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Design optimization of passenger SUV's crash box and bumper beam by using finite element method

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Abstract. The accident cases with front crash type occupy the largest data statistics with 7,372 cases. Theoretically, the accident cases which involve passenger cars, kinetic energy is absorbed by the complex system. Some components which are included in the system are crash box and bumper beam. The main purpose of this research is to obtain the absorption of kinetic energy when the accident happened, types of deformation, and optimization in the existing designs of crash box and bumper beam from vehicle unit. Finite element method combines with analytical value are used in the simulation. Whereas, the software used in solid modelling is SolidWork and the numerical analysis used in this research is Abaqus / Explicit. The average reaction force through simulation is obtained by averaging the results of curve plotting, while the average reaction force is obtained through formula analysis by taking material property and dimension data and then inputting it in the calculation. From the simulation, energy absorbed is 9,912 Joule from the whole original structure. The energy absorbed is less than the crash box work which is 14,066 Joule within an error value of 22 %. This is caused by the bending moment which is emerged by bumper beam. Then, optimization is done by increasing lateral lengths of bumper beam with 20 mm, 15 mm and 10 mm, therefore energy absorption increased with 20,362 Joule, 31,886 Joule and 16,348 Joule, respectively.

1.Introduction

Motor vehicle is a means of road transportation which is most popularly used by Indonesian people. In its operation, passenger vehicle also has risk of accident, several cases of accidents such as head-on collision, side collision, single-vehicle accident and so on. Head-on collision cases are on the highest position with 7,372 cases from the total of 27,265 cases [1]. When head-on collision happens, there is energy absorption management which involves a component called crash box and bumper beam whose function is to absorb the energy from the impact when a head collision happens. In the Asean NCAP 2017 [2], vehicle got the predicate of a 5-star car. With the result of good and adequate for the driver and good for the passenger next to driver [3]. In this research, the author will try to present crashworthiness analysis specifically for crash box and bumper beam part with finite element method also the possibility for design optimization of those components.

When there is a front crash there is energy absorption management, one of which involves components called crash boxes and bumper beams. The installation of crash boxes and bumper beams on vehicles is part of passive safety. Crash box and bumper beam is a passenger car part located behind the plastic bumper and in front of the front rail/chassis. Tasked with receiving impact energy in the event of a front crash. Crash boxes and bumper beams are not alone in absorbing hit energy, but assisted by other components such as chassis, front body and so on [4].

Characteristics of energy absorption hit on the crash box can be said to be unique, because it absorbs energy by buckling or bending lengthwise in the direction of the elongated axis of the vehicle. Research on Crashworthiness has grown rapidly in recent years in Indonesia, most conducted by educational institutions such as high-profile institutions [5]. Research on Crashworthiness requires complex facilities and infrastructure and requires a large cost investment, can be done by physical testing by reconciling actual accident cases and can also be done by numerical approach method. Crashworthiness is intended to ensure passenger safety in the event of a collision can also be intended for vehicle certification activities. In this study, the authors present a special crashworthiness analysis on the crash box and bumper beam with element method up to or finite element method and possible design optimization on the component.

Energy Absorption Theory is energy given at the time of an accident where type of mechanical energy is more precisely kinetic energy, and kinetic energy is energy stored in an object with the mass of *M* at the speed of *v*. When two structures collide, the stored energy must be transformed into another form. Another form in question is a change in the shape or deformation of the structure of the vehicle. Deformation can be in the form of long inactivity or shortening of a structure. The increase in length when the impact load attracts a structure and shortens when the load is the impact suppresses the structure. The equation below is a form of energy immortality, in which kinetic energy is transformed into structure shortening (δ^2_{max}) [6]. Where the energy or work is defined as in the formula below:

$$\frac{Mv^2}{2} = \frac{EA\delta^2_{max}}{2L} \tag{1}$$

To get δ^2_{max} the formula is simplified to:

$$\delta_{max} = \sqrt{\frac{Mv^2L}{EA}} \tag{2}$$

The formula is applied when the object or test specimen is in the form of a rod or does not have a hollow. While in Structural Impact, in the structure of crash boxes square type/square has a bending value of plastic moments per unit length of

$$M_0 = \frac{\sigma_0 H^2}{4} \tag{3}$$

Where :
M_0 = Bending moment of plastic per unit length
H = Crash box thickness (mm)
σ_0 = Yield stress (MPa)

$$\frac{P_m}{M_0} = 52.22\left(\frac{C}{H}\right)^{1/3}\left\{1 + \left(\frac{0{,}33\,V_0}{CD}\right)^{1/q}\right\} \tag{4}$$

Pm = The average of force used to deform the crash box on a certain length
V_0 = The average length of crash box's sides (the median of crash box's length and breadth)
C = The speed when the collision happen
D and q : Predetermined constant of equation.

