STRUCTURAL AND MODAL ANALYSIS OF A RAIL VEHICLE CAR BODY USING FINTE ELEMENT METHOD

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2018

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
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KUALA LUMPUR

2018

UNIVERSITY OF MALAYA
ORIGINAL LITERARY WORK DECLARATION

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Matric No: KQK 170028

Name of Degree: Master of Mechanical Engineering

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Structural and Modal Analysis of a Rail Vehicle Car Body Using Finite Element Method

Field of Study:

Mechanical Engineering - Applied Mechanics and Finite Element Analysis

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ABSTRACT

Rail vehicles are relatively heavy when compared to other transportation modes. The weight per seat is around three times higher for rail vehicle than for buses. Car bodies of modern rail vehicles are designed as light weight structures with the aim to minimize mass and thus operational energy demand. Weight is a key factor to consider when aiming at reducing the energy consumption as a weight increase of one ton causes an increase for the primary energy demand of 0.0259kWh/tonne.km. Considering the energy demand during the operation phase, composite material is said to be a good design alternative. The structural design of railway vehicle bodies depends on the loads they are subjected to and the characteristics of the material they are manufactured from. During operation the car body is continuously excited due to the dynamic interaction between track, wheels, bogie and car body. The dynamic behavior of railway vehicles relates to the motion or vibration of all the parts of the vehicle and is influenced by the vehicle design. The structural analysis of railway car body is highly intricate due to its dynamic nature. The complexity of contact force developed in the wheel-rail interface strongly influences the dynamic nature of the vehicle. During the research and development of the new transportation solutions, the computational tools can be used to study problems related to the impact of loads asserted on rail vehicle car bodies of existing or future railway vehicles. In this study, the impacts of car body load on the strength of the material, under frame components of the vehicle body, property of the material for the vehicle body are considered.

Keywords: Rail vehicle, mass reduction, static load, dynamic load, material strength

ABSTRAK

Kenderaan rel agak berat berbanding mod pengangkutan lain. Berat setiap tempat duduk adalah sekitar tiga kali ganda lebih tinggi untuk kereta rel berbanding dengan bas. Badan kereta kereta rel moden direka bentuk sebagai struktur ringan dengan tujuan untuk mengurangkan jisim dan dengan itu permintaan tenaga operasi. Berat adalah faktor utama untuk dipertimbangkan apabila bertujuan untuk mengurangkan penggunaan tenaga kerana peningkatan berat satu ton menyebabkan peningkatan untuk permintaan tenaga utama 0.0259kWh / ton.km. Memandangkan permintaan tenaga semasa fasa operasi, bahan komposit dikatakan sebagai alternatif reka bentuk yang baik. Reka bentuk struktur badan kenderaan keretapi bergantung kepada beban yang dikenakan dan ciri-ciri bahan yang mereka hasilkan. Semasa operasi badan kereta terus teruja kerana interaksi dinamik antara landasan, roda, bogie dan badan kereta. Tingkah laku dinamik kereta api berkaitan dengan pergerakan atau getaran semua bahagian kenderaan dan dipengaruhi oleh reka bentuk kenderaan. Analisis struktur kereta kereta api sangat rumit kerana sifat dinamiknya. Kerumitan kekuatan hubungan yang dikembangkan dalam antara muka kereta roda sangat mempengaruhi sifat dinamik kenderaan. Semasa penyelidikan dan pembangunan penyelesaian pengangkutan yang baru, analisis unsur terhingga boleh digunakan untuk mengkaji masalah yang berkaitan dengan kesan beban yang ditegaskan pada badan kereta kereta api kereta api kereta api sedia ada atau masa depan. Dalam kajian ini, impak beban badan kereta pada kekuatan bahan, komponen dibawah bingkai badan kenderaan, ciri-ciri badan kenderaan dipertimbangkan.

Kata kunci: kenderaan rel, pengurangan jisim, beban statik, beban dinamik, kekuatan bahan binaan.

