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ROLL OVER CRASH TEST ANALYSIS OF AN ELECTRIC BUS STRUCTURE

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ABSTRACT

The frame structure of a bus is designed to withstand the weight of the overall vehicle and impact force when involved in an accident. An analysis is required to ensure the design of the structure complies with the international safety requirements and regulations of the United Nations Economic Commission for Europe Regulation No. 66 (UNECE R66) for passenger bus. The analysis of the electric bus structure is crucial because the structure configuration has changed due to the difference of parts and components between traditional gas-powered buses and electric buses. The roll-over crash analysis of the bus is performed to determine whether the structure can deform and collapse without intruding the residual space of the bus. The finite element method is utilized to determine the crashworthiness and strength of the bus structure. The model of the bus structure is created in SOLIDWORKS software and ABAQUS software was used to perform the roll over crash simulation. Angular velocity was applied onto the bus structure along with boundary conditions that represent actual roll-over crash. Stress and deformation contour plots are analysed to determine the strength and survival space of the structure. This project attempts to develop an electric bus structure that complies with safety regulations.

1.0 INTRODUCTION

In commercial vehicle design and development, the structural strength is most crucial to ensure the safety of occupant especially in public transportation such as bus and train. Vehicle roll-over is the most catastrophic crash that causes fatalities and severe injuries. Even though roll-over accidents in Malaysia were recorded at only 11% of all the bus crash accidents, it is the most severe in terms of casualties and injury [1]. The main cause of the high fatality count is due to the inadequate structural integrity of the bus structure during roll-over accidents [2]. A gruesome roll over crash of a bus into a ditch claimed 20 innocent lives when the roof structure totally collapsed and detached itself from the main structure [3]. This is one of the many high profiles crash incidents that prompted authorities to further increase the safety aspect of the commercial vehicles. Finite element analysis (FEA) is a widely used computational method for automotive crash test analysis. Real experiments require a lot of resources to conduct but with FEA engineers can design and identify problems virtually and precisely with lower resources [4]. By minimizing the physical experiment of the structure, the development cost and time can be reduced as well as boosting the productivity of the design process [5].

In most development work, actual experiment is required to validate the simulation results. Once the simulation results are validated by experiment, parametric study and detail analysis can be pursued using FEA. In recent years, many academics have focused on the use of FEA to improve the vehicle structural integrity and passenger rollover protection [6-15]. The design of the bus structure must comply with the UNECE R66 regulations which states that the main bus structure must not intrude into the residual space of the bus during and after the roll over crash. The residual space is a space retained for the driver,

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passengers, and crew for their survival possible in case of an accident. The flexibility offered by FEA enables the engineers to add more complexity to the design without the additional cost involved and allows the structure design to be modified to optimize crashworthiness. In this project, an existing bus structure from the company MYEV Malaysia is subjected to a roll-over crash and analysed using finite element simulation. Different beam profiles were experimented to study their effect on the roll-over crash performance of the structure.

2.0 FINITE ELEMENT MODELLING AND SIMULATION

An existing bus structure from MYEV Malaysia was modelled in SOLIDWORKS as a 3D solid model. Figure 1 shows the 3D CAD model of the actual bus structure. The bus structure has an overall length of 12.52 m, width of 2.63 m and height of 2.62 m. The 3D CAD model was then simplified to a wireframe model so as to facilitate the finite element simulation. Figure 2 shows the simplified wireframe model of the bus structure.

