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Comparison of crash behaviour prediction of a car crash box using initial and updated finite element model

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Abstract. Topic of crashworthiness is gaining popularity as vehicle safety is becoming main concern to the vehicle manufacturers worldwide. Due to this factor, energy absorbing members on vehicle such as crash box is researched by many which lead to various strategies of design optimization has been carried out in order to seek a good energy absorber on vehicle. Among the popular method of determining the crash performance of a structure is by using dynamic analysis in computational finite element model (FEM). However, since finite element analysis (FEA) is only an approximation method which in many cases can be less reliable, model updating method is often suggested to improve its reliability. This study seeks to investigate the crash behaviour of initial and updated crash box model. The velocity of impactor, the deformation, collapse distance and energy transferred to the two models of crash box are compared. The findings show that the initial and updated model of the crash box in this study, do have different crash behaviour. However, the difference level is relatively small. The investigation on the method of validation for the updated model in terms of crash behaviour is highly recommended.

1. Introduction

In this day and age, number of vehicle has grown with the continuous development of the world economy. With the increasing number of automobile, rate of traffic accidents also raised considerably. Therefore, crashworthiness has become one of the most vital research topic when it comes to the concern of producing safer vehicles for consumers. Car crash box for instance, which is considered as an important energy absorbing members in vehicle, is researched by many [1–4]. There are numerous studies on crash box to study their crashworthiness performance [5]. Design optimization with numerous strategies have been proposed in order to produce an enhanced energy absorbing member on vehicles [6–8]. Mostly the computational analyses on these new designs or any enhancement done on crash box have to be validated in crash experiment [6,9-10]. This computational analysis which is mostly based on finite element analysis is widely used in the field of crashworthiness as it helps engineers and researchers to have the knowledge on the structural behaviour and its performance during impact or collision.

However, not all the finite element analysis simulated the exact result as obtained through experiment [10]. This is due to the fact that finite element analysis is only an approximate technique and the level of accuracy of the displayed results could vary from the experimental data. In fact, most of the previous studies have shown the concern of discrepancies in crashworthiness analysis. Therefore, it is essential for researchers to provide the solution to overcome the discrepancies problem

As researchers cannot totally rely on data from finite element analysis only, many studies has demonstrated that the finite element results are often need to be correlated and validated using experimental data [3,4,6,11–14]. There are many cases where discrepancies between finite element analysis data and the experimental data are unavoidable [13,15–17]. This discrepancy may be due to the wrong assignment of boundary conditions, material properties, assumption of localized effects like welding, bolt torque or any other reasons. In order to overcome the problems of discrepancies between these two sets of data, a method called model updating is introduced.

Model updating of a structural system is one of important topic with application in different problems especially in the field of structural engineering design and analysis. With the aid of model updating method, prediction capability of finite element model and the technique of modelling can be improved, as well as damage identification tool can be provided as shown in many previous study [14,18–23]. These studies explain that the model updating method normally employs numerically simulated data and experimental data from modal analysis to calibrate the model in study to better correlate the actual structure [23–30].

The aim of the present work is to investigate the crash behaviour of a crash box using initial and updated FE models. It is expected to have the different results of crash behaviour because both modes are developed using different model properties.

2. Finite element modelling and model updating

In order to facilitate this study, a top hat structure is selected as the representative structure of crash box (see figure 1). The configuration of the top hat used in this study are designed based on vehicle front substructures that are normally used in a car body which consists of dissimilar materials that are joined through spot welds. Two different types of steel used to make the top hat are joined together using resistance spot welding (RSW). Both materials are of different thickness; 1.0mm for the hat structure and 1.7mm for the flat surface. The geometrical dimensions of the structure are as shown in the figure 2.

The structure was modelled as surface where shell elements in quad shape are assigned to the model. In order to determine the appropriate element size, mesh convergence tests were carried out. The meshing properties for the top hat are shown in table 1. Material input for the structure was assigned as tabulated in table 2 below. CWELD element connectors were used to model the RSW joints between the flat and the top hat plate. CWELD element connectors were extensively utilized in modelling the spot weld joints due to the ability to replicate the stiffness of spot weld joints in the actual structure. The Young’s modulus and the diameter of the spot weld are declared to be 1000 GPa and 0.001m respectively. 20 CWELD elements are used in the FE model of the top hat (refer to figure 3).

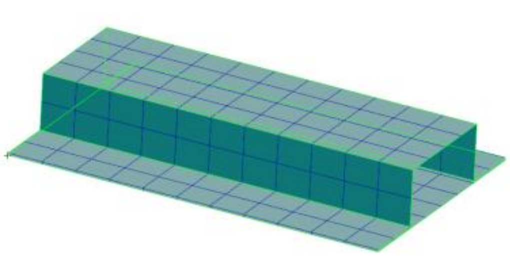


Figure 1. FE model of crash box structure.