ACKNOWLEDGEMENTS

Praise and thanks to God first and foremost whose blessing enabled me to accomplish this study. I wish to express my deepest appreciation to my supervisor, Professor Madya Ir. Dr. Nik Nazri Bin Nik Ghazali for his relentless guidance, helpful suggestions, close supervision and moral encouragement to complete this task.

A special thanks to my parents and my fellow engineers who had given me advice and motivation though out my research and assisting me in getting a better understanding of my project requirements. Last but not least, my sincere thanks is addressed to all those who had directly or indirectly help me to complete this study.

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LIST OF SYMBOLS AND ABBREVIATIONS

FEA	:	Finite Element Analysis
EMU	:	Electrical Multiple Unit
USA	:	Unite States of America
CA	:	Calcium
AL	:	Aluminum
Si	:	Silicon
Fe	:	Ferrum
GRP	:	Glass Re-inforced Plastic
FRA	:	Federal Railroad Administration
AAR	:	Association of American Railroads
APTA	:	American Public Transportation Association
RAM	:	Random Access Memory
MBS	:	Multi-body Simulation
HSS	:	High Strength Steel

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

Rail vehicles are relatively heavy when compared to other transportation modes. The weight per seat is around three times higher for rail vehicle than for buses. The rail vehicle's car body refers to the load carrying structure, including doors, windows and access panels. All access panels shall be designed to be watertight particularly for operation at high speeds under extreme weather conditions

The technical equipment for propulsion, braking, gearbox and etc is not included in the car body analysis, as these equipment usually are attached to the bogie. Sometimes the concept of car body is limited to only the load carrying structure of the vehicle. (EN, 2010). The strength of the complete car body and its structural elements shall comply with and be designed to equal or exceed, the FRA requirements. Car bodies of modern rail vehicles are designed as light weight structures with the intention to minimize mass and thus operational energy demand. Weight is a key factor to consider when aiming at reducing the energy consumption as a weight increase of one ton causes an increase for the primary energy demand of 0.0259 kWh/tonne.km. Considering the energy demand during the operation phase, composite material is said to be a good design alternative. The central structural design requirements are specified by the major static and dynamic loads. The carbody's first natural frequencies at AW0, AW1, AW2 and AW3 shall be greater than 10 Hz.

Railway vehicle structure generally consist of shells, plates and beam. The behavior of these members directly affect static and dynamic structure of the vehicle. The structural design of railway vehicle bodies depends on the loads they are subjected to and the characteristics of the material they are manufactured from. (König, Kopp, Winter, Friedrich, & Schön, 2012)

The car body design is a three-part, partially low-floor one way body. Car parts are inter connected with a type of articulated gangways ensuring also the interconnection between cars. The design should, furthermore, be reasonably easy to manufacture and maintain. For high speed trains it is important to have a good aerodynamic design with, for example a stretched front, smooth outer surface, enclosed undercarriage and etc. During operation the car body is continuously excited due to the dynamic interaction between track, wheels, bogie and car body.

The construction of car body that has sufficient stiffness with respect to vertical and lateral bending has a stiff cross section as well as being stiff in torsion is a challenge for the designer. The car body must fulfill comfort requirements. For passenger vehicles it provides the correct environment, like good ride comfort, the right lighting, space, temperature, fresh air and low sound level. Among these requirements, the car body must also comply to safety requirement setup for crash scenarios, derailment, fire and pressure waves in tunnels. The car body must also meet the specifications construction profile of the operational line, it must be strong enough as not to fail during typical maximum loads during cyclic loading.

The standard practice after the railway vehicle is manufactured, is get it be certified. Static and dynamic tests are performed according to international standards during the certification procedures, some standards specifications and requirements for static stress tests, vibration and crashworthiness of rail vehicle structure can be performed. The structural testing should consist of two steps involving static gauge test, dynamic strain gauge test and accelerometer test. The static strain gauge tests should include various load conditions including vertical bending at AW2 and diagonal jacking at AW0 load. The dynamic strain gauge and accelerometer test should run during actual operation over the revenue tracks. The static test can be completed at a suitable maintenance facility.