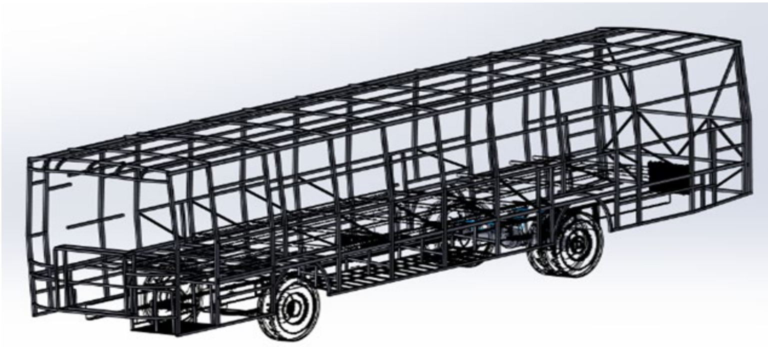

Figure 1. 3D CAD model of the bus structure

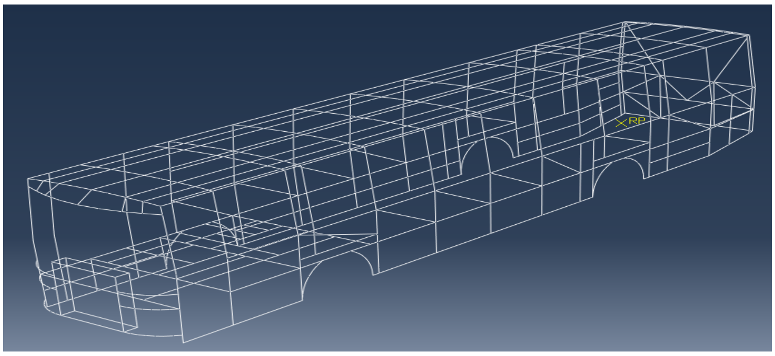

Figure 2. Wireframe model of the bus structure

The bus structure was meshed using deformable beam elements. Altogether 1484 beam elements with 2683 nodes were created. Element convergence test was carried out to determine the suitable element size for adequate accuracy and reasonable run time. The floor and residual space envelope were meshed using discrete rigid shell elements. Figure 3 shows the residual space envelope within the bus structure. Figure 4 shows the assembly of the bus structure and the floor.

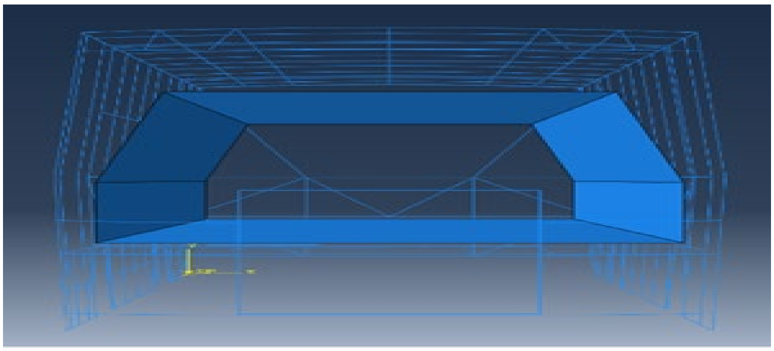

Figure 3. Residual space envelope within the bus structure

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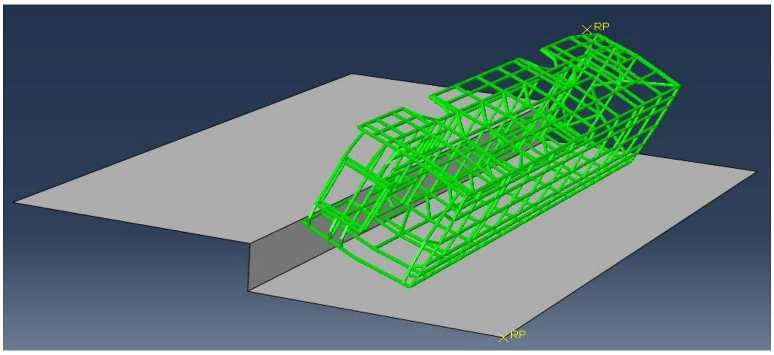

Figure 4. Assembly of the bus structure and floor

The bus structure is constructed from various combinations of square and rectangular hollow steel sections. The mechanical material properties of steel is given in Table 1. Essentially the bus structure consists of three main sections namely roof, wall and floor sections. Different beam profile combinations of roof, wall and floor sections were simulated to determine their effect on the roll over performance of the structure. Table 2 shows the different beam profile combinations, dimensions and chassis mass. The base line beam profile combination are the beams used in the existing bus structure.

