

THE ANALYSIS OF ELVIRA EV-1 CHASSIS MECHANICAL PERFORMANCE WITH VARIOUS BEAM CROSS-SECTION

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Abstract

Elvira EV-1, as an electric vehicle (EVs) has become one of the latest developments that contributes to achieving sustainable and reliable transportation. These EVs were built to serve as a relevant solution for campus operational mobility. However, at the core of its framework system, Elvira EV-1 still uses a ladder-type chassis, which is inferior to other types of chassis in terms of torsional rigidity. Therefore, to enhance its mechanical performance, this study determined the best option of beam cross-section for the Elvira EV-1 chassis. There were three types of the selected beam section, namely rectangular, I-beam, and C-channel. The mechanical performance of each type of chassis was examined using the Frame Analysis module provided by Autodesk Inventor. The results show that the rectangular chassis experienced the highest bending stress of the other types of chassis due to its low moment of inertia, which is almost 26.27% higher. Nonetheless, with the same setup, the shear stress that occurred at the C-channel type of chassis was greater than its material. The chassis would fail under the load subjected to it. Similarly, I-beam chassis has the maximum torsional stress greater than the yield strength of the material due to low torsional rigidity. In addition, the mass of the chassis with rectangular section provided a more lightweight structure, about 36,92% lower than the other type of chassis. According to these findings, it can be concluded that the chassis with a rectangular section has promising performance to be an option as the Elvira EV-1 chassis.

Key words : electric vehicle, frame analysis, cross-section, mechanical performance, stress

INTRODUCTION

Nowadays, the global transportation technology shown rapid development with a clear shift from the use of combustion engine vehicles to electric vehicles (EVs), which offer a more eco-friendly and energy-efficient vehicle [1]. In localized settings and limited range of transportation, such as university campuses, a small scale of EVs serve highly relevant solution for operational mobility. One of the innovation is the development of Elvira EV-1, an electric vehicle designed capable to carrying up to nine passengers and also build up as campus operational transportation, as shown in Figure 1.

Elvira EV-1 expected to have robust structural that ensures its durability, comfortable, and also safety to the passengers while remain lightweight and energy-efficient. The design of Elvira EV-1 prioritize simplicity, reliability, and cost-effectiveness, making it appropriate for operates at low speeds within short distance trips around the campus premises. In order to achieve

this, at the core of its framework system is using ladder-type chassis, a configurations conventionally used in commercial vehicle for its ease of manufacturing and robustness [2]. Generally, the ladder chassis consist of two longitudinal beams which connected by multiple cross members, which forming ladder-like structure [3], [4]. The ladder-type chassis offers advantages in load-bearing capacity and manufacturing simplicity; however, it is generally inferior to monocoque or space frame designs in terms of torsional rigidity [5]. To improve its mechanical performance while maintaining its weight, the selection of proper cross-sectional profile for the beam becomes essential.



Figure 1 Elvira EV-1

The geometry of chassis cross-sectional beam significantly influences the vehicles mechanical performance, such as strength, stiffness, and weight [6]. The study conducted by Zuo et al. (2016), which the analysis of sensitivity on vehicle body frames comprises of rectangular tubes, shows that the cross-sectional geometry play significant role to the stress distribution and deformation under dynamic loads [7]. Moreover, Kawamura et al. (2023) carried out the study on the cross-sections shape for automobile frame under multiple axial loads, demonstrated that hybrid and non-standard profile capable to improve its efficiency without increasing the weight [8].

Furthermore, in the context of EVs, Zhang et al. (2020) examined a light-duty electric truck's frame and created a finite element model to assess dynamic behaviour and load response, highlighting the significance of profile selection in enhancing durability and ride quality [9]. Moreover, Using finite element methods, Mureşanu et al. (2024) examined the crashworthiness of battery enclosure frames in EVs, highlighting the importance of structural profiles in energy management and rigidity under impact [10].