2. Materials and Research Method

The materials used in this study were crash boxes and bumper beam RE1 (4x2) M/T, with the name in the products catalogue is Beam Comp Front Bumper, part number 71130-SWA-000ZZ [7]. Crash box and bumper beam is a spare part assembly or assembled spare part. If it is decomposed, there are a total of 11 parts, 10 parts are symmetrical right and left parts and 1 connecting part is a bumper beam. The assembly of the 11 parts is using welding. Part assembled crash boxes and bumper beams are seen in the Figure 1. In the figure, there are two front and rear bumper arrangements, includes mountings, plastic body, number plate mounting and radiator mounting.

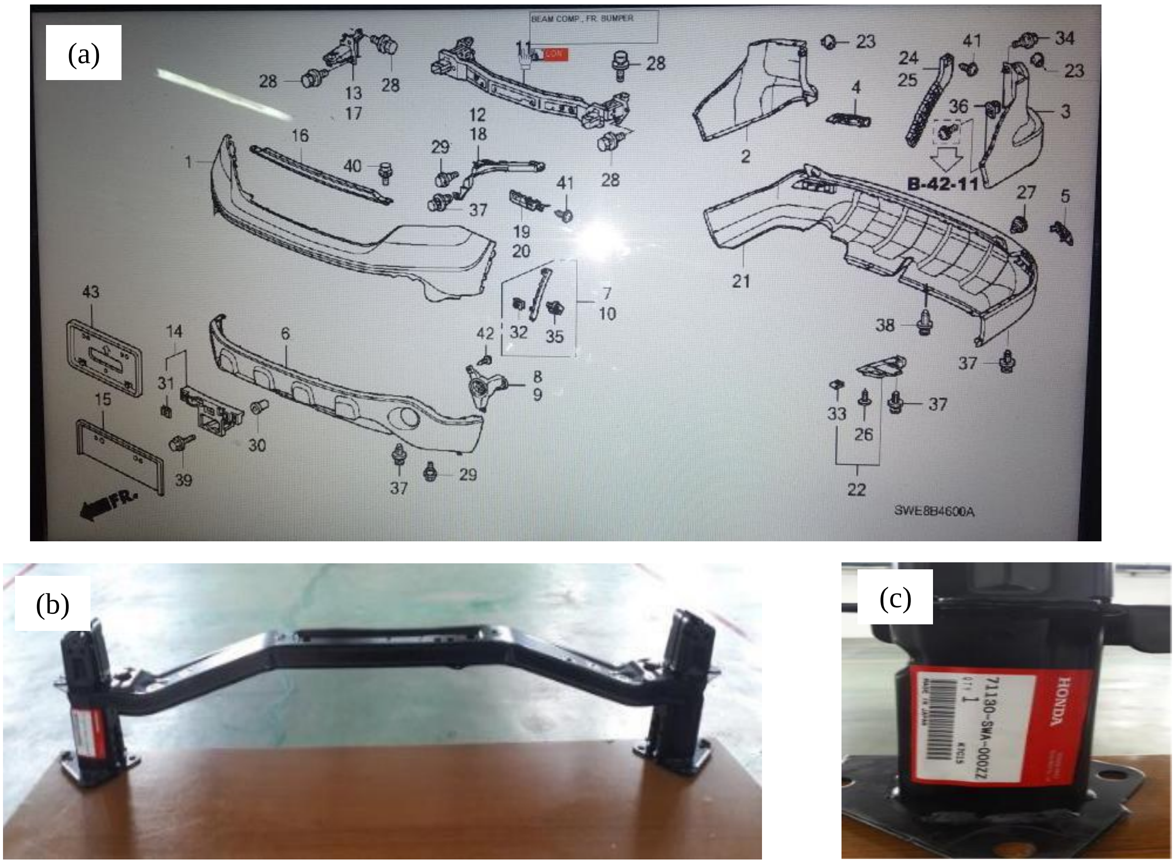


Figure 1. Crash box and bumper beam assembly : (a) assembly diagram; (b) assembly spare part; (c) spare part number.