Table 1. Mechanical properties of steel

Property	Measurement
Density (kg/m^3)	7850
Young's modulus (GPa)	210
Poisson Ratio	0.3
Yield Strength (MPa)	350
Ultimate tensile strength (MPa)	525
Elongation	20%

Table 2. Beam profile combinations, dimensions and chassis mass

Property	Baseline (d x w x t) mm	BPC 1 (d x w x t) mm	BPC 2 (d x w x t) mm	BPC 3 (d x w x t) mm
Roof	20 x 40 x 3	25 x 45 x 3	30 x 50 x 4	35 x 55 x 4
Wall	40 x 60 x 3	45 x 65 x 3	50 x 70 x 4	55 x 75 x 4
Floor	50 x 50 x 5	55 x 55 x 5	60 x 60 x 5	65 x 65 x 6
Chassis mass (kg)	1756.6	1972.3	2621.2	3037.1

The bus structure is loaded in accordance to UNECE R66 regulation where it is tipped and rolled into a solid ditch of 800 mm depth as shown in Figure 5. Gravity load is applied to the structure and with the given height of the bus structure and ditch, the impact speed is calculated and applied to the structure. Parts and components of the bus such as powertrain, battery pack, suspension and weight of the passengers are represented as point mass in the structure.

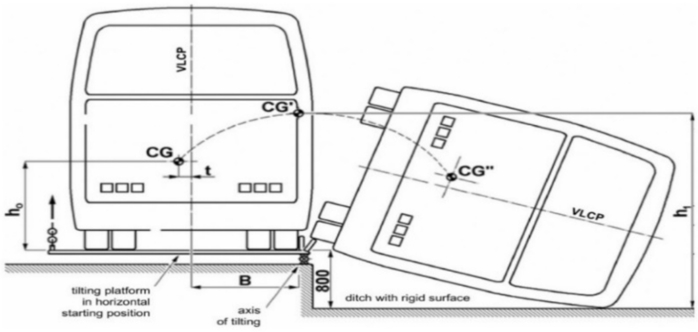

Figure 5. UNECE R66 Bus roll over crash test

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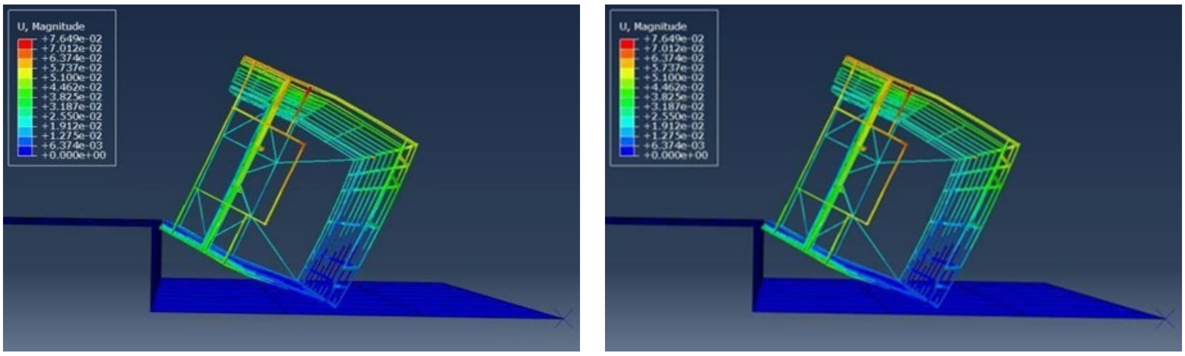
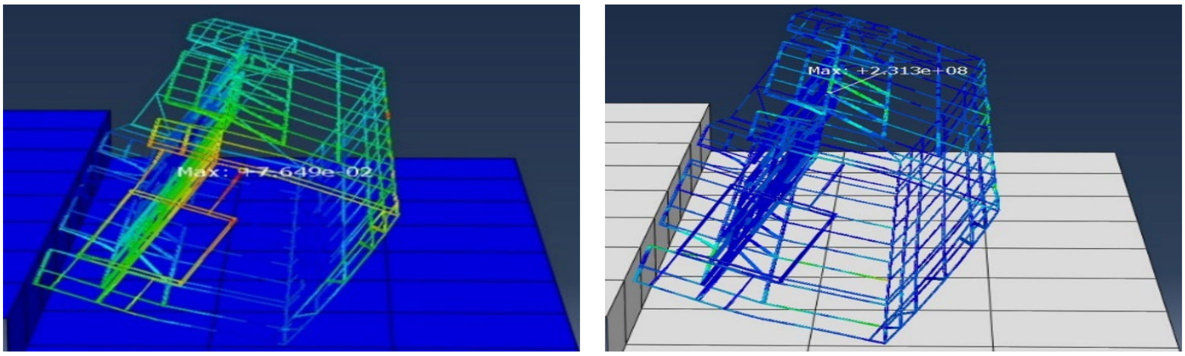
3.0 RESULTS AND DISCUSSION

