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STRENGTH CONSIDERATION ON CAR BODY MODIFICATION FOR PANORAMIC TRAIN

Dinny Harnany[1], Reyhan K. A. Adista[1], Achmad Syaifudin[1] ✉, Ary Bachtiar Krishna Putra[1], Singgih Priyambodo[2]

[1]**Mechanical Engineering Department**
Institut Teknologi Sepuluh Nopember
Surabaya 60111, Indonesia
dinny.harnany@me.its.ac.id

[2]**Division of Technical Engineering of Rollingstock**
PT Kereta Api Indonesia (Persero)
Bandung 40117, Indonesia

Abstract

Modifying the car body structure from the existing train to another car body type requires an analysis of several factors. The strength of the design due to overload and the durability of the structures due to operational loads need to be re-evaluated. Furthermore, stiffness analysis also needs to determine the characteristics of the structure when it is not loaded. This study numerically analyzed the considerations in selecting the structural steel profile for modification of the existing car body into a panoramic type using the ANSYS Workbench R19. The underframe structure can still be used, and other structures are modified with the UNP profile. The side wall, and roof are changed in shape and size following the glass design of the panoramic train. The solid 3D model is rebuilt into a surface model to simplify the analysis. Static structural analysis is used to clarify the strength of the design under overload, a combination of static and transient structural analysis is applied to calculate the operating life, and modal analysis is chosen to figure out the stiffness. The simulation results showed that the modified design had met the needs and requirements based on the PM 175 standard of 2015 by the Indonesian Ministry of Transportation and the international standard EN-12663.

Keywords: *Strength Analysis, Car Body, Railway Vehicle, Finite Element Method.*

1. INTRODUCTION

PT. Kereta Api Indonesia (KAI) initiated the design of the Panorama train (KA Panoramic), which will be adapted to Indonesia's natural topology and climate. The panoramic train is designed to be able to travel the Jakarta-Surabaya route. The Jakarta-Surabaya route has a beautiful view, so the idea of this panoramic train will be appropriate and will reward the passengers with a different traveling experience. The car body used for the panoramic train comes from the existing executive class train, thus the car body structure will have old and new frame structure, which will certainly affect the strength and durability of the structure. Analysis of the strength and durability of the Panoramic train structure needs to be carried out to ensure that the modification design made can meet the minimum requirements for mass transportation set by the Indonesian Ministry of Transportation (Kemenhub).

The train has a very complex structure and is composed of various components. Analysis of the strength and fatigue of the train car body is critical because it affects the safety of passengers. In general, the analysis carried out includes numerical analysis and experiments. Numerical analysis is preferred because it can show many entities that cannot be known experimentally. There have been many studies for train car bodies that use numerical analysis. Syaifudin et al. researched the strength consideration of the 6005a and 6061 series aluminum in extrusion shape for constructing the structures of the LRT car body. In the other work, Suprianto et al. observed the influence of track irregularity and railroad topology on

Corresponding Author:
✉ **Achmad Syaifudin**
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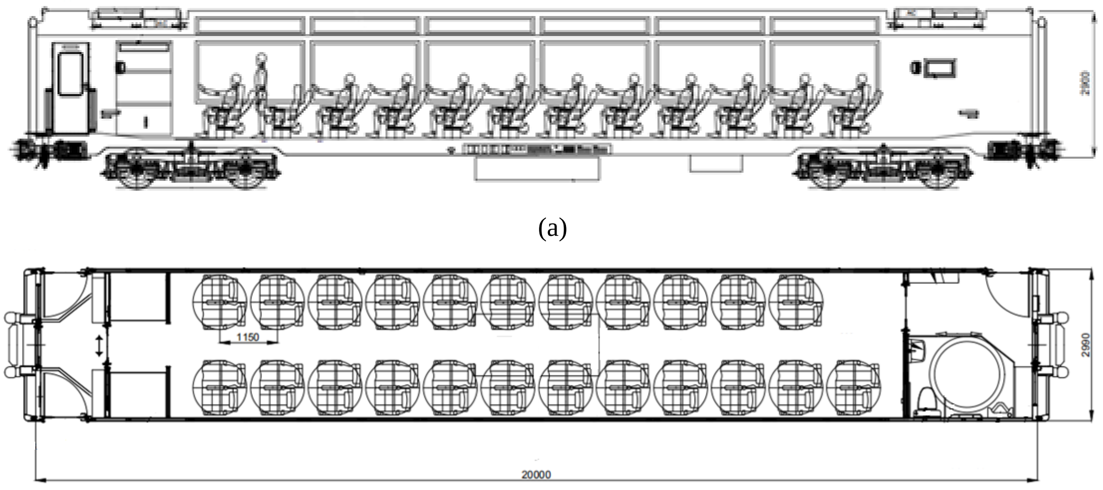
the fatigue failure of flat wagons considering structure stiffness. Hyun-Ah Lee et al researched the shape optimization in the design of train car body structures with extruded aluminum material. Woo Geun Lee et al investigated the use of magnesium metal alloy material for train car body structures. Kim Jungseok et al studied the tilting train car body structure with experimental and numerical methods which then compared the results of experimental testing with the results of numerical calculations which results from Experimental studies and numerical analysis if done correctly have little difference. Numerical analysis is widely used because of its convenience, cost, and time which is more efficient than experimental analysis. [1-5]