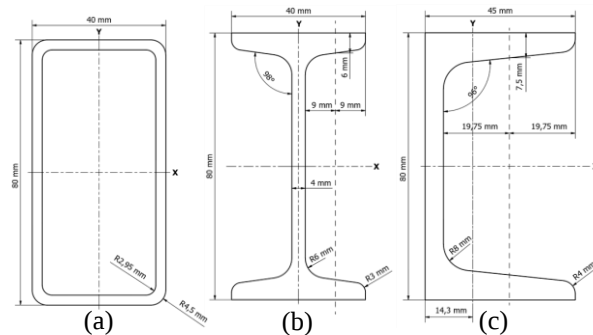


Figure 2 Beam section dimension, (a) rectangular; (b) I-beam (S-section); and (c) C-channel

Despite these developments, there is still a research gap that focuses on the mechanical analysis of ladder-type chassis for multi-passenger, low-speed electric cars that operate on campuses. Commercial vehicles and high-performance EVs, which have distinct design requirements and operating conditions, are the subject of the majority of existing research nowadays. Therefore, the purpose of this study is to use different cross-sectional profiles for the main longitudinal and cross members in order to examine and compare the mechanical behaviour of the Elvira EV-1 ladder chassis. Using finite element analysis to model realistic loading conditions, the study will evaluate performance in terms of bending stiffness, shear resistance, and torsional rigidity, and overall structural efficiency.

By addressing this research gap, the study will help improve the Elvira EV-1 platform and serve as a guide for the development of future EV chassis in applications that combine environmental sustainability, high occupancy, and low speed.

MATERIALS AND METHOD

In this study, three types of beam section were used to construct the Elvira EV-1 chassis, namely Rectangular, I-beam (S-Section), and C-Channel as shown in Figure 1, which each section according to ISO 657/14-2000, ISO 657/15-1980, and ISO 657/11-1980 standard, respectively [11]–[13]. The cross-section properties of each beam section presented in Table 1.

Table 1 Beam cross-section properties

Properties	Symbol	Unit	Beam Section		
			Rectangular [11]	I-Beam (S-Section) [13]	C-Channel [12]
Cross section area	A	cm ²	6.74	7.69	10.5
Area moment of inertia about x-axis	I _x	cm ⁴	54.2	77.7	102
Area moment of inertia about y-axis	I _y	cm ⁴	18	5.65	18
Polar moment of inertia	J	cm ⁴	43.8	9.61	1.92
Elastic section modulus about x-axis	W _x	cm ³	13.6	19.4	25.6
Elastic section modulus about y-axis	W _y	cm ³	9	2.82	5.85

Properties	Symbol	Unit	Beam Section		
			Rectangular [11]	I-Beam (S-Section) [13]	C-Channel [12]
Torsional section modulus	W_z	cm^3	15.3	1	1.727
Radius of gyration about x-axis	i_x	mm	2.84	3.18	3.12
Radius of gyration about y-axis	i_y	mm	1.63	0.857	1.3

Moreover, the chassis were designed using Frame Generator (FG) module which provided by Autodesk Inventor. The first step to this process was importing the sketch chassis into assembly file, then each line of the sketch were defined as beam with selected profile. The generated chassis are shown in Figure 3. The chassis has overall dimension which were 4055 mm $\times$ 1340 mm $\times$ 8 mm with 3380 mm wheel base, and 1060 track width.

After the chassis were generated, the next step was Frame Analysis (FA) which is a static analysis module of a structural frame, and this was also provided by Autodesk Inventor. The basis of FA was Finite Element Method (FEM) which is an analytical method using numerical technique to find the solution to the certain problems of partial differential equations by narrow down them to algebraic equations [14]. To perform an FA, there were several behaviour need to be assigned, namely material, constraint, and loads. The material of Elvira EV-1 chassis was using S235JR steel or well known as St37-2 steel which its properties was standardized by EN 10025-2:2004 standard [15], as presented in Table 2.

Table 2 Properties of S235JR (St37-2) steel [15]

Properties	Symbol	Unit	Value
Density	ρ	g/cm^3	7.85
Poisson's ratio	ν	-	0.3
Yield strength	σ_y	MPa	235
Tensile strength	σ_u	MPa	360
Young's modulus	E	GPa	205
Shear modulus	G	GPa	80

Moreover, the constraint of the chassis were four support, which was a floating pinned support and each of it located at main beam where the wheel axis was rested. The front support position was 252.45 mm from forefront, while the rear support located at 250.16 mm from the rearmost of the chassis, as shown in Figure 4. Meanwhile, the load subjected into the chassis was continuous load type and located at the top of the four longitudinal beam with total length of the load was 12,000 mm and with 1 N/mm magnitude. Therefore, the force total experienced by the chassis was 12,000 N or equal to 1,223.24 kg. The material, constraint, and load were the same for each type of chassis.