Car body vibration can be controlled either by focusing on the structural stiffness of the system or by optimizing the damping components. There are several duties on car body structural flexibility. The models range from simple beam models to detailed finite-element model. In most cases, models obtained from experimental model analysis and finite element calculation are used in the analysis. The dynamic behavior of railway vehicles relates to the motion or vibration of all the parts of the vehicle and is influenced by the vehicle design. Finite element method is a powerful numerical engineering analysis tool and widely used in statically and dynamic stress analysis of railway vehicles.

1.2 Problem Statement

The structural analysis of railway car body is highly intricate due to its dynamic nature. The complexity of contact force developed in the wheel-rail interface strongly influences the dynamic nature of the vehicle. During the research and development of the new transportation solutions, the computational tools can be used to study problems related to the impact of loads asserted on rail vehicle car bodies of existing or future railway vehicles. In this study, the impacts of car body load on the strength of the material, under frame components of the vehicle body, property of the material for the vehicle body are considered.

1.3 Objective

The objective of this research is to perform a structural and modal analysis on a rail vehicle car body to determine the static deformation and mode shapes respectively. The applied loads shall simulate passenger weight with a given set of under frame equipment to indentify its effects on strength of material and compatibility of the under frame equipment with the prototype design.

1.4 Scope of Project

The scope of the research are as follows:

i. Modeling of specified rail vehicle car body.
ii. Setting the neccesary boundary conditions.
iii. Static and dynamic simulation of rail vehicle car body using finite element analysis.
iv. Interpreting results and conclusion.

CHAPTER 2: LITREATURE REVIEW

Over the years, the design of rail vehicle car body has developed from a basic steel structure that meets the requirement of strength and functionality to a design which is more complex and efficient. The conventional steel and aluminum components are replaced with current day composite materials such as reinforced glass-fiber polymers. For that reason, composite materials enhance the way the products perform with reference to stiffness, impact absorption, strength and with the reduction of weight and conservation of space at the same time. Nonetheless, with these improvement in areas of material, production process, computational and design tools and optimization methods, further advancement on rail vehicle structural design is still being actively carried out.

2.1 History of Rail Vehicles

Far back as of the eighteenth century in Europe, workers from diverse areas of mining found out that it was easier for wagons that were loaded to move, provided that there was a guide for their wheels which was via a metal-made plate due to the reduced amount of friction. The demand for this transport system became higher during the Industrial Revolution in Europe in the early nineteenth century, primarily to carry raw materials to factories.

The two mechanical principles, guided wheels and use of external power, were first combined by the English mining engineer, Richard Trevithick, who on 24th February 1804 successfully adapted the steam engine. In 1825, the first public train power by steam generated from coal fired boilers was introduced by George Stephenson with the sole purpose of transporting coal. Hence, the industry in charge of rail today has evolved out of the major aim of transporting coal to the provision of service for passengers as well as the transportation of several cargo types. (Matsika, Ricci, Mortimer, Georgiev, & O'Neill, 2013).