Figure 6 shows the displacement and stress contours for the baseline beam profile combination subjected to roll over crash. Maximum stress of 231.3 MPa and maximum displacement of 76.5 mm were recorded at the left lower section of the wall structure as shown in Figure 7. Beam sections of the wall structure failed due to plastic bending. Failure stress at the deformed beams can be calculated using beam bending theory and energy absorbed by the deformed beams can be determined using Kecman method [16]. However, those methods are limited to single beam subjected to static load. Since the bus structure is a complex 3D spaceframe structure, it is more convenient and accurate to utilise finite element analysis to determine its response when subjected to impact load. Figure 8 shows the deformed structure with the residual space. It can be seen that the deformed section did not intrude the residual space hence the structure complies with the requirement. The existing bus structure can still comply with the requirement despite changes in mass and weight distribution of parts and components in the structure.



(a) Displacement (b) Stress

Figure 6. Displacement and stress contours for baseline beam profile combination



(a) Displacement (b) Stress

Figure 6. Displacement and stress contours for baseline beam profile combination

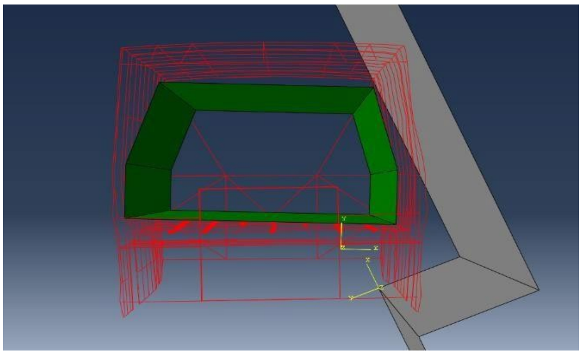


Figure 8. Deformed bus structure with the residual space for baseline beam profile combination

Figure 9 shows the displacement and stress contours for the beam profile combination 1 (BPC1) subjected to roll over crash. Maximum stress of 240 MPa and maximum displacement of 330 mm were recorded as shown in Figure 10. High stress was recorded at the left and rear lower section of the wall structure. High deformations were recorded at the left and front lower section of the wall section. Figure

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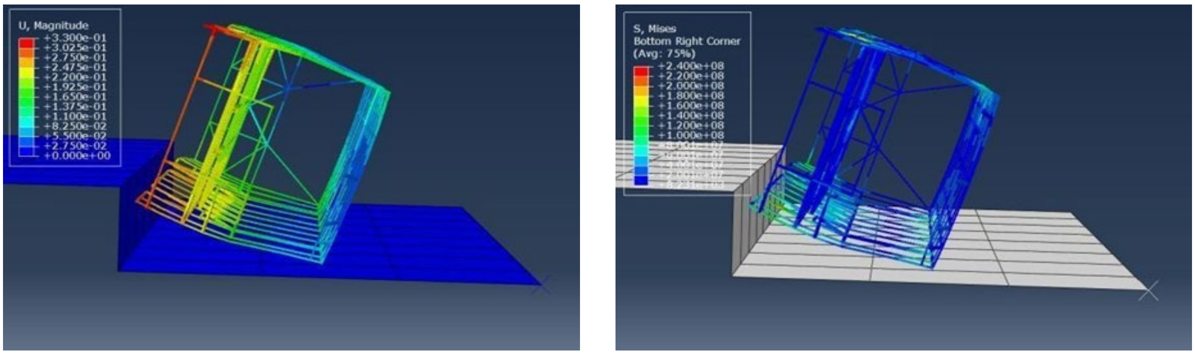
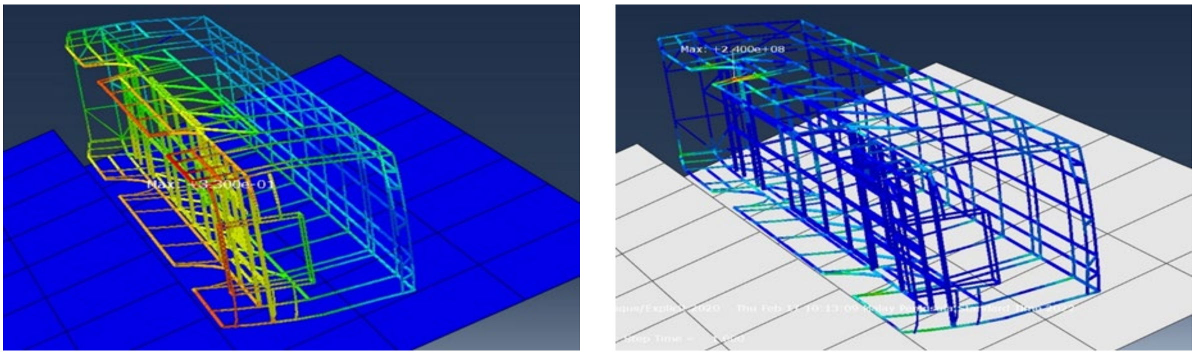
11 shows the deformed structure with the residual space. The residual space was not intruded by the deformed structure and therefore the structure complies with requirement.



