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COMPUTER SIMULATION INVESTIGATION OF CRASH BOX DESIGN AS SAFETY-PROTECTION TECHNOLOGY FOR INDONESIA HIGH SPEED TRAIN

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Abstract

The crashworthiness of a railway vehicle has been developed to provide energy absorption capacity and efficiency of energy absorption. This study presents a computer simulation to determine the energy-absorbing structure of the new addition of a crash box design on the Indonesian high-speed train in a collision scenario. The crashworthiness analysis in the crash box is done with software based on finite element methods. The crash box is modeled as a thin-walled structure located in coupler housing, between the draft gear and the car frame. The test model was carried out according to the 2019 SNI 8826 standard using a frontal impact test with an impactor mass of 38.807 kg and a speed of 10 m/s. The pattern of deformation and energy absorption is obtained by calculating the area under the graphical curve of the relationship between the force reaction and the displacement obtained from the simulation. The deceleration of the train is obtained from the graph of acceleration against time on the impactor. The simulation results show that the addition of a crash box design as an energy absorption module on a safety protection technology for railway vehicles can reduce the severity of the impact and improve passenger safety. The application of the initial crash box model also shows an unacceptable train deceleration in the SNI 8826 test standard.

Keywords: Crash Box, Energy Absorption, Finite Element Analysis, High-Speed Train, Crashworthiness.

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1. INTRODUCTION

Collision accidents on trains are much lower than on other transportation methods, but the effect of train weight results in serious casualties and economic losses from collision accidents [1]. Thin-walled steel structures as energy absorbers have been widely used due to their excellent energy absorption capacity and extraordinary lightweight[2]. Alavi Nia and Parsapour (2013) examined the crashworthiness of single-cell and multi-cell batteries and found that adding partitions would help increase energy absorption in crash boxes[3]. Multi-cells with different segments have been studied by Kim (2002), Zhang et al. (2006), and Najafi and Rais-Rohani (2011), who showed that the specific energy absorption (SEA) value of a multi-cell is higher than that of a single-cell. Many studies on energy absorption structures are used for automobiles, and there are few references with respect to railway vehicles[4–6].

SNI 8826 is an Indonesian standard (SNI) that regulates crashworthiness requirements for railway vehicle bodies. The objective of the requirements described in the standard is to reduce the consequences of collision accidents. The measures considered in this standard

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provide the last means of protection when all possibilities of preventing an accident have failed. It provides a framework for determining the crash conditions that railway vehicle bodies should be designed to withstand based on the most common accidents and associated risks. In this study, a crashworthiness analysis of multi-cell crash boxes for Indonesia high-speed trains was carried out using computer simulations based on the 2019 SNI 8826 standard.

2. METHOD

The crash box is a passive safety system on the car that is used to minimize engine damage or fatalities by converting impact energy to strain energy and converting it into a deformation pattern on the crash box. Structure geometry, materials, and loading condition are design parameters affected by the energy absorption of the crash box[7]. Energy absorption (EA) is the ability of the crash box to absorb impact energy when a collision occurs. The energy absorption is obtained by calculating the area under the reaction force and displacement curves. Energy absorption in the crash box can be analyzed by equation 1.

$$EA = \int_0^{\delta} f(x)\,\mathrm{d}x \tag{1}$$

Where F(x) is the crushing force in the axial direction and δ is the crash box displacement after the collision. The minimum value of δ is 2/3 of the crash box length[8].

Specific energy absorption (SEA) is one of the most important performance indicators in energy absorption devices, particularly when a weight reduction goal is pursued. It is defined as the ratio between the absorbed energy and the mass of the specimen (m) [9]. Specific energy absorption in the crash box can be analyzed by Equation 2.

$$SEA = \frac{EA}{m} \tag{2}$$

Where EA is the energy absorption and m is the crash box mass (Costas, 2013).

2.1. Railway Vehicle Categories and Crash Scenario

For the application of the 2019 SNI 8826 standard railway vehicles are classified into crashworthiness design categories. Railway vehicles are divided into four categories as indicated in Table 1.