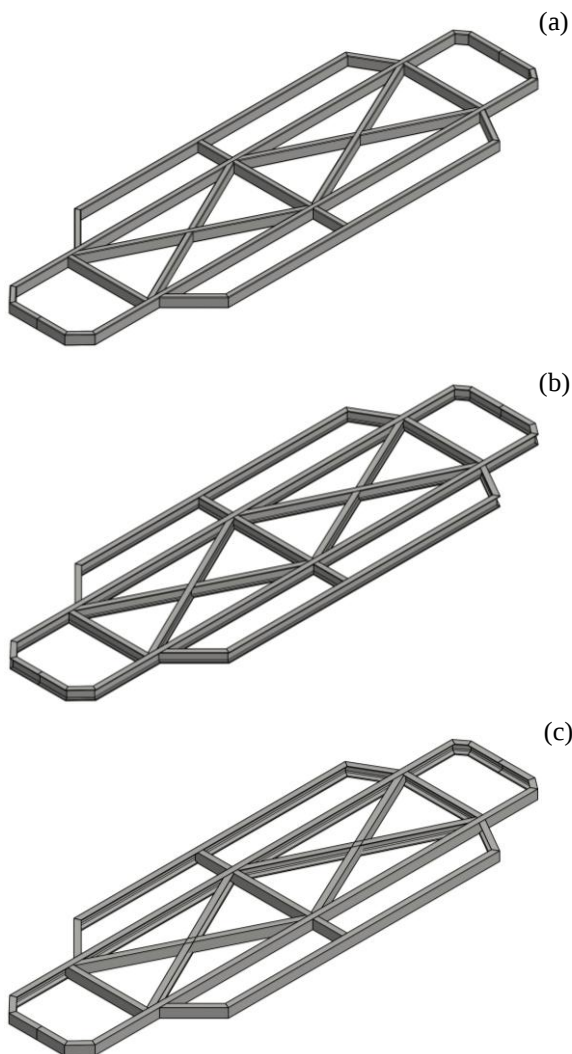


Figure 3 Generated chassis with (a) rectangular; (b) I-beam (S-section); and (c) C-channel section

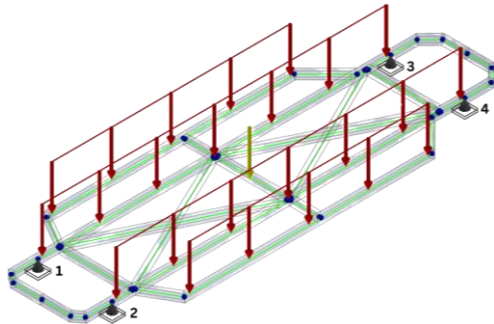


Figure 4 Chassis support and load location

RESULTS AND DISCUSSION

Frame analysis was conducted to determine the mechanical performance of Elvira EV-1 chassis with various beam section, namely rectangular, I-beam (S-section) and C-channel. The examined mechanical performance were displacement, bending, shear, and torsional stress. The analysis result respectively shown in Figure 5, 6 and 7 for each mechanical performance. The mass, displacement, and bending stress also presented in bar chart as shown in Figure 8, in order to simplify the discussion.