This paper analyzes structural strength against static loads and structural fatigue (life) to dynamic loads. Modal analysis is also carried out to see the level of rigidity of the structure according to the design requirements. Structural analysis needs to be done to assess whether the modified structure has met the requirements that have been set. It is feared that the modification results do not meet safety standards.

2. METHOD

The geometry of the Panoramic KA car body is shown in Figure 1. It is divided into several main components such as underframe, side wall, end wall, roof, side sill, and center sill, as shown in Figure 2. The Panoramic train model is a modification of the executive train class. The structure of the side wall and end wall are changed in the dimensions of the glass. The roof on the panoramic train is completely changed in shape and structure with glass on the roof. Needs from PT KAI (Persero) require the calculation of the Panoramic train structure to have a dynamic coefficient of two (2) for the construction calculation, determining the type and size of the material, and assessing whether the existing underframe can still be used for the Panoramic train. The main components of the Panoramic train have different types of materials. Underframe, side sill, and center sill parts of the existing frames use SPA-H material, while SS 400 material is used for side wall, end wall, and roof components which are UNP profile steel. UNP is profile specification from Indonesian steel industry, which is similar to European standard for U channel BS EN 10025-2 [6]. The selection of the SS400 material refers to the existing executive class train material and the availability of UNP profile steel in Indonesia which has similar material properties to the SS400.

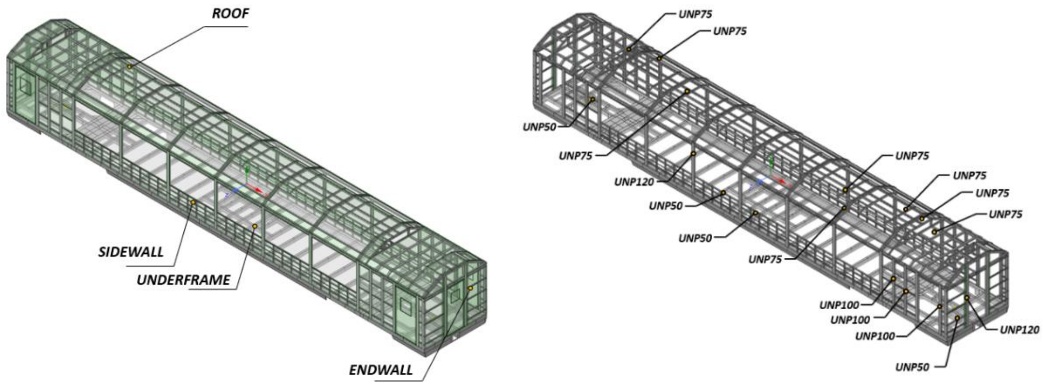


(a)

(b)

Figure 1. (a) KA Panoramic front view, (b) KA Panoramic top view (all units in millimeters)

The initial modification of the Panoramic train, seen in Figure 2, used the U-channel profile steel (UNP) with different profile size. The side wall sections used variations in channel sizes of UNP120, UNP100, and UNP50. The end wall sections used variations in channel sizes of UNP120 and UNP50. The roof section used a UNP75 profile. The selection of each UNP channel adjusts the location of each section. Details of UNP channel profiles can be seen in Table 1 and Figure 2.



