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Review of Crashworthiness Capability of Optimum S-shape Structure

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Abstract: Considerable study interest has been directed towards the use of thin walled structures for crashworthiness applications. Because of their light weight and high energy absorption capability. This review draws together information from a variety of sources to compare the findings of researchers in this field. A selection of researches and studies about S-shaped structures, as a highly simplified model of the front member of a vehicle body which plays an important role in absorbing energy during collision, is presented.

Key words: Crashworthiness, S-shape, thin-walled structures, impact crushing behavior

INTRODUCTION

Higher speed transportation increases the probability of traffic accidents which in turns causes serious damages to passengers. Design of auxiliary metal structure or structural components capable of sustaining prescribed loads and dissipating undesirable energies while undergoing plastic deformation is one of the prime means of energy absorption systems. Therefore the crash characteristic of energy absorbing component has received considerable attention over the past decades (Pugsley and Macaulay, 1960; Johnson, 1972; Meng *et al*., 1983; Gupta and Velmurugan, 1997).

The main criteria of occupant safety are the peak of crushing force and energy absorption of the occupant compartment during an accident. Optimization of the crashworthiness of a vehicle were considered in different papers as increasing the vehicle safety by decreasing the maximum force that passengers can tolerate whilst increasing the amount of its energy absorption. The value of the absorbed crash energy in frontal impact depends on vehicle construction, mechanical properties of materials and geometric characteristics of elements sections (Lukooevieius and Parnovskij, 2001). In ideal situation, the front side frame is expected to fold progressively during frontal crash of the car. Recently, the crashing characteristics of the 2D S-shape square tube under an axial load and the effectiveness of the reinforcement at the curved parts has been investigated (Han and Yamazakiy, 2003).

CIRCULAR THIN-WALLED STRUCTURE

Pugsley and Macaulay (1960) had done The pioneering work on the behavior of thin-walled structures. Since that time, the static and dynamic crushing tests and analysis of tubes attracted many researchers and many article have been published. Abramowicz and Jones (1984a) investigated the behavior of circular and rectangular tubes experimentally. Theoretical results of the tubes compared to the experimental data and several deformation mode have been explored.the effect of the wall thickness to length ratio of the tubes on the static and dynamic axial crushing loads were explored.

Abramowicz and Jones (1984b) described the concept of dynamic plastic buckling in his article.

This theoretical study predicted four deformation modes which govern the behavior for different ranges of the parameters.

Abramowicz and Jones (1986) explained dynamic progressive buckling of tubes, in that analyses transverse inertia did not affect the buckling mode.

Abbas *et al*. (2003) developed plastic curved fold model with partly inside and partly outside folding and variable straight length. The effect variation of hinge angle during the formation of a fold on circumferential strain considered. Variation of crushing load, have been computed. It can easily observe that most of the earlier models can be easily derived from the Gupta model. In this model maximum hinge angle and the final radius of curvature of fold determined mathematically.

SQUARE THIN-WALLED STRUCTURES

The crushing response of axially compressed box beams in relation with the lumped mass-spring model attracted many researchers in 1970's and early 1980's. A simplified expression for calculating the mean crushing load of closed hat section members have been proposed by Ohkubo *et al*. (1974). A simple equations to calculate maximum and mean of crushing force of spot welded box column with hat-type cross-section have been proposed by Masanori and Funahashi (1978). An investigation of contribution of buckling of each wall of box column to the crushing resistance have been done by Mahmood and Paluszn (1981).

Chen and Wierzbicki (2001) showed that box beam with multiple cells are better in case of crashworthiness and weight efficiency than the simple box beam. They offered closed-form solutions to calculate the mean crushing strength of single-cell, double-cell and triple-cell hollow aluminum profiles under quasi-static axial loading. on that research better behavior of The triple-cell section in term of highest energy absorption than single section and double section was shown. Kim (2002) obtained the analytical solution for the mean crushing force of a multi-cell profiles with four square elements at the corner. The SEA of the new multi-cell structure was increased over the usual square box column. Zhang *et al*. (2006) recently developed a theoretical solution to the square multi-cell columns by dividing the section into three basic components.

S-SHAPE STRUCTURE

As a highly simplified model of the front side member of a vehicle body which plays an important role in absorbing energy during collision, various investigators in previous works have studied the crushing behavior of the S-shaped structures.