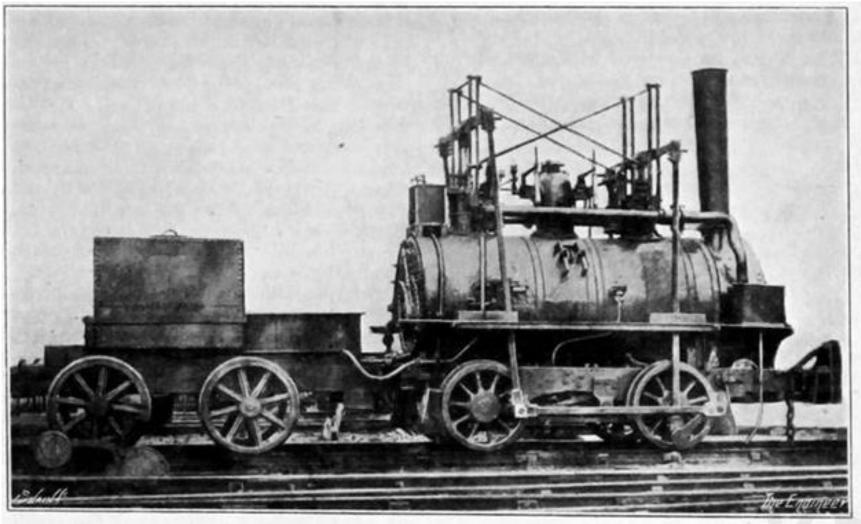

Figure 2.1 First Passenger Train

2.2 Types of Rail Vehicle

It is important to state that two rail vehicles types majorly are in existence, they are the vehicles for the cargo and the vehicles meant for the passengers and they are different in their purpose of use. Furthermore, factors like ride comfort, conditioning of the interior environment, increased top speed, noise control, crashworthiness, fire retardant materials' application, and in-train security are critical factors of consideration for the passenger vehicles. In opposition, cargo vehicle's design is focused more towards increased structural strength and rigidity for better carrying ability of large volume goods.

On a normal basis, freight trains are usually known for transporting high density, low-value goods like aggregates, coal, and many more. Nevertheless, with inter-modal transport being introduced, the rail-way industry has witnessed an upsurge in the transportation of high-value goods with low density. Moreover, the demand in the market for transporting goods that are frozen and chilled has resulted to the usage of refrigerated containers as well as wagons. (Matsika et al., 2013)

2.2.1 Passenger Vehicles

From the perspectives of the functional design, rail vehicles meant for passengers are grouped based on the segment of the target market. The most common categories are heavy rail (urban trains with top-speed within 100 to 160 km/h), light rail, metro, trams, and high-speed trains (with top-speed above 300km/h). Furthermore, the required necessities for design differs within categories which comprises of availability of interior space, dynamic features, external body aerodynamics and also track gauge.

2.2.2 Cargo/freight Vehicles

Cargo-vehicles are characterized by lengthy train sets that are coupled together, and which travels normally at speeds that are relatively low. In contemporary times, there is an increase in public transportation’s length from 750m to 1000m. However, this upsurge in length comes with challenges in operation. Interestingly, the highest operation speed for European railways is between 120 to 160 km/h, also the average speed is only about 30 to 40 km/h. Furthermore, the increase in the dynamic instability and aerodynamic drag is caused due to the fact the most wagons are designed without being streamlined.

2.3 Traction Power (Propulsion)

On a general note, rail vehicles traction area achieved via the usage of locomotives that are dedicated. Although, in contemporary times, electrical multiple units (EMUs) have been applied particularly for passenger train, of which there is the benefit of having a train set that is of an overall lesser length. More so, in vehicles meant for passengers, almost every unit makes provision of power for the train via traction motor. The most widely used means of power is diesel-based engines as well as electrical units with overhead catenary system, third or fourth rail system.

Even though electrical-based powering is of more preference as a result of its low relative impact on the environment, however the possibility of always having rail infrastructures with electrical systems is not certain. Consequently, in some cases, the application of diesel units occurs. Also, in certain instances, dual as well as hybrid units are also made use of. Magnetic levitation (also known as: Maglev) is one of the relatively novel technological-based application for the transportation of passengers. Its benefit is that it has a higher ride quality and it's friendly to the environment.

2.4 Comparison of Rail vehicle 50 years ago and now

Presently, the global railway network comprises of around 1.3 million km of tracks, transporting about 2.2 trillion passengers coupled with an estimated freight tonnes of about 10.3 trillion. It is possible to state that it may be shocking for many who witnessed the decline in railway network as the overall length-km of railway network is about the exact value of the length-km today. However, there have been balances in the closures of previous 30 years due to the construction of newly constructed railways comprising of a combination of freight and high speed routes. For clarity purposes, diverse cases in several countries have been tabulated in Figure 2 with sufficient figures for purpose of revealing the comprehensive total trend. However, the functional purpose of rail vehicles is the movement of either passengers or cargo or even the both of them. Hence, the definition of a system's productive ability as stated here is the addition of freight-km and passenger-km, divided by the system's route-km. It is essential to also state that for every country shown, the data at the upper and lower parts refers to the findings as of the past 50 years and the recently accessible figures, respectively. Also, the last column indicates the rate of production currently in comparison with that of past 50 years. (Palacin, Raif, Deniz, & Yan, 2014)