(a) (b)

Figure 2. (a) Panoramic car body component, and (b) Material profile mapping

Table 1. UNP profile for Panoramic car body

Train Construction Component	UNP Profile	Thickness
Side wall	UNP120	9 mm
	UNP100	7 mm
	UNP50	3 mm
Roof	UNP75	5 mm
End wall	UNP120	9 mm
	UNP50	3 mm

In this study, there are two types of analysis, strength analysis and stiffness analysis. Analysis of the strength of the static load is carried out to determine the resistance of the structure, while the analysis of the strength of the dynamic load is carried out to determine the life of the modified structure. Modal analysis is also carried out to determine the stiffness of the structure. Static load in this study is exceptional, and dynamic load is operational according to the train operating mode. To identify the deformation, the transient nonlinear structural analyzes are built-in ANSYS R19.0 (ANSYS Inc., Pennsylvania, USA).

The standard used is PM 175 of 2015 by the Ministry of Transportation [7], Indonesia and the European standard EN-12663. European standard EN12663 has several criteria for the type of train, where each criterion has a different test load. Panoramic trains are based on European standard EN-12663 for longitudinal loads classified as P-II criteria by testing a compressive load of 1500 KN (Case BL1) and a tensile load of 1000 KN (Case BL2), which is carried out separately with the location of the loading on the train yoke stopper [8]. The vertical load based on the PM 175 2015 and EN-12663 standards are calculated with the following formula:

$$P_v = k.P_k \tag{1}$$

Where k is the dynamic coefficient, P_v is the total vertical load, and P_k is the total load on the train such as passengers and components on the train. The dynamic coefficient k in this study uses a value of two (2) by the request of PT. KAI (Persero). The operational load is obtained by calculating the longitudinal load based on the actual component load. Operational load is used to analyze the strength of the structure against cyclic loads. There are variations in conditions [9] in calculating operating expenses, as follows:

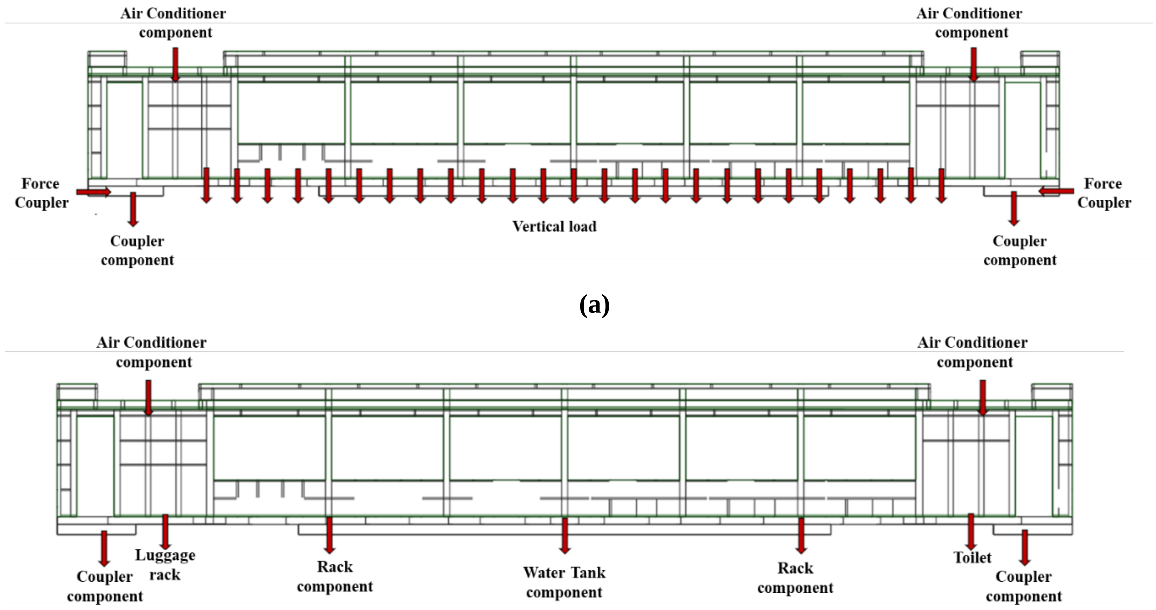
i. Turning and descending conditions with passengers (BO1 Case). The turning radius used in this condition is 1000 m and the inclination is 10 ‰.
ii. Turning and descending conditions without passengers (BO2 Case). This mode is similar to the BO1, but there is no passenger load.
iii. Constant speed conditions with passengers (BO3 Case). The constant speed is 120 km/h, while the vertical load is the same as in the case of BO1.
iv. Constant speed conditions without passengers (BO4 Case). This mode is similar to the BO2, but there is no passenger load.