Table 1. Railway Vehicle Categories (Indonesian National Standarization Board, 2019)

Category	Definition	Examples of Vehicle Types
K-I	Inter-city trains with operating speeds of up to 200 km/hour	Locomotives, trains
K-II	trains with dedicated railway infrastructure	MRT, LRT, Air-propelled trains, AGT (Automated Guideway Transit)
K-III	urban railways with level crossings	KRD, KRL
K-IV	light rail specifically designed and operated in urban areas that are on the same level as the road	Tram trains

Crash design scenarios are created to represent the most common crash situations and the ones with the most fatalities.

1. Collision at the fore-end between two identical train sets;
2. Collision of the front end with non-identical train sets;

3. Collision at the front end of a train unit with motorized vehicles at level crossings;
4. Collision of a rail unit with light obstructions (e.g. animals, rocks, fallen trees).

Table 2 summarizes the design scenarios of collisions between railway facilities with different design categories and different operating conditions in the validation of collisions.

Table 2. Crash Design Scenario (Indonesian National Standarization Board, 2019)

Design Collision Scenario	Collision Obstacle	Operational Characteristic of Requirement	Collision Speed – km/h				Collision Conditions
			K-I	K-II	K-III	K-IV	
1	Identical Train Unit	All Systems	36	25	25	15	Identical Train Unit
2	72 ton (the total weight of the rolling stock and cargo)	Mixed traffic with vehicles with a central coupler	36	n.a.	25	n.a.	See C.1 and C.2
3	15 ton obstacle	Level crossing	V – 50 ≤ 100	n.a.	25	n.a.	See C.3 and C.4
	3 ton obstacle		n.a.	n.a.	n.a.	25	
4	Light obstacle	adapted to the obstacle deflector	See Table 3	n.a.	See Table 3	n.a.	See 6.5

From Tables 1 and 2, computer simulation of the Indonesia High-Speed Train is modeled with K-I and Scenario 1 (identical train collision with a speed of 36 km/h).

2.1.1.Deceleration

The average longitudinal deceleration in the survival space must be limited to 5g for scenario 1 and scenario 2 (Indonesian National Standarization Board, 2019). The deceleration can be calculated by equation 3.

$$a=(v^2-u^2)/2s \tag{3}$$

where v is the final velocity, u is the initial velocity, and s is the crash box displacement after the collision.

2.2. Crash Box Geometry

Figure 1 shows the space available for the multi-cell crash box model on the Indonesian High-Speed Train. The Crash Box consists of four blocks of aluminum extrusion cut curved on the sides. Figure 2 shows the geometry of the aluminum extrusion beam designed by PT. INKA (Persero).

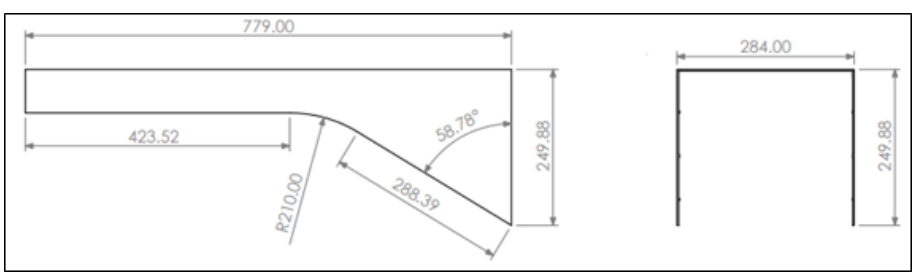

Figure 1. Available Space for Crash Box Model

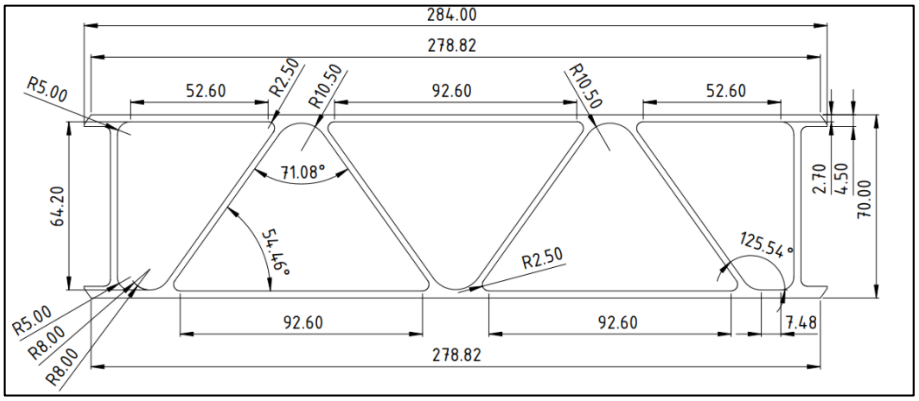

Figure 2. Initial Multicell Design by PT. INKA (Persero)