(a) Displacement (b) Stress

Figure 9. Displacement and stress contours for beam profile combination 1 (BPC 1)



(a) Displacement (b) Stress

Figure 10. Maximum stress and displacement for beam profile combination 1 (BPC 1)

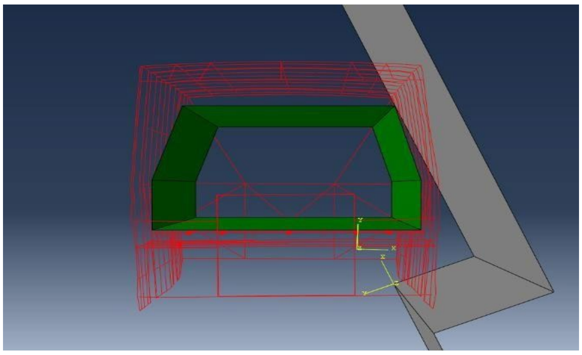


Figure 10. Deformed bus structure with the residual space for baseline beam profile combination 1 (BPC 1)

Figure 11 shows the displacement and stress contours for the beam profile combination 2 (BPC2) subjected to roll over crash. Maximum stress of 260.4 MPa and maximum displacement of 289.2 mm were recorded. This time high stress was recorded at the right and middle lower section of the wall structure as shown in Figure 12. High deformations were recorded at the left and front lower section of the wall section. Figure 13 shows the deformed structure with the residual space. The residual space was not intruded by the deformed structure and therefore the structure complies with requirement.

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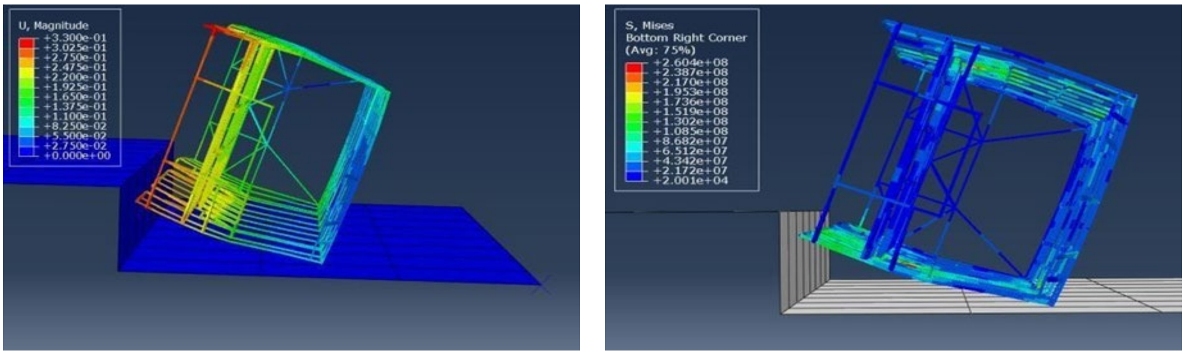
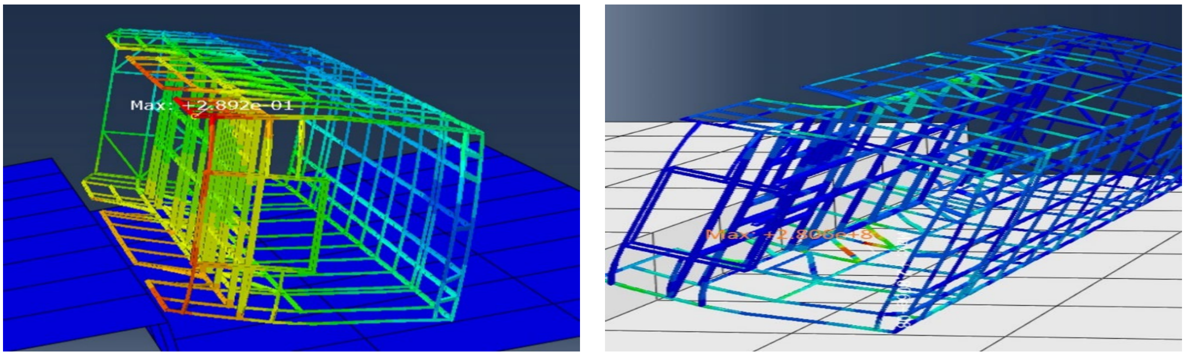