The material data used for the structure of crash boxes and bumper beams are tabulated in the Table 2:

Table 1. Materials and thicknesses used in crash box and bumper beam [8]

No	Part Name	Materials	Thickness (mm)
1.	Bumper Beam	JSC 440W	1.4
2.	Front Crash Box Rear Crash Box	JSC 780Y	1.8
3.	Right Support Left Support	JSC 780Y	2.2

The data in Table 2 are property materials in materials used for bumper beam structure and crash box structure of JSC 440 W and JSC 780 Y.

Table 2. Mechanical properties JSC 440W and JSC 780Y

No	Material Properties JSC440W		Value	Unit
1.	Density		7800 7.8 x 10^{-9}	Kg/m^3 Tonne/mm^3
2.	Elasticity	Young's Modulus	270 2.7 x 10^5	GPa MPa
		Poisson's Ratio	0.3	-

No	Material Properties JSC 780Y		Value	Unit
1.	Density		7800 7.8 x 10^{-9}	Kg/m^3 Tonne/mm^3
2.	Elasticity	Young's Modulus	400 4 x 10^5	GPa MPa
		Poisson's Ratio	0.3	-

In this research the authors used several data collection techniques as mentioned in the points below. Data collection techniques used by the authors in the study are (see Figure 3):

1. Direct Observation Technique, this is done directly by the author when measuring dimensions and geometry on the research object of this final task, namely crash box and bumper beam.
2. Document Engineering is performed when the author searches for property material references.
3. Interview techniques will be conducted to the holder of vehicle brands that crash boxes and bumper beam beams will be analyzed in this research.

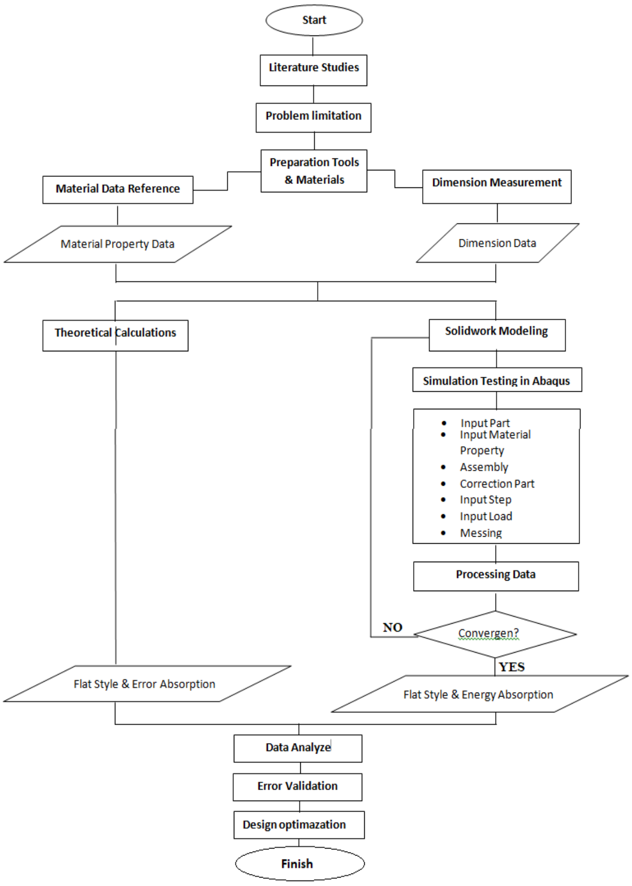


Figure 3. Research flowchart

While the data management techniques used by the authors in this research are by the use of number management software or commonly called Microsoft Excel and other programs needed in data processing. Technical implementation of data collection in this research is as follows:

1. Measurement of dimensions of crash boxes and bumper beams using dimension measuring instruments such as what has been described in the tool and material parts.
2. The shape of the crash box is getting smaller towards the front of the vehicle, causing the area of the cross-section is not the same, will be taken cross-sectional area and determined the area of the cross-section average, namely the middle value of both ends of the profile crash box.
3. Sampling displacement, initial speed, initial acceleration, reaction force and energy absorption are done by setting the research time step and iteration time and will be done automatically by CAE software. For example, we will examine a collision for 6 milliseconds, while the iteration we input is 50. Then sampling data will appear at 0 s, 1ms, 2ms, 3ms and so on up to a full time of 6ms.