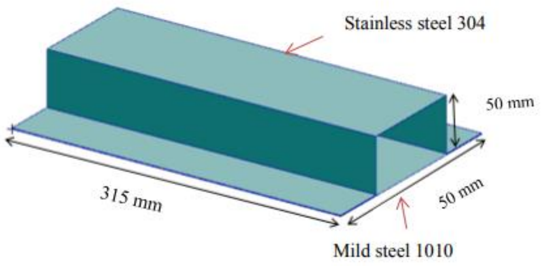


Figure 2. Dimensional value of crash box model.

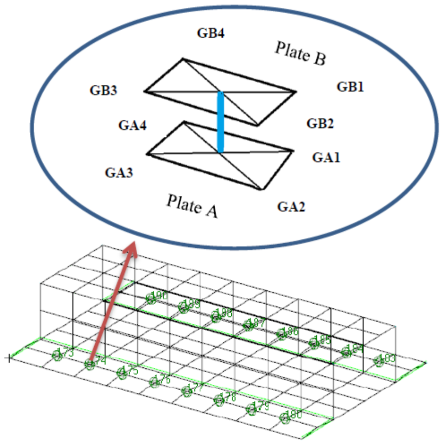


Figure 3. Location of spot weld joint.

Table 1. Meshing properties for top hat plate structure

Properties of meshing	
Element type	CQUAD4
Element number	171
Nodes number	266
DOF number	1330

Table 2. Input properties of material.

Material	Mild steel 1010	Stainless steel 304
Young’s modulus (GPa)	200	190
Density (kg/m^3)	8000	8030
Poisson ratio	0.33	0.30
Thickness (m)	0.0017	0.001

Model updating was performed on the finite element model of the crash box. Updating parameters were determined by conducting sensitivity analysis on all existing parameters of the crash box such as material and physical properties used for the model. These properties include the Young's modulus and density of mild steel and stainless steel, plates thickness, diameter of CWELD elements and Young's modulus of the CWELD elements. At the end, the sensitivity analysis had determined four parameters, which only involve the material properties of the model, as the updating parameters. Table 3 shows the updated values of each the updating parameters selected during sensitivity analysis. The value shown for updated model will be the properties used in the updated model.

Table 3. Updated values of updating parameters.

Material	Initial value	Updated value
Young's modulus of mild steel (GPa)	200	192.74
Young's modulus of stainless steel (GPa)	190	161.50
Density of mild steel (kg/m^3)	8000	9200.00
Density of stainless steel (kg/m^3)	8030	8142.42

3. Crashworthiness analysis

Crash simulation was performed on both initial and updated model in order to study the crashworthiness performance of both the initial and updated model. The rear part of the crash box is constraint to be fixed and the impactor, which is modelled as a box, is modelled as rigid (refer to figure 4). The velocity of the impactor is set to be 10 m/s. Hard-contact interaction was defined between the impactor box and the end of the box that is not declared as rigid with additional self-contact interaction between the two structures during the process of deformation. The friction coefficient is set as 0.2 and the time step is set as 10 ms.

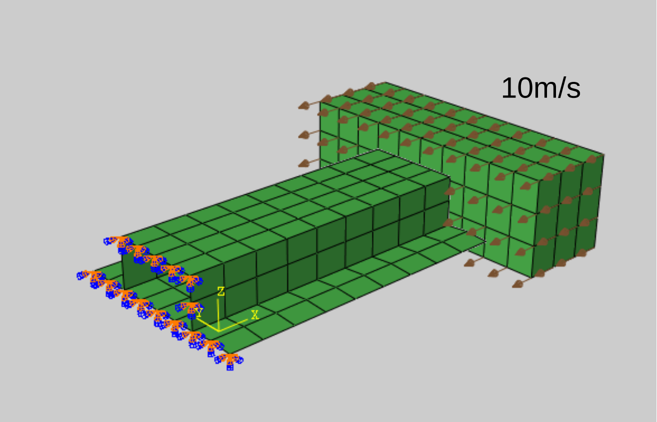


Figure 4. FE simulation set up in isometric view.