Table 3. Aluminum Alloy 6061 Properties

Properties	Value
Density [kg.m^{-3}]	2713
Young's Modulus [GPa]	69.04
Poisson's Ratio	0,3
Bulk Modulus [MPa]	67.686,27
Shear Modulus [MPa]	25.954,88
Yield Strength [MPa]	150
Tangent Modulus [MPa]	450
Specific Heat Constant Pressure [J/kg.m]	915.7

Table 4. Structural Steel Properties

Properties	Value
Density [kg/m^3]	27.523.937,86
Elastic Modulus [GPa]	200
Poisson's Ratio	0,3

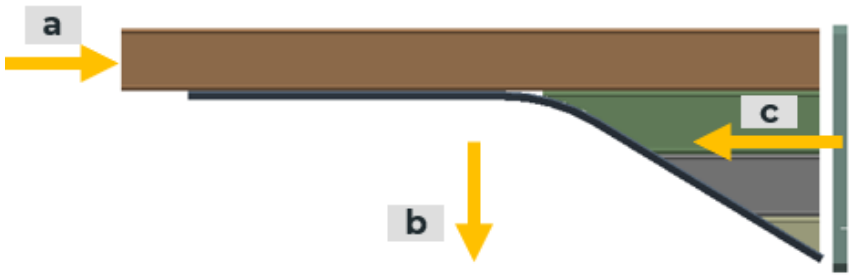

Figure 3. Load simulation settings with (a) is fixed support, (b) is earth gravity (9.807 m/s2), and (c) is the impactor.

3. RESULTS AND DISCUSSION

In the frontal load test mechanism, the impactor pushes the crash box, and the impactor's collision energy is converted into strain energy, resulting in a change in the shape of the crash box. Strain energy is obtained from the area under the curve between force reaction and displacement, with the strain energy assumed to be the same as the kinetic energy converted from the impactor.

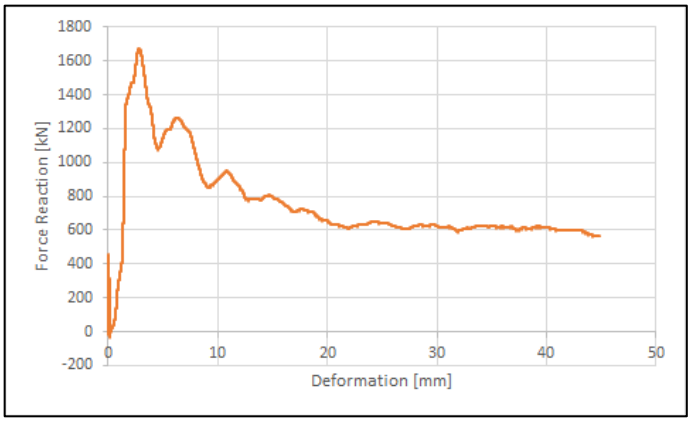

Figure 4. Force Reaction vs Deformation Curve

Figure 4 shows the curve between force reaction and deformation. From the calculation of the area under the force reaction and deformation curves, the energy absorption (EA) value is 34,256 kJ. Crash box mass is 32,006 kg, then a specific energy absorption ratio of 1.07 kJ/kg is obtained. From the simulation results, it is proven that the crash box is able to absorb energy and reduce impact energy during a collision before it is passed on to other components[10]. From Figure 4, it can be seen that the deformation occurred up to 45 mm, which is a fraction of the total length of the crash box, which is 779 mm. The impactor pushes the crash box, and energy absorption also reduces the speed of the impactor[2,11]. Deceleration needs to be limited because, during high-value deceleration, train passengers can experience secondary collisions.