	Route-km	Freight (million tone-km)	Passengers (million passenger-km)	Productivity	Ratio 1998/1950
Canada	69,167	149,000	4,532	2.22	
	69,677	304,233	1,341	4.39	1.98
Mexico	23,332	9,391	3,025	0.53	
	26,613	41,957	1,799	1.64	3.09
USA	360,137	864,000	51,161	2.54	
	170,200	1,979,835	19,449	11.75	4.62
Argentina	42,864	17,309	13,229	0.71	
	34,059	7,659	10,642	0.54	0.75
Brazil	36,681	8,066	10,267	0.50	
	26,962	428,873	1,539	15.96	31.94
France	41,300	38,900	26,400	1.58	
	31,939	48,136	55,311	3.24	2.05
Germany	49,819	58,200	48,840	2.15	
	40,826	68,490	60,514	3.16	1.47
Italy	21,550	10,400	23,578	1.58	
	16,003	21,720	49,700	4.46	2.83
UK	31,336	36,200	32,472	2.19	
	16,536	12,292	28,656	2.48	1.13
Russia/USSR	116,900	602,000	88,000	5.90	
	147,500	3,362,200	384,000	25.40	4.30
S Africa	20,175	23,411	n/a	1.16	
	25,555	95,591	9,675	4.12	3.55
China	22,200	39,406	21,236	2.73	
	54,616	1,287,420	354,261	30.06	11.00
Japan	27,401	33,823	118,000	5.54	
	27,404	24,747	395,278	15.33	2.77
India	54,845	44,163	67,065	2.03	
	62,725	277,567	357,013	10.12	4.99

Upper value 1950 data from International Historical Statistics, Mitchell, BR, Europe 3rd. Ed., 1992
Africa, Asia & Oceania, 2nd Ed., 1995, The Americas, 2nd Ed., 1993.
Lower value, for various recent years, from World Bank Railway Database, 1998
Productivity defined as (million tonne-km + million passenger- km)/route-km

Figure 2.2 Comparison of Rail Network growth around the world

It can be seen that extreme growth has been experienced by some systems in size such as China, having the highest productivity rate. Besides that, the USA shows a decrease in route of more than half over the years. In general, all but one of the system has shown an increase in productivity. These comparisons provide a clear visibility on the non-occurrence of usage declination as suggested by many in the past 50 years that the purpose of the railway has been achieved and that its end would eventually come. On the contrary, regardless of the extreme development in the air and road traffic as of the past 50 years, it can be said that the railways have, with the minimum expectation, maintained their standard, and even enhanced their productivity rate.

2.5 Basic requirements of Material for Rail Vehicle

2.5.1 Lightweight

Light weighting is gradually becoming an increased and essential topic of discussion. There have been indications by previous studies of recent to the fact that over the past 30 years, rail vehicles are heavier. However, even though there are often attributions of the vehicle mass increases to improved environments for passengers such as enhanced accessibility, air-conditioning provisions, among others, yet clear undesired side-effects exists for vehicles with heavier rails. Furthermore, additional operational energy would be consumed by a heavier vehicle than a vehicle that is lighter, therein adding more cost to its running expense. Moreover, trains that are heavier have more likelihood of causing additional track damages, which could as well lead to increased cost of renewing and maintaining the infrastructures.

In addition, a normal metro-vehicle, with a six-car configuration would have together with its interior, a flooring material of about 250m^2. The weight of this should be an overall weigh of about 4 tonnes, therefore giving an opportunity of the representation of a significant light weight. Based on the rate of functioning, the key necessity for constructing a floor is its capability to support induced loads of the passengers, yet without exercising failure or deflection. Furthermore, the construction of the floor must as well make provisions for a certain insulation level. It can however be seen from figure 3 that contemporary interior construction of floors are most times very difficult assemblies of many materials which could employ use of: insulative materials, woods, inserts and elastomers. (Hudson, Carruthers, & Robinson, 2010)