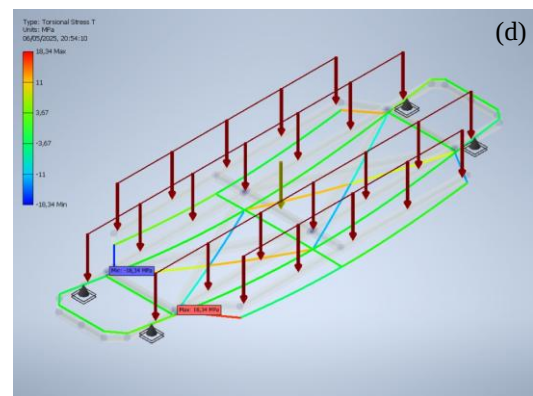
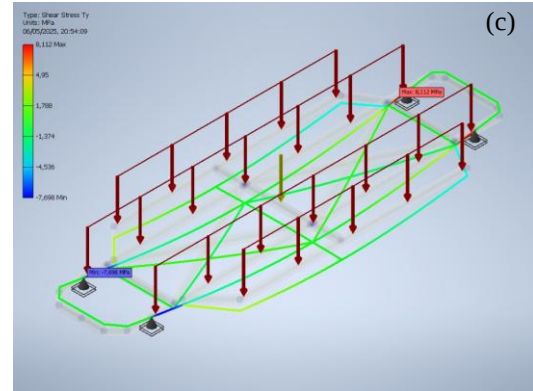
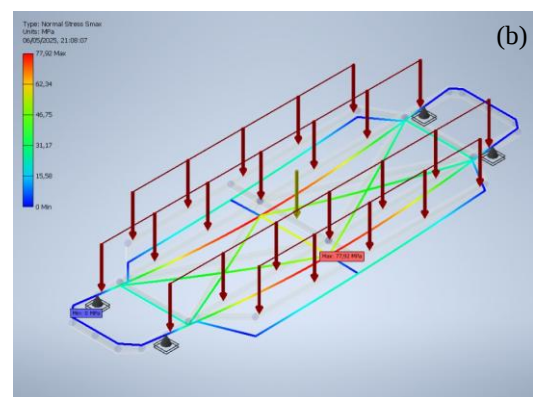
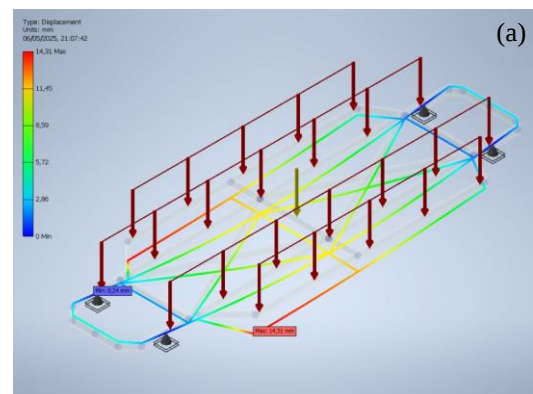
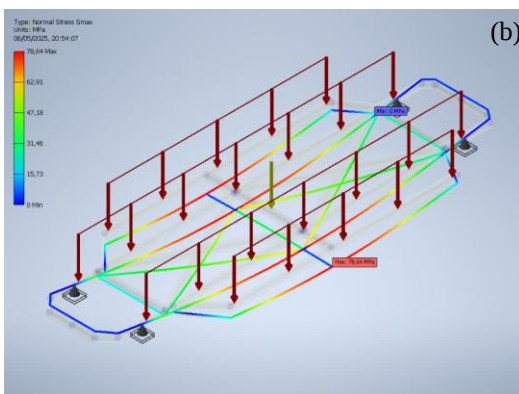
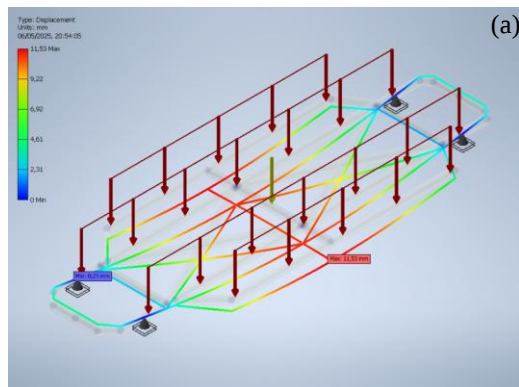


Figure 5 Analysis results of chassis with rectangular section; (a) displacement; (b) bending stress; (c) shear stress; and (d) torsional stress