(a) Displacement (c) Stress

Figure 11. Displacement and stress contours for beam profile combination 2 (BPC 2)



(a) Displacement (b) Stress

Fig 12. Maximum stress and displacement for beam profile combination 2 (BPC 2)

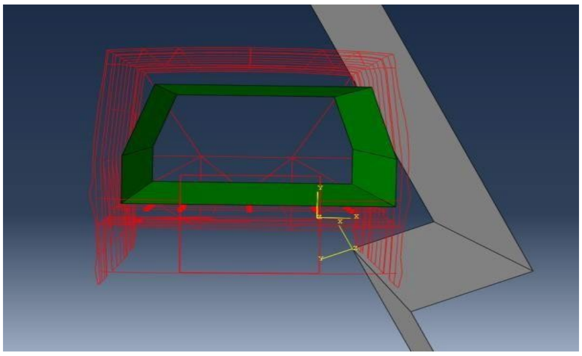


Figure 13. Deformed bus structure with the residual space for beam profile combination 2 (BPC 2)

Figure 14 shows the displacement and stress contours for the beam profile combination 3 (BPC3) subjected to roll over crash. Maximum stress of 260.2 MPa and maximum displacement of 238 mm were recorded. High stress was recorded at the right and middle lower section of the wall structure as shown in Figure 15. High deformations were recorded at the left and front lower section of the wall section. Figure 16 shows the deformed structure with the residual space. The residual space was not intruded by the deformed structure and therefore the structure complies with requirement.

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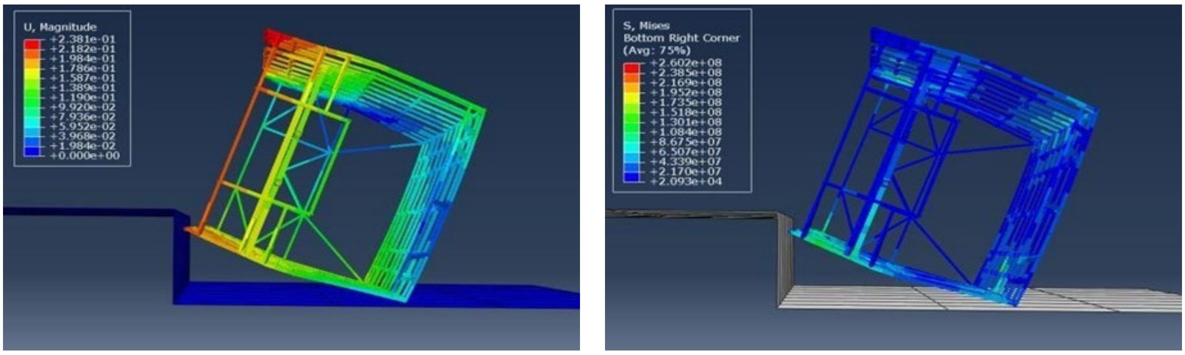
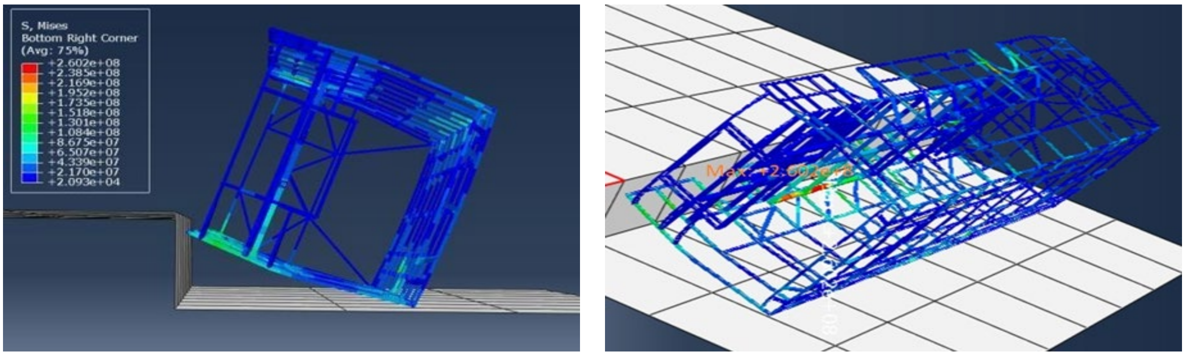