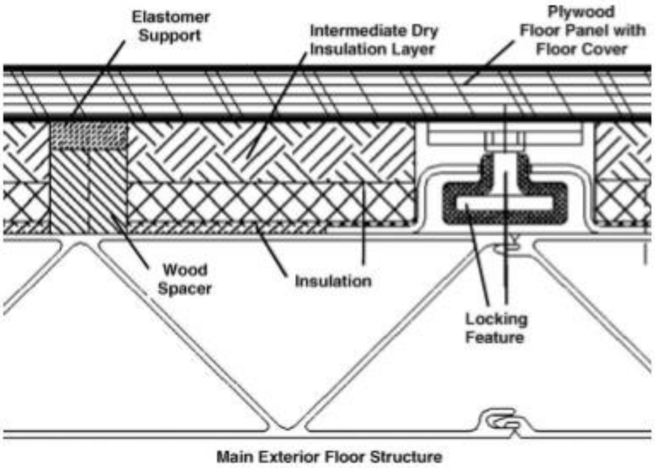

Figure 2.3 Typical Rail Vehicle Floor Structure (Hudson et al., 2010)

2.5.2 Cost

It is highly unlikely to optimize both mass and cost as the material used in producing the lightest solution will not also be the solution that is cheapest. For that reason, the both properties are seen as a trade-off boundary.

2.5.3 Safety - Crashworthiness

The ability to absorb high impact energy and be survivable for the passengers is called "Crashworthiness" of the vehicle. Crashworthiness of a rail vehicle depends highly on how the materials, construction and design of the vehicle work as one. From a collision perspective, the two crucial safety concepts in vehicle industry to take into consideration are crashworthiness and penetration resistance. Crashworthiness relates to the potential of absorption of energy via controlled failure modes and mechanisms that results in a gradual decay in the load profile during absorption. On the other hand, penetration resistance relates to the total absorption without permitting projectile or fragment penetration. Additionally, materials deformation and progressive failure behavior from the aspect of stiffness, yield, strain hardening, elongation and strain at break are also very important in the energy absorption capacity of the vehicle. (Daehn, 2014)

2.6 Current material in use

2.6.1 Steel

Steel technologies has evolved within the last 10 years and are often adopted in novel designs by all types of auto-makers. Furthermore, the suppliers of components as well as the industry for steel invests heavily in the innovation of products. As a result, this investment has led to the production of successful cost-effective stainless steel usage, newly formulated iron, steels with higher strength as well as fabrication, assembly and new-design methods. The quality of steel produced focuses on the decrease in weight and concurrent improvement in stiffness and strength. Therefore, vehicles are being made lighter and safer concurrently.

2.6.2 Aluminum

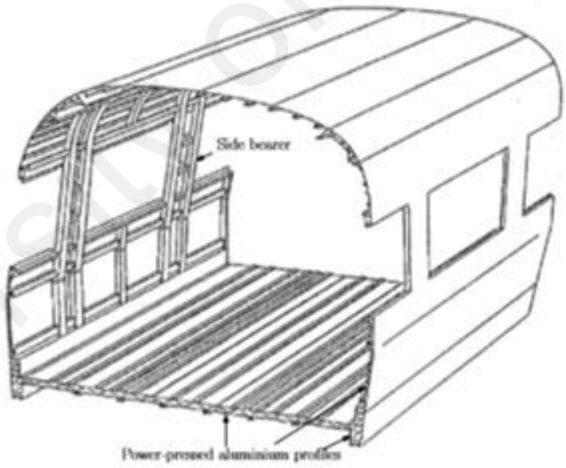

Figure 2.4 Aluminum car body structure (Wennberg, 2011)

There are a many advantages of employing aluminum in rail vehicle power train, chassis and body structures. The usage of aluminum offers an extensive potential reduce in weight of a rail vehicle car body. At present steel construction, the vehicle is made up of stamped body panels spot welded together to which stamped steel fenders, doors, hood and deck lid are bolted. The two common methods of designing and manufacturing an aluminum car body structure are by using stamped option and the other system which involves castings, extrusions and stampings welded together, known as space frame. Adequate formability is one of the requirements for aluminum sheets to produce intricate stampings at acceptable economical rates. Furthermore, the aluminum alloys selected for exterior panels should contain the ability of age hardening to offer suitable strength for dent resistance during the oven paint baking. (Mori & Abe, 2018)