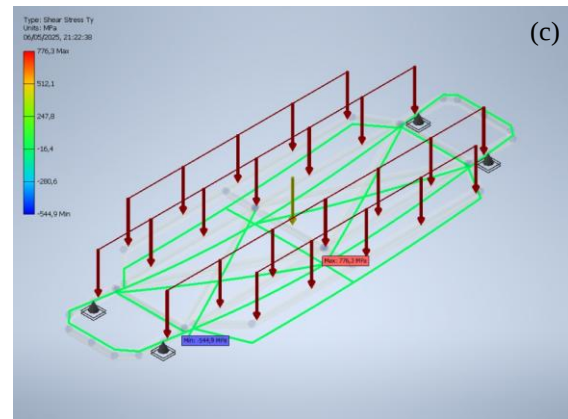
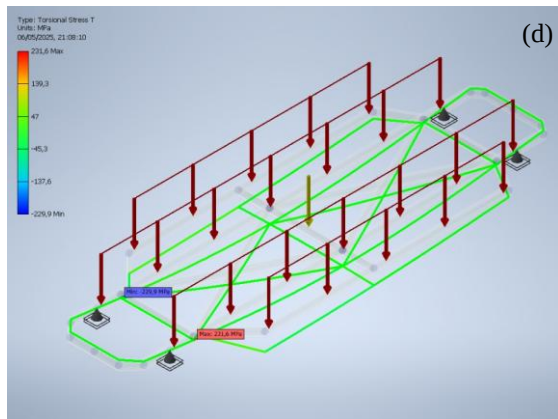
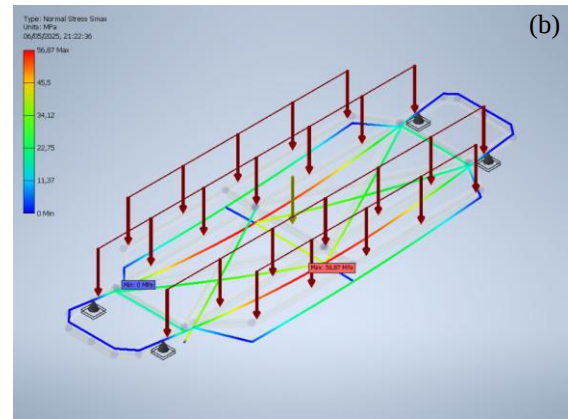
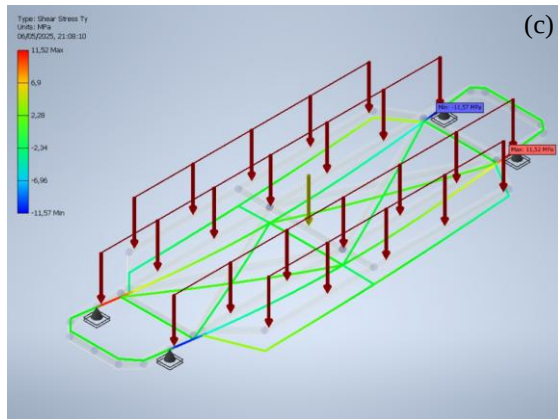


Figure 6 Analysis results of chassis with I-beam section; (a) displacement; (b) bending stress; (c) shear stress; and (d) torsional stress

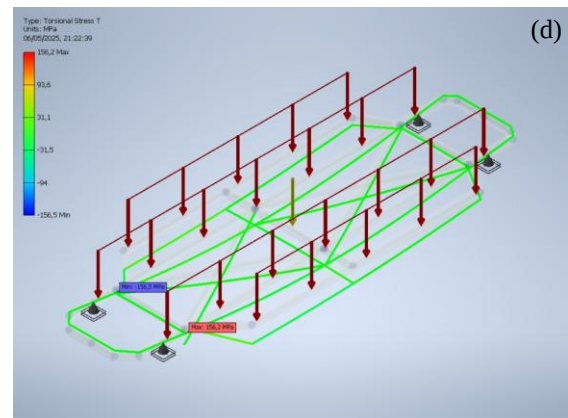
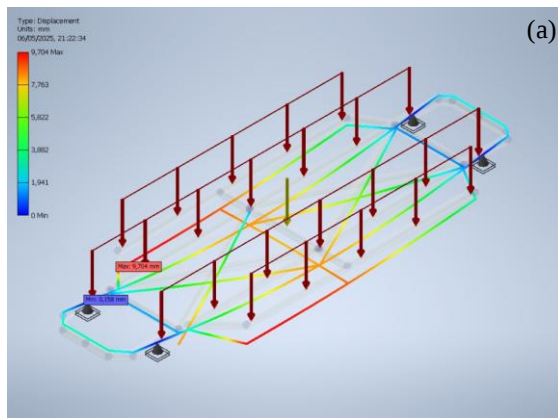


Figure 7 Analysis results of chassis with C-channel section; (a) displacement; (b) bending stress; (c) shear stress; and (d) torsional stress