3. Results and Discussion

The modelling conducted on Solidworks software obtained four components which were assembled in an assembly [9]. The assembly is as shown in the Figure 4 below:

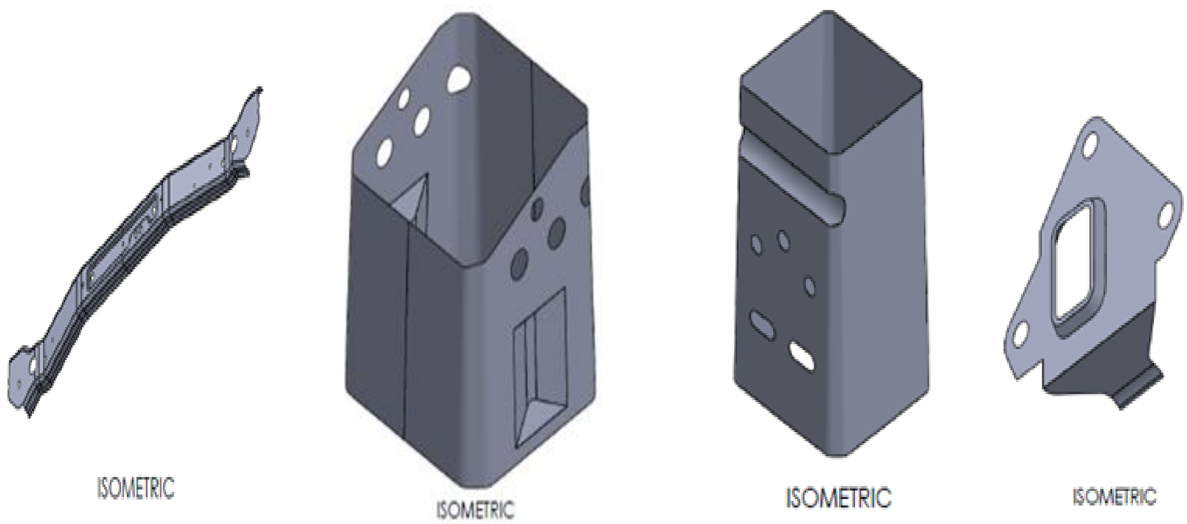


Figure 4. The result of Crash Box and Bumper Beam modelling by using Solidworks software.

The material used for Bumper Beam is JSC 440W with 1.4 mm thickness and for Crash Box is JSC 780Y with 1.8 mm thickness [10]. Results from the tensile test are shown in Figure 5.