Existence of vertical and horizontal eccentricities cause difficulty in analyzing this kind of structures theoretically. When a frontal collision accrued, the member is subjected to biaxial bending ,torsion and an axial compression (Chung *et al*., 1996; Meadows, 1992; Yoshitake *et al*., 1996). Kim and Wierzbicki (2000, 2001a) developed, the interaction curves for the sectional collapse under complex loading condition they also investigated the large rotation bending reaction with reference to non-principal axis was studied. The deformation modes were identified and failure loci were derived. The force and moment response of the thin-walled prismatic member under combined loading with aim of super beam element and Shanley spring model was calculated theoretically by Kim and Wierzbicki (2001b).

Kim and Wierzbicki (2004) analyzed The crushing behavior of thin-walled rectangular cross-section ''S'' shaped frames subjected to complex loading cases and The main application of that study was the aluminum space frame structure, therefore the strain rate effect is not measured. The analytical explanation of the crushing resistance was derived. Deformation modes of the structure were identified by using the analysis of the fully plastic bending moment with different orientation angle of bending axis. the finite element results validate the analytically derived crushing force. The crushing forces were taken from two different sections in the case of dynamic loading. The overall response and the range of the crushing force were quite similar in both loading cases except for the initial peak force. It is well known that the inertia effects are responsible for peak magnitudes of the instantaneous crushing force and contribute little to the crash energy dissipation. This is confirmed in the comparison of crushing energy absorption.

Kim and Wierzbicki (2001a) discussed several design aspects of closed hat-type S-frame which were different in Type of hat-type cross-section, orientation of the cross-section, Position of the internal stiffening member, aluminum foam-filling, hat type double cell profile with cut-out portion of the internal member and Triggering dent. Kim and Wierzbicki (2001b) investigated different cross sections. two types of design of the S-frame were offered to be optimum over the other cases. These optimum case described blow:

- Design 1 contains internal stiffener located diagonally to improve bending resistance. This kind of cross-section shows a high resistance to plastic bending but acts unwell in axial compression. For improving the response of structure to axial compression two end portions of the inner stiffener were removed and triggering dents introduce. 190 and 203% Improvement of specific energy absorption The total energy absorbed by this model and the specific energy respectively compared to double-hat/double-cell profile member
- Design 2 use of aluminum foam as reinforcing agent increased energy absorption of structure about 160 and 184% improvement in specific energy absorption

Han and Yamazakiy (2003) investigated crushing behavior of the s-shape square tube during The axial impact crushing by explicit finite element method. effects of the reinforcement at the curved parts and the shape perturbation of the straight end parts of the tube on improving crashworthiness of S-shape are verified. The model without the shape perturbation, shows deformation at the straight parts before column buckling at the curved parts.

Han and Yamazakiy (2003) showed that energy absorption of structure increased about 27%, so It can be inferred that shape perturbation can improve crashworthiness characteristic of S-shape structure.

Genetic Algorithms (GAs) have been widely used as optimization tools in various problem domains, including engineering and etc. (Khajavi *et al*., 2010).

The optimum geometry of the S-shape square tube, the reinforcement at curved parts and the shape perturbation of the straight end parts were achieved by using optimization. Multi-objective optimization which is also called multi criteria optimization or vector optimization, has been used in many different case study (Khalkhali *et al*., 2010; Tavasoli *et al*., 2010).

Khalkhali *et al*. (2010) and Nariman-Zadeh *et al*. (2001) used genetic algorithms both for optimal design of generalized GMDH-type neural network models of S-shaped box beam crash behavior and for multi-objective Pareto based optimization of such structures. The generalized GMDH-type neural network's topology provided small networks so that polynomial expressions for dependent variables of the process were achieved consequently. Two different polynomial relations for absorbed energy and peak crushing force were found by evolved GMDH type neural network using some numerically obtained input-output data using the FEM. The derived polynomial models have been then used in evolutionary multi-objective Pareto based optimization processes. The objective functions that conflict with each other were selected as specific energy absorption (E) and peak crushing force (F_{max}) in a deterministic design approach. The reliability-based robust multi-objective optimization included some statistical moments of those objective functions such as mean and variances. Both the deterministic and probabilistic multi-objective crashworthiness optimization of S-shaped box beam led to the discovering some important trade-offs among those objective functions. Further, it was shown that the results of 4-objective optimization include those of 2-objective optimization in terms of Pareto frontiers and provided, consequently, more choices for optimal design.

Two optimum design points out of all non-dominated four-objective optimization process compromising all objective functions were presented. In order to compare the robustness behavior of different design points obtained from both deterministic and probabilistic optimization approaches, the probabilistic metrics of deterministic design points, were presented.

The Pareto of Mean of peak crushing force versus the mean of specific energy absorption in 4-objective optimization presented (Khalkhali *et al*., 2010).