The loading and the components on the Panoramic Train in this study can be seen in Table 2 and Table 3. PT Industri Kereta Api (PT. INKA) also sets a maximum deflection limit of 11.5 mm for a tare load and 15 mm for a full load [10]. The relationship between train cars and the loading that occurs during operational conditions is determined by creating a free body diagram so that the compressive and tensile forces experienced by each train car can be determined [20]. In operational load calculation for fatigue assessment, each time a train makes a turn, is ensured to have a braking condition that affects the load that occurs between the train car couplings. Therefore, the train's braking forces are considered [15]. We choose the train car that has the most tensile or compressive load based on hand calculations and free body diagrams on the arrangement of train cars in each condition. This way, we only have to run simulations on the chosen train car.

Table 2. Loading case

Study case	**Case type**	**Load**		**Annotation**
		Longitudinal	**Vertical**	
Exceptional Load (Static-Transient)	BL1	1500 kN (Compression)	280 kN	Longitudinal load from standard, vertical load with a multiplier of 2, with an operating speed of 70 km/h.
	BL2	1000 kN (Tension)	280 kN	Longitudinal load from standard, vertical load with a multiplier of 2, with an operating speed of 120 km/h.
Operational Load (Fatigue)	BO1	420 kN (Compression)	140 kN	Longitudinal load from operating conditions, turning radius R=1000 m, inclination = 10 ‰, with an operating speed of 70 km/h.
	BO2	420 kN (Compression)	106 kN	
	BO3	23 kN (Tension)	140 kN	Longitudinal load from operating conditions, operating speed 120 km/h.

The loading position adjusts the position of each component and passenger on the Panoramic train so that the results obtained are more accurate. The placement of support points and loads refers not only to the EN 12663 standard, but also to the testing procedures conducted by PT Industri Kereta Api (Persero) on the structure of train cars [17]. The location of the loading and the support on the Panoramic train can be seen in Figure 3 and Figure 4. Details of the main components of the Panoramic train can be seen in Table 3.



(a)

(b)

Figure 3. (a) KA Panoramic component load including passenger, (b) KA Panoramic component load

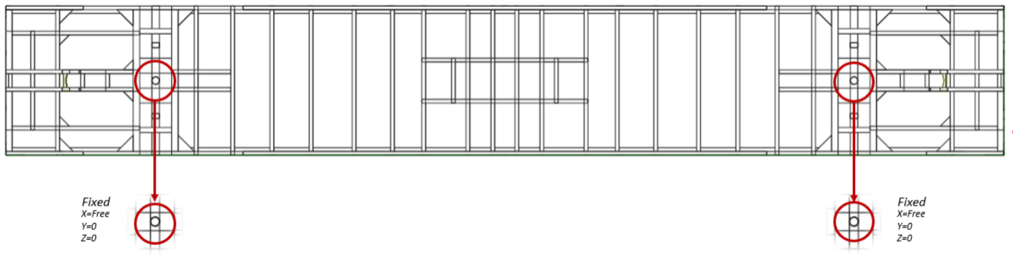


Figure 4. Fixed support placed on the main center beam.

The installed components and weight of the installed components are based on the weight calculation and load distribution data of the K1 4TS executive class carriage from PT Kereta Api Indonesia (PT. KAI) [18], but the number of installed components is adjusted according to the needs of the Panoramic train.

Table 3. KA Panoramic main component

No.	Component	Weight (kg)	Quantity	Total (kg)
1	Coupler	381	2	762
2	Brake Equipment	797	1	797
3	Double Chair	150	23	3450
4	AC	500	2	1000
6	Luggage Rack	200	2	400
7	Water Tank	1500	2	3000
8	Septic Tank	200	2	400
9	Toilet	500	2	1000
Total				10809

The acceptability of the strength analysis with static loads based on PM 175 of 2015 and EN12663 is the most significant stress on each component composed of several different materials not exceeding 75% of the yield stress of each material [7-8]. Strength analysis with cyclic loading is safe if the structure can withstand without damage for a minimum of up to 10^6 cycles [8]. The properties of the materials used in the Panoramic Train SPA-H, SS400, and tempered glass can be seen in Table 4 [11,12,16].