4. Crashworthiness of initial and updated crash box model

Several crashworthiness output are analysed in evaluating the crash behaviour of the initial model and updated model of the crash box. Figure 5 compares the velocity of the impactor in the direction of crash for both of the models, while figure 6 shows the resultant displacement of the impactor in both simulation of the different model. It appears that from the both figures, the updated crash box model is able to decelerate the impactor slightly faster than the initial model. Also, based on the displacement curve in figure 6, the crush distance of the updated crash box model is slightly shorter than the initial one which suggests that the updated model is capable of stopping crash faster that initial model [10].

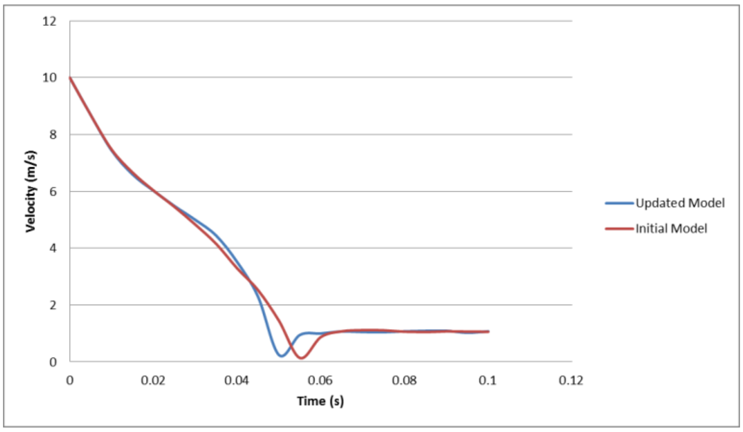


Figure 5. Velocity curve of impactor.

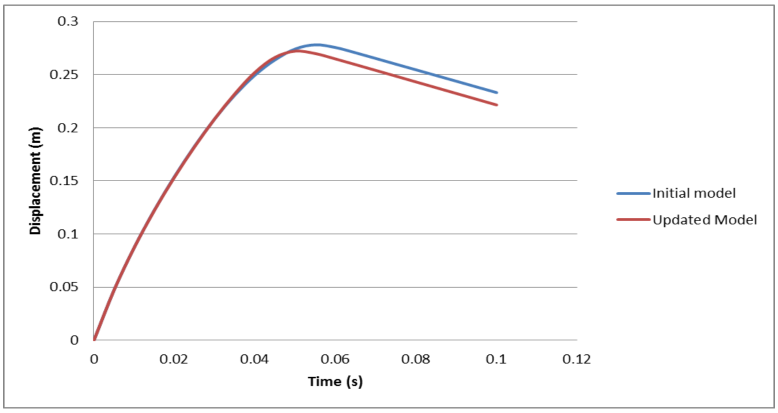


Figure 6. Resultant displacement of impactor.

During the time of impact by the rigid impactor, the impactor's kinetic energy was mainly dissipated by internal energy due to the crash box's deformation. The dissipated energy is considered as the energy absorbed by the crash box in order to prevent further crash on itself. The energy absorption ability is always considered as the key content of crashworthy structure. Figure 8 shows the change of energy between the impactor and crash box. It could be seen that both models absorb impact kinetic energy in almost similar behaviour. However, the kinetic energy is absorbed slightly faster than the initial model and therefore suggests that the updated model has slightly greater potential in enhancing the energy absorption capacity. This is consistent with the findings of a past studies that stated that energy absorption capacity is better when energy absorption process is completed faster [4,31].

