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Modeling and optimization of tapered rectangular thin-walled columns subjected to oblique loading for impact energy absorption

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Abstract

Thin-walled column plays an important role for passenger safety during vehicle collision due to its ability to dissipate kinetic energy by deform in a controlled manner. In oblique impact scenario, crash force acting obliquely to the longitudinal axis of the thin-walled column causes to deform via a combination of axial and global bending which is unstable with an associated reduction in energy absorption. Tapered rectangular thin-walled column has been considered due to its ability to withstand oblique impact as effectively as axial impact. Hence, in this paper, numerical investigation has been carried out to optimize tapered rectangular thin-walled column to be used in design of energy absorption. There are two stages of research method adopted in this study. The initial stage was the developed and verification of the used finite element (FE) model. Model verification is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and its solution. In this study, experimental approach was not adopted due to several constraints and therefore FE model could not be validated by experimental. To make this study is reliable; the FE model was being verified by using validated model from literature. FE model was developed and validated based on Z. Ahmad FE model. Based on the verification process, deformation mode and energy absorption predicted by the developed FE model agree with the validated FE model. Energy absorbed for developed FE model is 1672J, while energy absorbed for validated model is 1676J. The percent different is 0.24% which is quite small value. Therefore, the developed FE model can be used for simulate crash response of thin-walled tube for this study. Figure 1 shows comparison of load-deflection response of both developed FE model and Z. Ahmad FE model. The second stage was the design optimization. The design objective was to maximize specific energy absorption (SEA) and the design variables were aspect ratio, tube thickness and length. The first stage of design optimization is to create design sample points. In this optimization scheme, full factorial design of experiment was used. Since there are three factors (design variables) and three levels for each factor, a total of 27 runs cover the spectrum of full factorial design. The design points will be representing the design variables. The design variables selected in this study are commonly used in other researches study that subjected to oblique loading. The tube thickness,t ranges from 1mm to 3mm, the aspect ratio,a (width/breadth) ranges from 0.5 to 2, the tube length,L ranges from 100mm to 300mm. Validated FE model was used to analyse the crash response based on the design samples. FEA results of SEA is obtained from the analyses and later will be used for constructing response surface model (RSM). RSM is employed to determine the value of design variables of the thin-walled tubes so as to maximize the SEA when impact occurs. The response is SEA (t,a,L) which is approximated using second order polynomial function. The approximation of the response then evaluated to check the fitness of the model to the true system. Based on the statistic parameters, it is shown that the adjusted coefficient of multiple determination (R^2_{adj}) does not differ much from the coefficient of multiple determination (R^2), whereas the value of R^2 is close to unity which indicates the fitness of the models. By using the approximation of the response function, the response surface of SEA is constructed with respect to design variables. RS model using quadratic polynomial function is given as equation (1) below. The optimal design is obtained by using the constrained nonlinear

multivariable optimization algorithm provided by MATLAB. The result obtained was the tube thickness is 3mm, aspect ratio is 0.5, and the tube length is 300mm. This means that, in order to maximize energy absorption capability, tapered rectangular thin walled column should have 3mm thickness, aspect ratio of 0.5, and tube length of 300mm.

$$SEA(t,a,L) = 1384 + 7042.55t - 4553.32a + 20.25L - 535.29t2 + 1872.03a2 - 0.04L2 - 1582.03ta + 4.56tL - 3.77aL \quad \text{(Eq.1)}$$

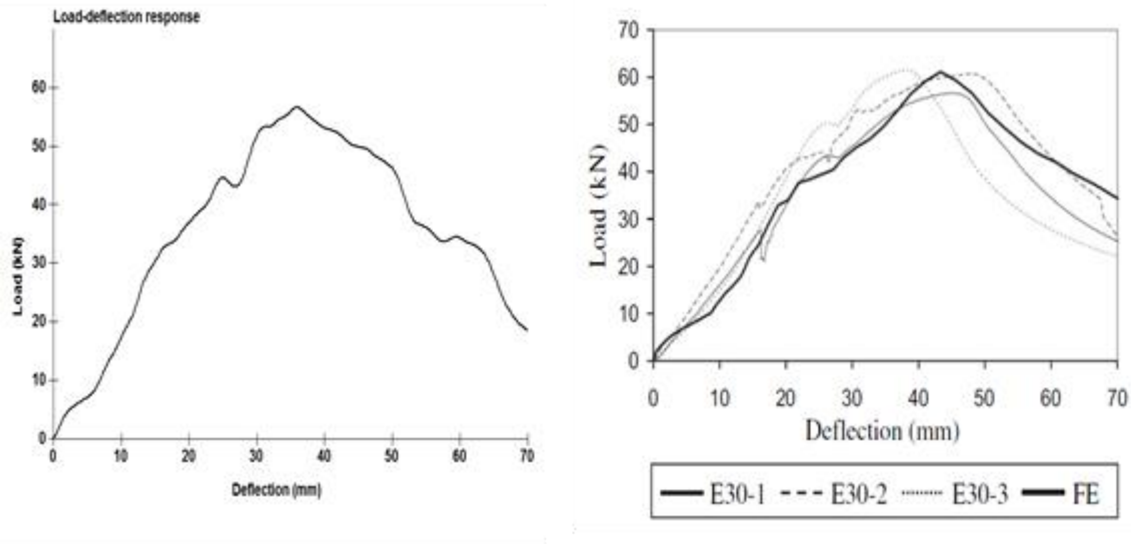

Figure 1: load-deflection response of developed FE model (left) and Z. Ahmad experimental and numerical results (right)