Table 4. Material properties and material model

Material	SS 400	SPA-H	Tempered glass
Modulus of elasticity (GPa)	190	200	74,71
Poisson's ratio	0,3	0,3	0,3
Density (kg/mm^3)	7,86 x 10^{-6}	7,7 x 10^{-6}	2,53 x 10^{-6}
Yield Strength (MPa)	245	335	255
Ultimate Strength (MPa)	510	490	522

The material model used in this simulation is isotropic bilinear, which the value of tangent modulus can be derived from the yield and ultimate strength of the material.

In calculating the cycle life of the Panoramic train construction due to cyclic loads, data on the alternating stress and cycles are needed or commonly called the S-N curve [12]. The S-N curve of each material is shown in Figures 5. The S-N curves for tempered glass materials are approximated by the S-N curves for pure glass materials [19]. The S-N curve for JIS SS400 will utilize data from ASTM A36 due to the equivalence between the two materials. Specifically, the JIS SS400 material is considered to have the same properties and characteristics as the ASTM A36 material [11,14]. The SPA-H material is equivalent to ASTM A588, but the S-N Curve data for ASTM A588 is not available. Therefore, the S-N curve for SPA-H is based on data from HPS (LT), which has similar characteristics to ASTM A588 [13].

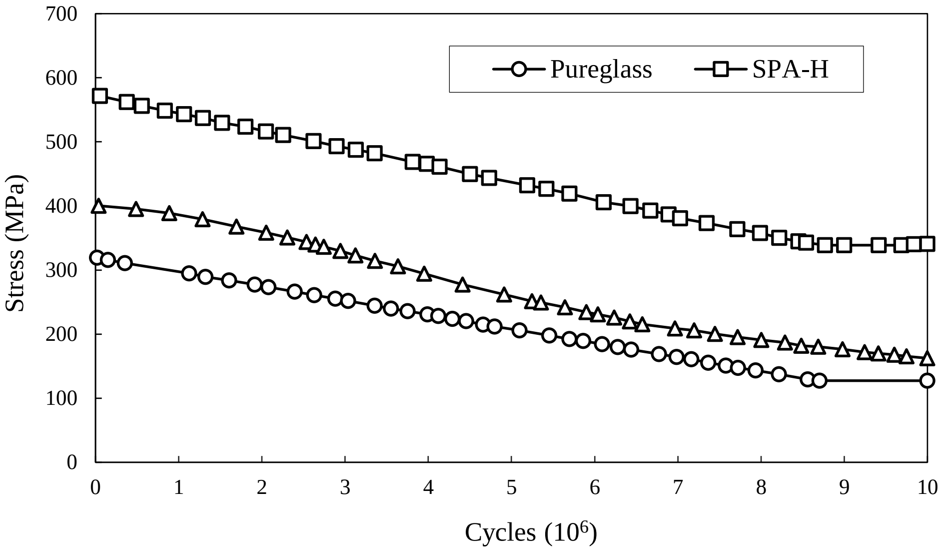


Figure 5. S-N curve for Panoramic train material

3. RESULT AND DISCUSSION

Modal analysis is carried out to help determine the natural vibration characteristics of a panoramic railway structure. This analysis shows the movement of the construction structure when it is not receiving a load, whereas, in this analysis, the natural frequency value and the mode shape of the construction are obtained. The frequencies of the first six vibration modes are shown in Table 5 and the corresponding deformation forms can be seen in Figure 8**.**

Table 5. Result of modal analysis

No.	Mode shape	Frequency	Maximum deformation (mm)
1	1	12,435 Hz	0,733
2	2	13,471 Hz	0,882
3	3	15,953 Hz	0,534
4	4	17,823 Hz	0,963
5	5	18,085 Hz	1,053
6	6	20,437 Hz	1,358

The modal analysis results show that the first vibration mode occurs predominantly on the roof of the Panoramic train, namely on the AC section. While the second to sixth vibration mode occurs predominantly on the side glass window. This condition is nothing to worry about because the resulting deformation is minimal (less than 3mm). However, the deformation may be even more significant if the external force excitation is considered. It is recommended to add dampers in the area of the dominant deformation component.