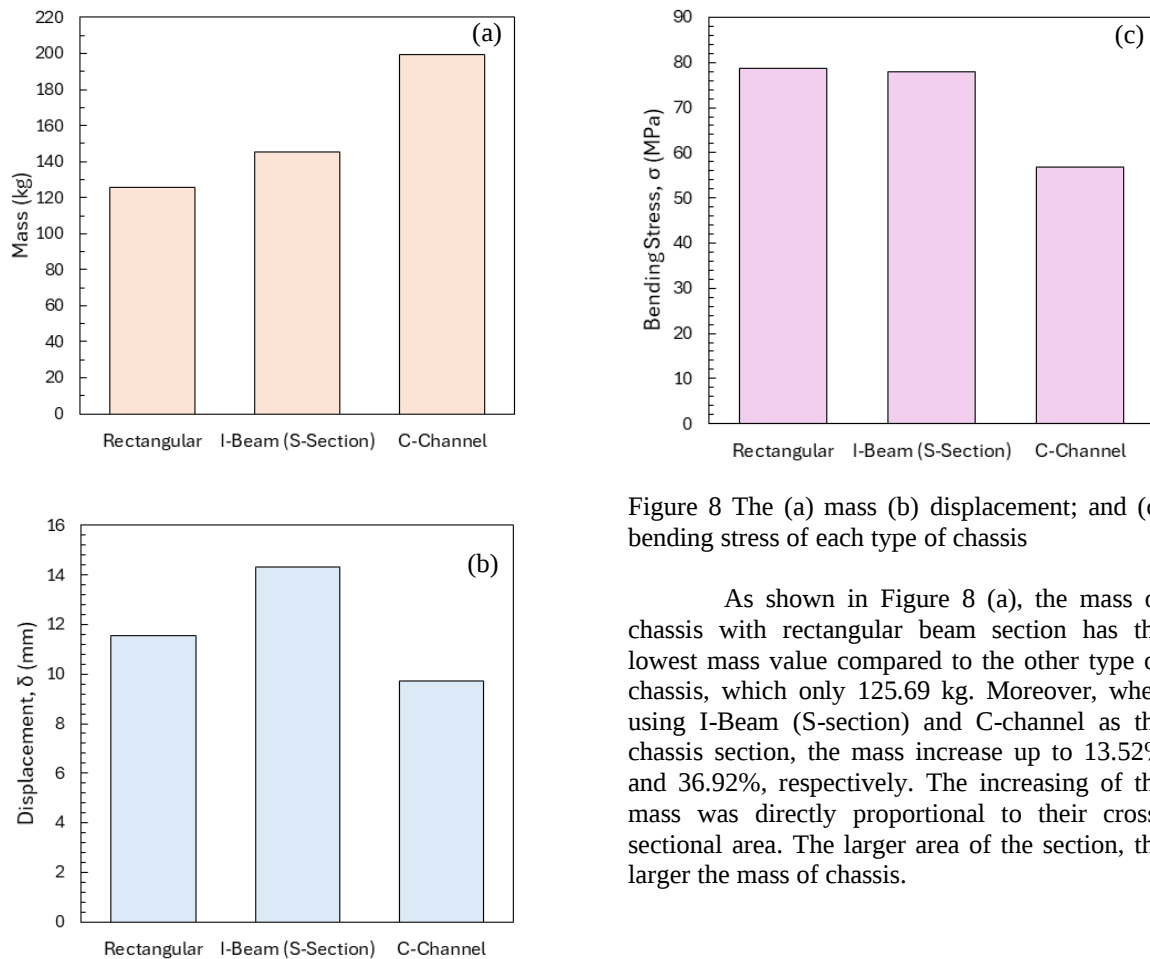


Figure 8 The (a) mass (b) displacement; and (c) bending stress of each type of chassis

As shown in Figure 8 (a), the mass of chassis with rectangular beam section has the lowest mass value compared to the other type of chassis, which only 125.69 kg. Moreover, when using I-Beam (S-section) and C-channel as the chassis section, the mass increase up to 13.52% and 36.92%, respectively. The increasing of the mass was directly proportional to their cross-sectional area. The larger area of the section, the larger the mass of chassis.