The recent instance of aluminum applications in vehicles include power trains, chassis, body structure and air-conditioning. Aluminum castings have been practiced in a variety of automobile parts for a long period of time. Engine blocks are being manufactured with aluminum instead of cast iron, resulting in significant weight reduction. For chassis applications, aluminum castings are used about 40% of wheels, brackets, brake components, suspension, steering components and instrument panels. Lately, development effort to apply wrought aluminum is becoming more active than applying aluminums castings.

2.6.3 Magnesium

Magnesium and its alloys show great involvement in the rolling stock applications of railways due to its cost efficiency, mechanical properties, evolved processes in manufacturing, and availability of large reserve for resources. However, the alloy parts/components of higher strength are essential for weight reduction efforts which is widely used in the railway industry apart from aviation, military, automobile and communications industries. (Ren et al.).

Magnesium has a 1783 $kg/m^{3,}$ value of destiny, which is about 2/3 (two out of three) of aluminium and 1/6 (one out of six) of steel. Hence, leading to a 33% lightness than aluminium and a 75% lightness than the components for steel. Furthermore, the strength-to-weight ratio of magnesium which is higher than aluminium is one, which is the primary factor for increase in demand. The desired purity for grade of 9980A, with regards to ASTM B92 as of 2007, for commercial magnesium is a value of at least 99.80 wt% Mg with impurities below 0.05% of Ca, Al, Si and Fe.

However, Magnesium also has its set of mechanical/physical property disadvantages such as similar yield strength but lesser ultimate fatigue strength, creep strength and tensile strength compared to Aluminium. Nevertheless, magnesium has several clear advantages that comprises of more improved ability to manufacture, extensive life span as well as more rapid solidification as a result of lesser latent heat. Furthermore, the rail components that form rail vehicle car body structure are created using a range of manufacturing processes such as casting, extrusion and welded plate's assembly. Various materials are considered, mainly aluminium, magnesium and Glass Reinforced Plastic (GRP).

Table 2.1 Properties of Mg, Al and Fe

Property	Magnesium	Aluminium	Iron
Elastic modulus (106MPa)	44.126	68.947	206.842
Tensile strength (Mpa)	240	320	350
Melting point (0C)	650	660	1.536

2.6.4 Sandwich Design

The configuration of a Sandwich design makes provision of an effective mixture of low-weight as well as elevated bending rigidity. The structure of sandwich normally consists of face-based sheets which is responsible for carrying stresses for bending as well a core of lower density that is able to resist stress of the shear. However, absorptions with elevated energy in the course of impact, makes the designers to get attracted to the structures of the sandwich. Moreover, a Sandwich configuration also has high strength-weight ratio and also causes a collision-based energy dispel via synergistic mechanisms for bending as well as core crushing and the face sheets' stretch. In the transportation industry, composites of sandwich have been employed in roof panels that are structural in railway-coaches of high speed, high-speed locomotives front-cabins. (Ning, Janowski, Vaidya, & Husman, 2007).

Furthermore, structures of Sandwich comprises of 3 major elements, a central core, and two exterior faces (known as skins) as depicted in figure 5. The materials for the face usually are sheet-metals or fiber reinforced plastics whereas the inner core material normally are of lesser density like: structures from the honeycomb, foams made from polymer, or balsa wood. However, there exists an endless amount of materials as well as combinations which could be employed in constructing the sandwich and each of them have its own precise advantages.