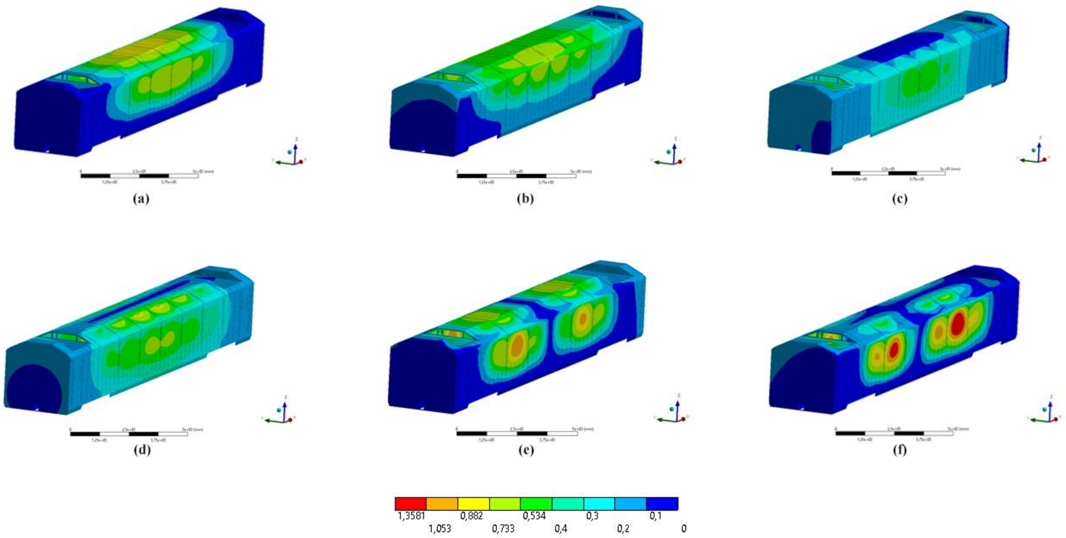


Figure 6. (a) Mode shape 1, (b) Mode shape 2, (c) Mode shape 3, (d) Mode shape 4, (e) Mode shape 5, (f) Mode shape 6

Strength simulation results on the Panoramic train carriage can be seen in Table 6 and the maximum stress-deformation position can be seen in Figure 9 to Figure 10. The simulation results show that all Panoramic train car body parts are safe against transient (quasi-static) loads. The side wall section has the smallest safety rating, which is 1.33 for compressive load conditions and on the side wall for tensile load conditions, which is 1.67. The calculation requirement explains that the load has been calculated by multiplying the loading coefficient of 2. It means that the train (track) 's operational conditions have been considered. In the case of trains, the safety rating for overload loads is at least 1.75. So, all the safety scores obtained are sufficient. Thus, it can be concluded that the specification of the frame profile used to modify the existing train to become a panoramic train has met the requirements [7-8]. The results of the deformation in the case of exceptional loads show the numbers 5.62 mm and 4.87 mm, and this is still within the maximum limit set, which is 15 mm, so it meets the requirements [10].

Table 6. Result of BL1 and BL2 load case

Study Case	Max. Vertical Deformation (mm)	Component	Max. Stress (MPa)	Allowable Stress (MPa)	Material	Safety Factor
BL1	5,62	Side sill	120,05	251,25	SPA-H	2,09
		Underframe	140,59	251,25	SPA-H	1,78
		Side wall	137,86	183,75	SS 400	1,33
		Roof	73,44	183,75	SS 400	2,50
		End wall	86,99	183,75	SS 400	2,11
BL2	4,87	Side sill	75,78	251,25	SPA-H	3,31
		Underframe	114,48	251,25	SPA-H	2,19
		Side wall	109,56	183,75	SS 400	1,67
		Roof	66,31	183,75	SS 400	2,77
		End wall	78,31	183,75	SS 400	2,34