Table 3 The summary of Elvira EV-1 chassis mechanical performance with various beam section

Beam Section	Mass (kg)	Displacement, δ (mm)		Bending Stress, σ (MPa)		Shear Stress, τ (MPa)		Torsional Stress, T (MPa)	
		Min	Max	Min	Max	Min	Max	Min	Max
Rectangular	125.69	0	11.53	0	78.639	-7.698	8.112	-18.337	18.337
I-Beam	145.34	0	14.31	0	77.921	-11.575	11.52	-229.94	231.56
C-Channel	199.27	0	9.7	0	56.874	-544.85	776.31	-156.55	156.19

Furthermore, Figure 8 (b) shows the chassis with I-beam section has 14.31 mm maximum displacement, which were the highest among all the type of chassis. In comparison, I-beam section has 77.7 cm³ moment area of inertia about x-axis, this was more higher than the rectangular one, which only has 54.2 cm³. Generally, in bending structure, the displacement directly affected by the inertia of the beam section. Larger inertia usually came with lower displacement [16]. Nevertheless, by the observation of the results presented in Figure 5(a) and 6(a), the maximum displacement of both chassis occurs at

distinct place, the displacement of rectangular chassis lie at the middle side of the longitudinal beam, while the I-beam chassis, occur at the angled corner of the side beam. Consequently, high torsional stress could exist due to the twisted beam. The chassis with C-channel beam also experienced same phenomenon as I-beam chassis does, as shown in Figure 7(a). In addition, the value of maximum torsional stress of both chassis also confirmed this phenomenon, precisely 231.56 MPa for I-beam chassis and 156.55 MPa for the C-channel chassis, as shown in Figure 5(d) and 6(d). Compared to the chassis with rectangular section, it

only has 18.337 MPa of maximum torsional stress, as shown in Figure 7(d). Therefore, it can be concluded that, the reason I-beam and C-channel chassis experienced this due to their low torsional rigidity [17], [18]. Besides, the maximum displacement of both section also occurs at the same spot. In addition, the maximum torsional stress of I-beam chassis more greater than its material yield strength, which obviously caused permanent deformation to the chassis.

Figure 8 (c) shows the maximum bending stress that happened on each type of the chassis. The chassis with rectangular experienced higher bending stress than the other, which was 78.639 MPa. Nonetheless, while using I-beam section, the stress only reduced up to 0.91%. Meanwhile, C-channel section could significantly reduce the stress occurs at the chassis up to 27.67%. The stress reduction was directly proportional to the value of inertia moment area each section. The larger the inertia, the less bending stress occurred [19]. The maximum bending stress of all the type of chassis exist at the middle beam due to it is the furthest point from the support, as shown in Figure 5(b), 6(b), and 7(b).

On the other hand, the shear stress value of each chassis has upside down state compared to the bending stress value, as shown Figure 5(c), 6(c), and 7(c). The chassis with C-channel experienced the highest shear stress, even much higher than the tensile strength of its material (360 MPa), which up to 776.31 MPa. This definitely would lead the chassis to fail against the load. This unique phenomenon might be caused by asymmetrical geometry of C-channel section. Unlike rectangular and I-beam, the C-channel neutral axis were off its centre, while the shear stress mostly occurs on this axis. In addition, C-channel has open-section geometry, which caused low value of polar moment inertia (see Table 1) and lead to higher torsional shear stress.

Table 3 shows the summary analysis results of mechanical performance each type of chassis with the addition mass produced by the chassis with different beam section. According to these findings, the rectangular section seems offer promising mechanical performance compared to the other type of chassis. Although this type of chassis has the highest maximum bending stress, however, on the other mechanical performance seems more stable, such as shear and torsional stress. Besides, the bending stress value yet below its material yield strength. Therefore, it still safe for Elvira EV-1 to use the chassis with rectangular section. In addition, the rectangular chassis provided most lightweight structure, which was important properties to increase the efficiency most of EVs.

CONCLUSIONS

This study determine the mechanical performance of Elvira EV-1 chassis with various beam cross-section. The results showed that the rectangular section chassis has the highest value of maximum bending stress due to its low moment area of inertia. However, when changed to I-beam section, the value only reduced 0.91%, while the C-channel provided better performance which could significantly reduce the stress up to 27.67%. Nonetheless, C-channel chassis has the most significant value on its shear stress, which was 776.31 MPa. This value even more higher than the tensile strength of its material. Therefore, the chassis obviously would fail against the load subjected to it. Similarly, I-beam chassis has the maximum torsional stress about 231.56 MPa, which was greater than the yield strength of St37-2 material due to low torsional rigidity of this section. This surely could leave a permanent deformation to the chassis. In addition, the mass of chassis with rectangular section provided more lightweight structure with 125.69 kg of mass, which 36.92% lower among the other type of chassis. According to this findings, it can be concluded that the chassis with rectangular section has promising performance to be the Elvira EV-1 chassis.

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