Nowadays research interest has been directed towards the use of different materials and hybrid structures for crashworthiness applications, because they can be designed to provide impact energy absorption capabilities which are superior to those of metals when compared on a weight basis (Tavasoli *et al*., 2010).

Use of different material can be more effective in automobile crashworthiness and light weighting than structure modification. Aluminum and magnesium alloys, high-strength steel, composite material can be use instead of traditional material of mild steel to improve crashworthiness and light weighting (Li *et al*., 2003). Better behavior of hybrid S-shape box beam which is constructed from two parts, one part is made of steel which has higher stiffness and better characteristic against bending and the other part is made of aluminum which has better energy absorption characteristic and lower weight in term of crashworthiness and light weighting. Through comparison with a simple S-shape made of steel advantages of such a hybrid S-frame was shown (Hosseini-Tehrani and Nikahd, 2006).

Hosseini-Tehrani and Nikahd (2006) did the comparison of maximum energy absorption for three different types. Two hybrids S-frame including steel and aluminum parts with different kinds of connection for two parts were consider. Comparison of mass and maximum energy absorbed for various models were also presented. Notghi and Nariman-Zadeh (2010) modeled the hybrid S-shape structure in way that nearly 50% of hybrid S-shape box beam is made of aluminum. Two different polynomial relations for absorbed energy and peak crushing force have been found by evolved GMDH type neural network using some numerically obtained input-output data using the FEM. The derived polynomial models were then used in evolutionary multi-objective Pareto based optimization processes.

The objective functions which conflict with each other were selected as absorbed energy (E), weight of structure (W) and peak crushing force (F_{max}). The multi-objective crashworthiness optimization of hybrid S-shape box beam led to the discovering some important trade-offs among those objective functions. Such combined application of GMDH neural network modeling of numerical input-output data and subsequent non-dominated Pareto optimization process of the obtained meta-models was very promising in discovering useful and interesting design relationships and can be readily applied to other real world crashworthiness problems employing more complex structures.

Three optimum point were suggested from 3-objective optimization value of these point was presented (Notghi and Nariman-Zadeh, 2010).

Zhang and Saigal (2007) investigated the crushing behavior of an idealized three-dimensional space frame. The crushing behavior of a 3D S-shape extruded aluminum frame with 45° curvature angle (α) and 45° rotation angle (β) was studied over an axial loading. The effect of different cross-section reinforcements (parallel 'horizontal and vertical' and diagonal 'right and left' internal lateral support profiles) and aluminum foam-filled reinforcement were determined.

Zhang and Saigal (2007) also showed based on the numerical analyses that the left diagonal reinforced structure showed the highest specific energy absorption (SEA = 3.813 J g^{-1}). This is 177% more than the SEA of the empty column structure (SEA = 1.375 J g^{-1}).

In addition, the aluminum foam-filled reinforcement raised the energy absorbed by the 3D space frame structure by an additional 78%. The results show that aluminum foam is an capable choice energy absorber. However, it does not enlarge the SEA of the structure due to the increased mass and increases the peak force significantly (Zhang and Saigal, 2007).

CONCLUSIONS

There are many different factors that effected on crashworthiness capability of s shape structure. The capability of energy absorption of structure can be increased by using different material or it can be increased by using stiffeners or changing the cross section.

REFERENCES

Abbas, H., B.L. Tyagi, M. Arif and N.K. Gupta, 2003. Curved fold model analysis for axi-symmetric axial crushing of tubes. Thin-Walled Structures, 41: 639-661.

Abramowicz, W. and N. Jones, 1984a. Dynamic axial crushing of circular tubes. Int. J. Impact Eng., 2: 263-281.

Abramowicz, W. and N. Jones, 1984b. Dynamic axial crushing of square tubes. Int. J. Impact Eng., 2: 179-208.

Abramowicz, W. and N. Jones, 1986. Dynamic progressive buckling of circular and square tubes. Int. J. Imapct Eng., 4: 243-270.

Chen, W. and T. Wierzbicki, 2001. Relative merits of single-cell, multi-cell and foam-filled thin-walled structures in energy absorption. Thin-Walled Struct., 39: 287-306.

Chung, T.E., Y.R. Lee, C.S. Kim and H.S. Kim, 1996. Design of aluminum space frame for crashworthiness improvement. http://papers.sae.org/960167/.

Gupta, N.K. and R. Velmurugan, 1997. Consideration of internal folding and non-symmetric fold formation axisymmetric axial collapse round tubes. Int. J. Solids Structures, 34: 2611-2613.