* Note: The allowable stress is 75% of the yield point of the material used

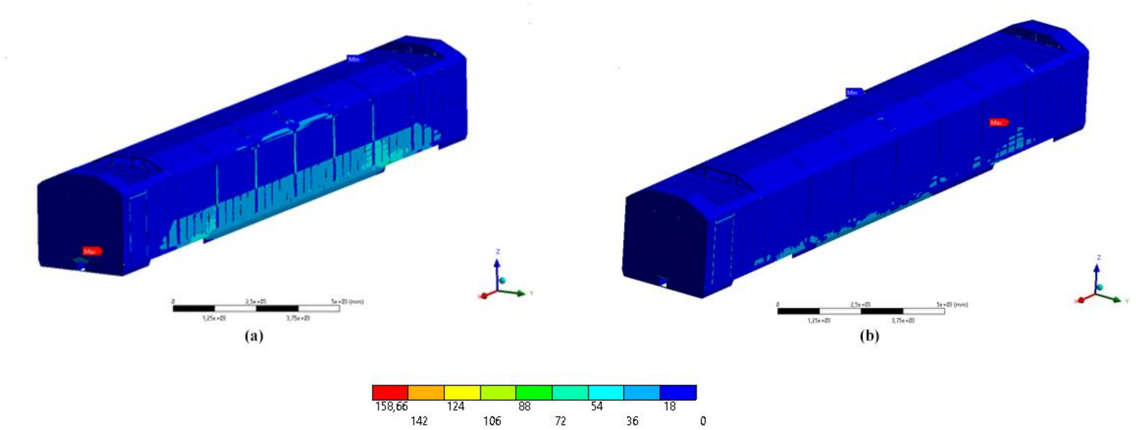


Figure 7. (a) Case BL1 stress distribution result, (b) Case BL2 stress distribution result

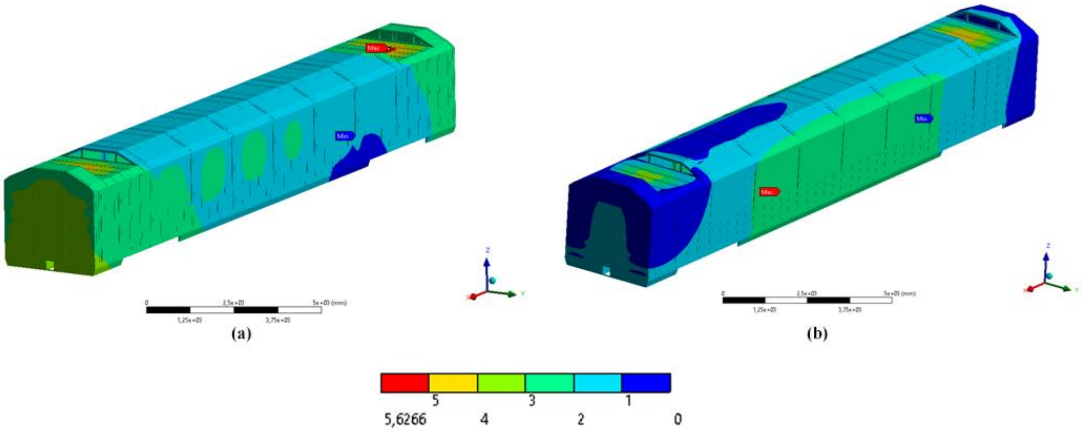


Figure 6. (a) Case BL1 deformation result, (b) Case BL2 deformation result

The results of the fatigue simulation with operational loads carried out can be seen in Table 7 and the cycle distribution on the Panoramic train construction can be seen in Figure 11. It can be seen in Table 7 that the average stress and stress amplitude vary with different patterns under conditions with various conditions, normal vertical load and no vertical load conditions. This condition shows that the changes in the average and maximum stress are not affected by the type of vertical loading. In addition, the cycle life for all parts of the Panoramic train structure shows a cycle value greater than 10^6 (million) cycles at an operational speed of 120 km/hour, where the smallest cycle life occurs on the side sill and underframe. Meanwhile, the laminated glass used in Panoramic trains generally has the longest cycle life for all types of loading. This shows that the Panoramic train structure generally can reach unlimited working life [8,12]. The number of cycles below 10^6 indicates limited working life and short working life is indicated by the number of cycles below 10^3.

