutout was located near the loaded end, progressive buckling occurred. Specimens buckled in global bending mode displayed highly similar force deformation relationships. The presence of a cutout with small size located near the loading end can significantly reduce the peak buckling force and cause a greater crushing deformation of thin-walled tubes. Additionally, as the size of cutout rises, the mean buckling value increases. Results from this study will help to design a useful steel cylindrical tube type collapsible impact energy absorbers, with geometric discontinuities, in future.

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