(b) Displacement (d) Stress

Figure 14. Displacement and stress contours for beam profile combination 3 (BPC 3)



(c) Displacement (d) Stress

Fig 15. Maximum stress and displacement for beam profile combination 3 (BPC 3)

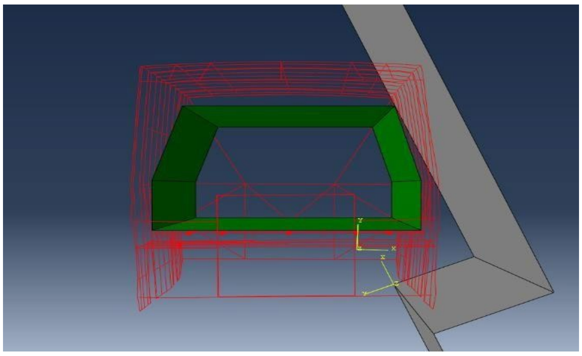


Figure 16. Deformed bus structure with the residual space for beam profile combination 3 (BPC 3)

Table 3 summarises the maximum deformations and stresses for all beam profile combination. All beam profile combinations complied with the UNECE R66 regulation where the deformed structures did not penetrate the residual space. Baseline beam profile combination had the lowest deformation and stress values. Beam profile combination 1 (BPC1) exhibited the highest deformation while beam profile combination 2 (BPC2) showed the highest stress value. Increasing the size and thickness of the beam sections increased the deformation significantly. The stress however is only slightly increased. Further increasing the beam size and thickness as in BPC3 resulted in lower stress and displacement as compared to BPC2. Despite the higher impact force due to increase in chassis mass, the selected beam sections increased the strength and rigidity, therefore resulting in lower stress and displacement. Generally, increasing the size of the beam sections will increase the mass and stiffness of the bus structure. This in turn will increase the impact force during roll over crash due to the higher kinetic energy. Therefore, the right combination of beam sections is important to ensure that the bus structure has adequate rigidity to support the weight of parts, components and occupants, and safely absorb the impact energy. Hence, selection of beam section sizes must satisfy these conflicting requirements, and this can be achieved by carrying out detail parametric study using FEA.

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Table 3. Maximum deformations and stresses for all beam profile combinations

Beam profile combination (BPC)	Max. deformation (mm)	Max. stress (MPa)
Baseline	76.5	231.3
BPC 1	330	240
BPC 2	289.2	280.6
BPC 3	238.1	260.2

4.0 CONCLUSIONS

An existing bus structure from MYEV Malaysia was analysed using finite element simulation to determine its roll over crash performance. To comply with the UNECE R66 regulation, the deformed bus structure must not intrude into the residual space to ensure safety of the occupants. Several beam profile combinations for the bus structure were simulated. All beam profile combinations fulfilled the UNECE R66 regulation. It was found that the baseline beam profile combination gave the best result with lowest deformation and stress values. Results also showed that increasing the beam section size and thickness increased the deformation, but the stress values were not significantly affected. A more detailed parametric study can be conducted to further optimize the bus structure in terms of weight, stiffness and roll over crashworthiness. Parameters of interest can be beaming cross sectional shapes and sizes, and materials. Configuration and arrangement of the beam members that made up the bus structure can also be explored. Simulation validation by experiment may need to be performed but this will require collaboration with bus manufacturers and testing authority.

5.0 CONFLICT OF INTEREST

The authors declare no conflicts of interest.

6.0 AUTHORS CONTRIBUTION

Ab. Ghani, A. R. (Conceptualization; Methodology; Supervision)
Yusof, A. (Data curation; Formal analysis; Writing - original draft)
Amir, A. (Resources; Project administration)
Othman, M.Z. (Resources; Editing)

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