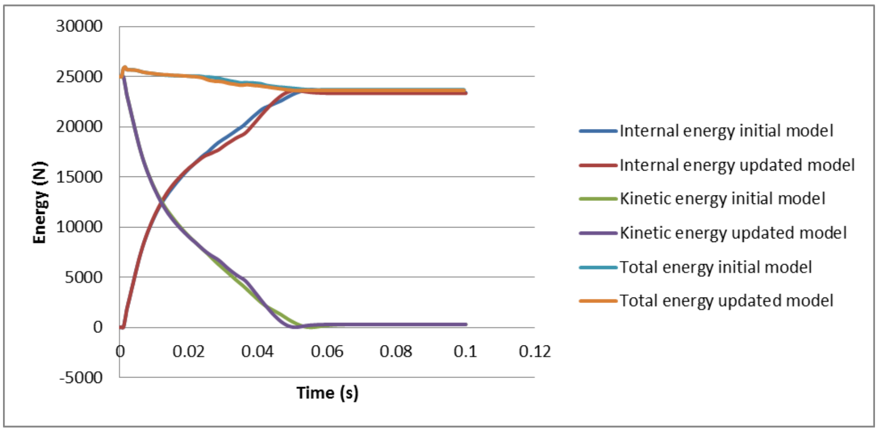
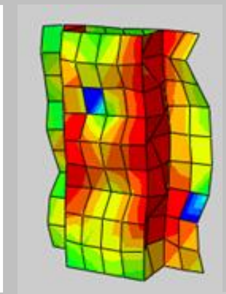
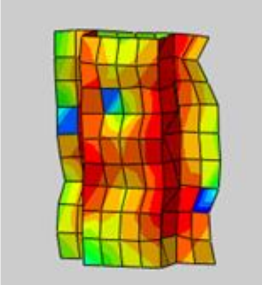
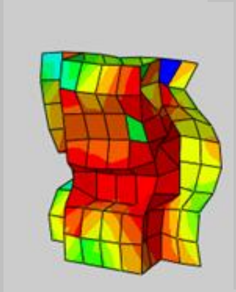
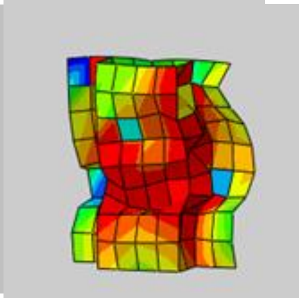
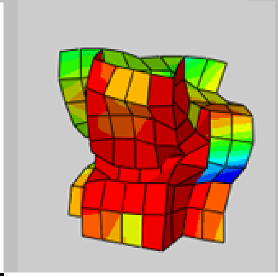
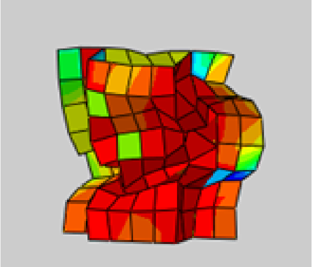
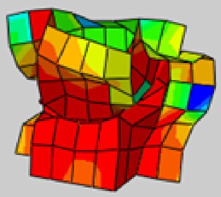
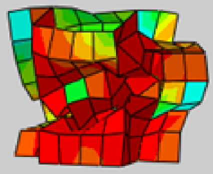
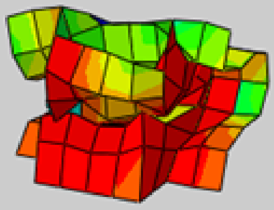
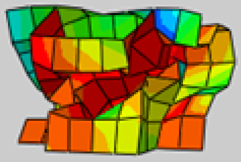
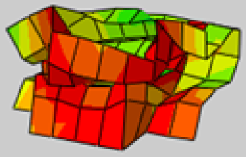
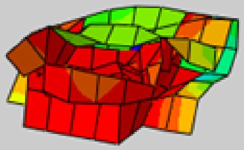
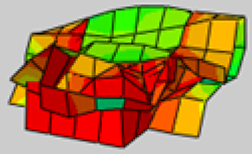
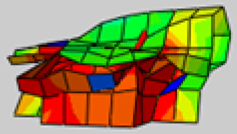
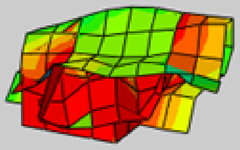
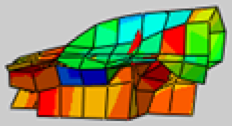
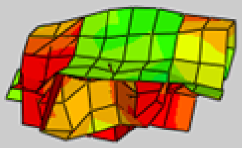


Figure 7. Energy balance for the whole model.

Table 4 shows the qualitative comparison of deformation for the initial and updated model. Comparison of crash box deformation during the impact is presented through sequential deformation in each time frame in the simulation. Although the pattern of deformation is almost the same, the stress distribution in each element is different in both models. In addition, the pattern of deformation started to behave a bit different at step time 15 ms onwards.

Table 4. Sequential crush behaviour of crash box in stress distribution.

Step time (s)	Initial model	Updated model
0.005		
0.010		
0.015		

0.020		
0.025		
0.030		
0.035		
0.040		
0.045		
0.050		

5. Conclusion

This study has been set out to investigate and compare the crash behaviour of a crash box design using two different finite element models, which is the original and the updated model. Some important observations are noted, which show that the initial and updated model of the crash box in this study, do have different crash behaviour. However, the percentage of the difference is relatively small. In the terms of crashworthiness performance, even though the updated model shows slightly better crash characteristics, it would be less significant to stress out its performance since the model only outshine the other model in just a slight manner. It is more significant if the crash outputs of both models are correlated with the output of crash experiment. This research will serve as a base for further studies of investigating the performance of updated finite element model in simulating the crash behaviour of its actual structure. Further work needs to be done where the method of validation for the updated model in terms of crash behaviour is highly needed in order to determine the level of accuracy of the information provided by the updated model in terms of crashworthiness.

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