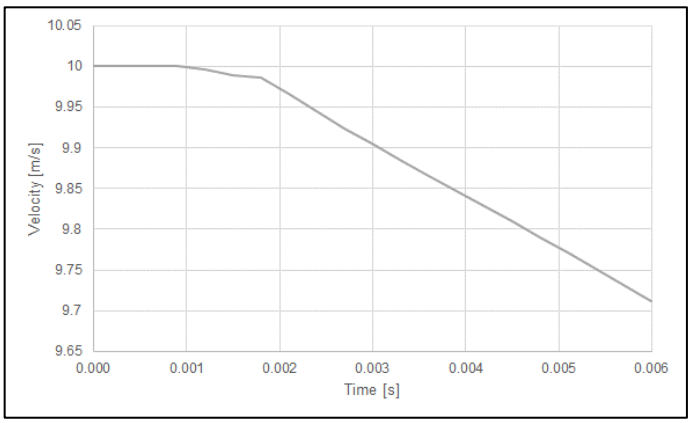

Figure 5. Velocity vs Time Curve

Figure 5 shows the speed versus time curve. From the calculations, it is obtained that the average deceleration (a) of the impactor due to the impact scenario with a crash box is 99.91 m/s2 or 10.187g. From the simulation results, it was found that the crash box design still does not meet the 2019 SNI 8826 deceleration standards.

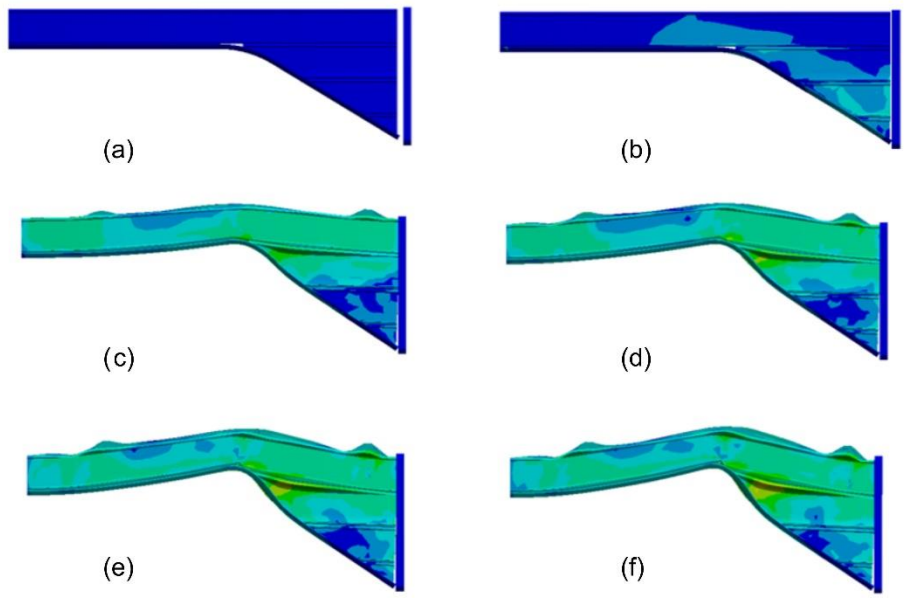

Figure 6. Deformation pattern on time step (s) : (a) 0.001 (b) 0.002 (c) 0.003 (d) 0.004 (e) 0.005 (f) 0.006

From Figure 6, it can be seen that as time increases, the impactor approaches until it hits the crash box. The deformation that occurs is localized upward buckling in the center of the crash box. Areas in blue receive the lowest stress (example: deformation pattern 0.001 s); green indicates a higher stress than blue (example: deformation pattern 0.003 s); and yellow indicates a higher stress than green (example: deformation pattern 0.005 and 0.006 s). This condition shows that the curvature at the bottom of the crash box and its cover concentrates the stress in that area[9,12]. As the applied stress increases, the curvature will deform first and push the crash box upwards.

4. CONCLUSION

The addition of a multi-cell box has an important effect on increasing energy absorption performance. The absorption of energy in the initial crash box model causes a deceleration that does not meet the 2019 SNI 8826 standards because deformation patterns are dominant in buckling mode.

5. ACKNOWLEDGMENTS

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