Han, J. and K. Yamazakiy, 2003. Crashworthiness optimization of S-shape square tubes. Int. J. Vehicle Design, 31: 72-85.

Hosseini-Tehrani, P. and M. Nikahd, 2006. Two materials S-frame representation for improving crashworthiness and lightening. Thin-walled Struct., 44: 407-414.

Johnson, W., 1972. Impact Strength of Material. Edward Arnold, London. ISBN 0844800104, pp:361.

Khajavi, M.N., B. Notghi and G. Paygane, 2010. A multi objective optimization approach to optimize vehicle ride and handling characteristics. World Acad. Sci. Eng. Technol., 62: 580-584.

Khalkhali, A., N. Nariman-zadeh, A. Darvizeh, A. Masoumi and B. Notghi, 2010. Reliability-based robust multi-objective crashworthiness optimization of s-shaped box beams with parametric uncertainties. J. Crashworthiness,

Kim, H.S. and T. Wierzbicki, 2000. Numerical and analytical study on deep biaxial bending collapse of thin-walled beams. Int. J. Mech. Sci., 42: 1947-1970.

Kim, H.S. and T. Wierzbicki, 2001a. Crush behavior of thin-walled prismatic columns under combined bending and compression. Comput. Struct., 79: 1417-1432.

Kim, H.S. and T. Wierzbicki, 2001b. Effect of the cross-sectional shape of hat-type cross-sections on crash resistance of an S-frame. Thin-Walled Struct., 39: 535-554.

Kim, H.S., 2002. New extruded multi-cell aluminum profile for maximum crash energy absorption and weight efficiency. Thin-Walled Struct., 40: 311-327.

Kim, H.S. and T. Wierzbicki, 2004. Closed-form solution for crushing response of three-dimensional thin-walled S frames with rectangular cross-sections. Int. J. Impact Eng., 30: 87-112.

Li, Y., Z. Lin, A. Jiang and G. Chen, 2003. Use of high strength steel sheet for lightweight and crashworthy car body. Mater. Design, 24: 177-182.

Lukooevieius, K. and V. Parnovskij, 2001. The restoration of an automobile deformed side members. Trans. Eng., 16: 35-38.

Mahmood, H.F. and A. Paluszny, 1981. Design of thin walled columns for crash energy management-their strength and mode of collapse. http://papers.sae.org/811302/.

Masanori, T. and A. Funahashi, 1978. Energy absorption by the plastic deformation of body structural members. http://papers.sae.org/780368

Meadows, D.J., 1992. Aluminum crashmember in axial and bending collapse. SAE Paper No. 922113

Meng, Q., S.T.S. Al-Hassani and P.D. Soden, 1983. Axial Crushing of Square Tubes. Int. J. Mechanical Sci., 25: 747-773.

Nariman-Zadeh, K.N., A. Masoumi, A. Darvizeh and B. Notghi, 2001. Robust multi-objective optimization of the S-shape energy absorbers with parametric uncertainties. Proceedings of the Annual International Conference on Mechanical Engineering, May 11-13, Tehran, Iran, pp: 187-192.

Notghi, B. and N. Nariman-Zadeh, 2010. Multi-objective crashworthiness optimization of two materials S-shape energy absorption box beams using GMDH-type neural networks and genetic algorithms. Proceedings of the International Symposium on Innovation in Intelligent Systems and Applications, June 21-24, Kayseri and Cappadocia, Turkey.

Ohkubo, Y., T. Akamatsu and K. Shirasawa, 1974. Mean crushing strength of closed that section members. http://papers.sae.org/740040/

Pugsley, A.G. and M. Macaulay, 1960. The large scale crumpling of thin cylindrical columns. Int. J. Mechanics Applied Mathe., 13: 1-9.

Tavasoli, N., A. Dravizeh and B. Notghi, 2010. Multi-objective crashworthiness optimization of composite hat-shape energy absorption using GMDH-type neural networks and genetic algorithms. Proceedings of the ASME 2010 International Mechanical Engineering Congress and Exposition, Nov. 12-18, Vancouver, British Columbia, pp: 202-207.

Yoshitake, A., K. Sato and T. Okita, 1996. Impact absorbed energy of hat square column in high strength steels. http://papers.sae.org/960020/.

Zhang, X., G. Cheng and H. Zhang, 2006. Theoretical prediction and numerical simulation of multi-cell square thin-walled structures. Thin-Walled Struct., 44: 1185-1191.

Zhang, C. and A. Saigal, 2007. Crash behavior of a 3D S-shape space frame structure. J. Mater. Process. Tech., 191: 256-259.