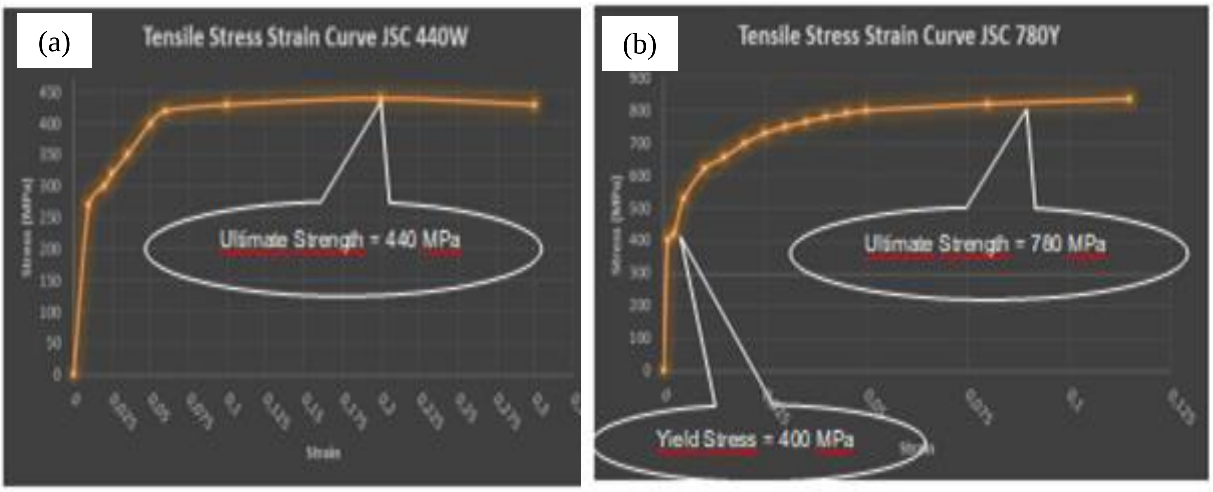
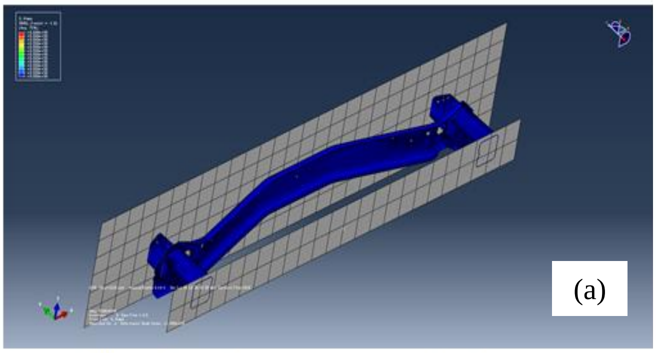


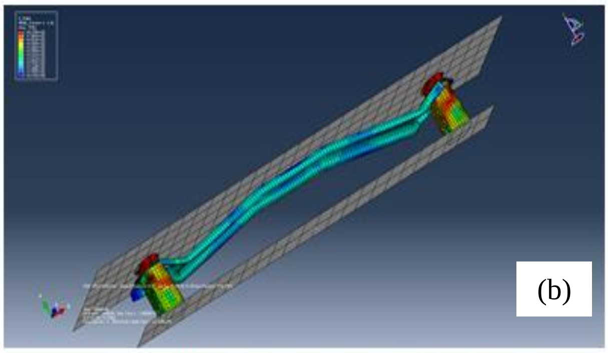
Figure 5. Tensile stress-strain curve: (a) material JSC 440W; (b) material JSC 780Y.

After the simulation was carried out on Abaqus/Explicit then it was found out that the total structural deformation was as far as 95.33 mm and average reactional force as many as 103,765 Newton. The visualization is as shown in the Figure 6.

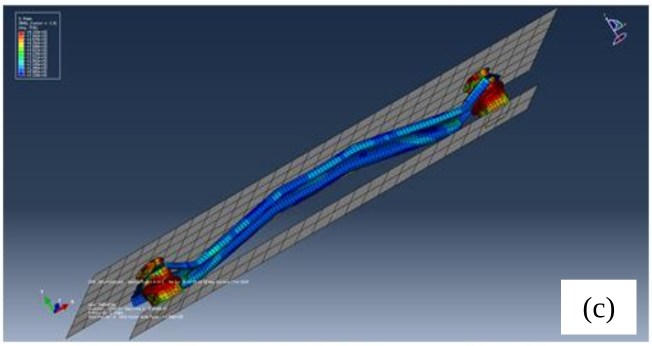
Thus it is expected that the crushing energy absorbed by the whole structure of crash box and bumper beam as many as 9,912 Joule. It can be seen from the result of the simulation that the type of deformation that happened to the crash box was buckling type and the deformation that happen to the bumper beam was bending [11-15].



Initial Conditions Before Optimization Structure Deformation



Current Condition of Deformation of Optimization Structure



Final Condition After Optimization Structure Deformation

Figure 6. The visualization Crash Box and Bumper Beam by using Abaqus/Explicit : (a) condition before optimization; (b) current condition optimization; (c) after optimization

While the result of manual calculation from the work of the crash box only generated 14,066 Joule of absorbed crushing energy. This is considered as a handicap when the crash box is working on its own the performance of energy absorption is reduced by the bumper beam [16]. To find out the error value that happens, the author conducted a simulation test partially on the crash box. The result of the simulation indicated the amount of energy absorption of 18,260 Joule, with the error value of 22%.