Table 7. Result on fatigue load strength

Study Case	Component	Max. Stress (MPa)	Min. Stress (MPa)	Stress Amplitude (MPa)	Stress Average (MPa)	Life Cycle
BO1	Side sill	51,41	40,35	5,53	45,88	$1{,}53\times10^7$
	Underframe	63,02	59,09	1,96	61,05	$8{,}30\times10^6$
	Side wall	62,27	54,59	3,84	58,43	$1{,}23\times10^8$
	Roof	41,18	2,20	19,49	21,69	$2{,}60\times10^8$
	End wall	38,58	36,59	0,99	37,58	$2{,}85\times10^8$
BO2	Side sill	53,14	40,57	6,28	46,85	$1{,}38\times10^7$
	Underframe	60,64	13,21	23,72	36,92	$9{,}32\times10^6$
	Side wall	58,97	51,57	3,70	55,27	$6{,}51\times10^8$
	Roof	37,79	9,26	14,26	23,52	$2{,}93\times10^8$
	End wall	40,63	38,48	1,07	39,56	$2{,}65\times10^8$
BO3	Side sill	30,02	18,47	5,77	24,25	$2{,}35\times10^8$
	Underframe	52,02	49,25	1,38	50,64	$1{,}47\times10^7$
	Side wall	43,36	38,50	2,43	40,93	$2{,}41\times10^8$
	Roof	39,46	2,15	18,65	20,81	$2{,}76\times10^8$
	End wall	14,37	12,38	0,99	13,38	$6{,}68\times10^8$

Study Case	Component	Max. Stress (MPa)	Min. Stress (MPa)	Stress Amplitude (MPa)	Stress Average (MPa)	Life Cycle
BO4	Side sill	21,24	18,88	1,18	20,06	$2{,}17\times10^{8}$
	Underframe	46,13	12,88	16,63	29,51	$2{,}12\times10^{7}$
	Side wall	40,05	35,49	2,28	37,77	$2{,}70\times10^{8}$
	Roof	36,83	8,89	13,97	22,86	$3{,}03\times10^{8}$
	End wall	16,05	1,80	7,13	8,93	$6{,}30\times10^{8}$

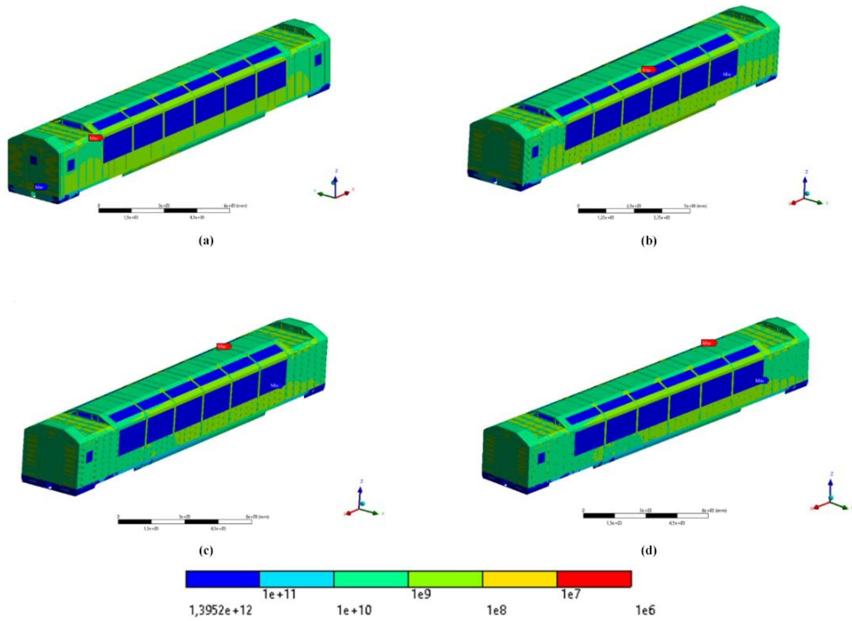

(a) (b) (c) (d)

Figure 9. (a) Case BO1 fatigue life distribution, (b) Case BO2 fatigue life distribution, (c) Case BO3 fatigue life distribution, (d) Case BO4 fatigue life distribution

4. CONCLUSION

An investigation into the effect of modifying the car body structure of an existing train to become a panoramic train has been completed in this paper. This study utilized numerical simulations based on the finite element method by considering the strength, stiffness, and durability of the modified structure. The numerical study indicated that the modification of executive class train cars to panoramic trains still fulfills all the design requirements and objectives. The Panoramic train construction frame structure used the U-channel profile (UNP) with sizes of UNP50, UNP75, UNP100, and UNP120 has met the predetermined requirements, and no more modification is needed. The evaluation method applied in this study is recommended to be used as a standard numerical analysis procedure in modifying/upgrading existing train car body structures to other types or shapes of car bodies.

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