The error value happens because the author omitted the crash initiator and stiffness which can be found in the crash box. Therefore in the analytic calculation by using the formula, crash box is considered as thin-walled square tube. The analysis can be seen briefly in Table 3.

Table 3. The result of bumper beam optimization variation

Analysis Type	Object of analysis	EA Performance (J)	Error Value
Simulation	Crash Box and Bumper Beam	9,912	Not Compared
Simulation	Crash Box	18,260	22 %
Calculation	Crash Box	14,066	

Next, the author conducted design optimization on the bumper beam. This optimization was based on the front-most point of the bumper beam in the original structure is a bit more backward compared to the structure crash box and bumper beam of other vehicles.

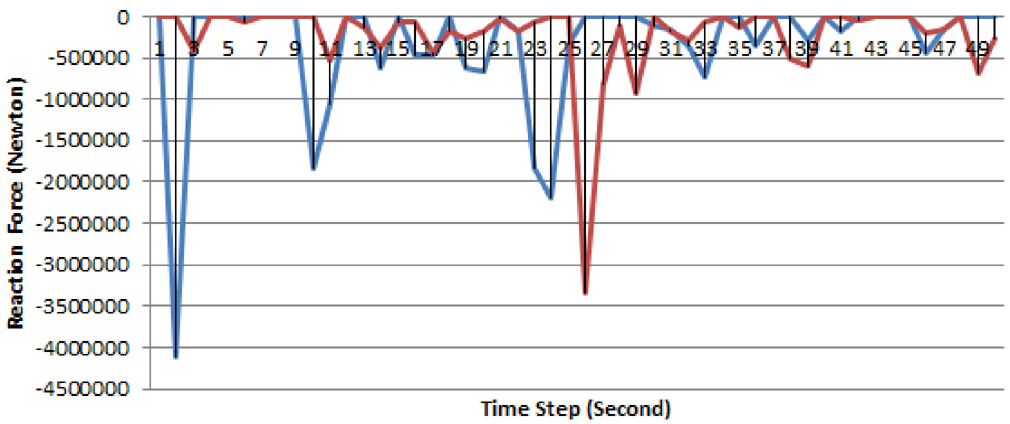


Figure 7. Comparison reaction forces between original structure and optimization structure.

The optimization was conducted with 3 extension variations which are 10 mm, 15 mm and 20 mm, with displacement variation and Mean Crushing Force variation. The optimization showed increasing in the value of crushing energy absorbed by the structure. The result is as shown in the Table 4 below.

Table 4. Simulation result on design optimization variation.

No	Optimization Variation (mm)	Mean Crushing Force (N)	Displacement (m)	Absorbed Kinetic Energy (J)
1	10	179,660	0.09099	16,348
2	15	350,636	0.09094	31,886
3	20	223,100	0.91270	20,362

The result of the above optimization indicated the increase in kinetic energy absorption in the case of head-on collision [17]. From the optimization data, it is concentrated that, by increasing the length of the bumper beam in the lateral direction of the vehicle will increase energy absorption. The previous 9,912 Joules rose to 16,348 Joules for 10 mm optimization, 31,886 Joules for 15 mm optimization and 20,362 Joules for 20 mm optimization.

4. Conclusion

The kinetic energy absorbed during the crash test simulation of the complete structure (crash box and bumper beam) is 9,912 Joules. A smaller value when compared to the kinetic energy that the crash box can absorb, which is 14,066 Joules. Validation the error, when compared to the crash box simulation test alone, is 18,260 Joules, which is 22%. The deformation characteristic of the crash box is buckling and what occurs in the bumper beam is bending. Optimization of the crash box and bumper beam structural design can be done by increasing the lateral length of the bumper beam by 10 mm, 15 mm and 20 mm. The value of kinetic energy obtained after optimization increases from 9,912 Joules to 16,348 Joules for optimization of 10 mm length, 31,886 Joules for optimization of 15 mm length and 20,362 Joules for optimization of 20 mm length.

Acknowledgements

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