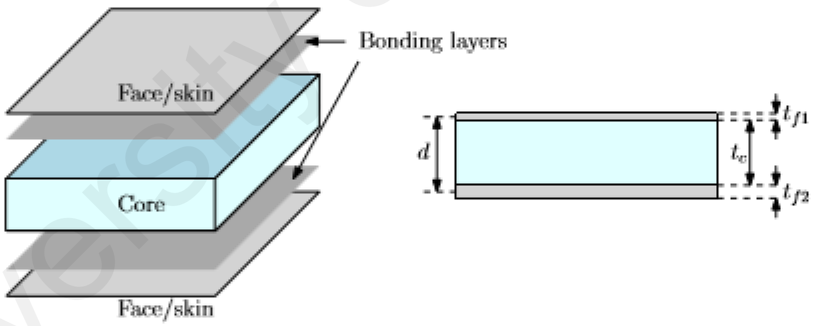

Figure 2.5 Typical Sandwich Structure

The said materials are combined using a lamination technique. This laminated material can achieve up to 30% of weight savings with polymers that are reinforced with glass in comparison to steel as well as the possibility of around 60% savings of mass for the composites of carbon fiber. Moreover, the savings of potential weight also depends on the structure's constraint and functionality. Multi-functionality design is a combination of strength, thermal and acoustic insulation of different materials into one panel as shown in figure 6.

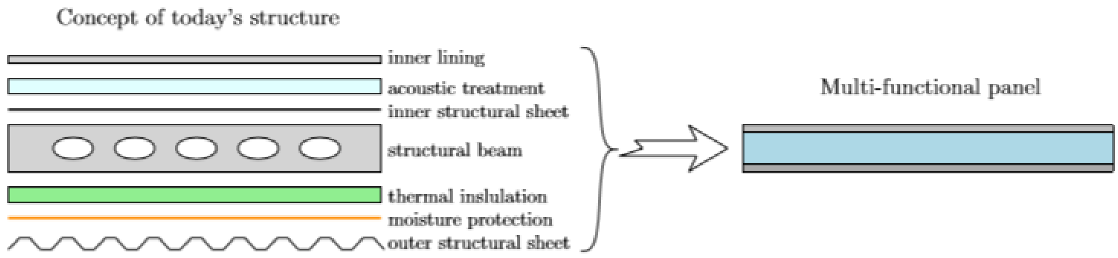

Figure 2.6 Multi-functional Layer

The sandwich structure is capable of functioning in a manner similar to that of an I-beam with regards to bending, also the reason for the outer faces is the withstanding forces that are tensile and compressive as that of an I-beam flanges. Importantly, the inner-core is responsible for carrying majority of stresses for the shears. Figure 2.7 illustrates a solid length beam, L which is bent to a curvature's radius.

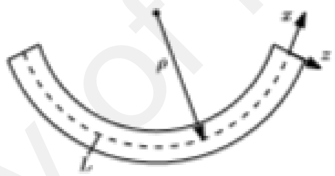

Figure 2.7 Bending of Solid Beam

The relation between bending moment (Mx), Strain (Ɛx) and stress (σx) for a beam bent as shown in figure 2.7 with a constant Young's modulus, E, can be expressed as:

$$\sigma_x = \varepsilon_x E = \frac{m_x z E}{D}$$

where D is the flexural rigidity of the beam, calculated as:

$$D = EI = E \int z^2 dA$$

However, with the introduction of composite materials for weight reduction, some few aspects might rather consist of an impact that is negative. Simply because, a rail vehicle that is lighter can be easily pushed out of the track than a heavier rail vehicle during strong cross winds. This issue can be resolved by addressing the need for ballasting the end cars of the rail vehicle to increase stability. Energy absorption and crash safety is another concern to be addressed when using composites. Metals in general are well known for having creditable properties for energy absorption. Laminated or structures of sandwich have a broad range in modes of failure, whereby just some of them might produce enough properties for the absorption of energy. During the selection process of materials, the discovery of the mode that would be the first to fail and the process of producing a structure of consistent failure in like-manner is the toughest aspect. (Wennberg, 2011)

2.6.4.1 Composite

On a general note, a composite is referred to as the production of a material from two or additional materials components that is left distinct and separated from each other. Figure 8 illustrates a composite lamina of unidirectional state. Furthermore, the make-up of this lamina consists of some fibers, the matrix as well as the reinforcement material, usually known as a polymer. Importantly, the fibers are covered by the matrix, which also makes them to be intact. This however, produces a high rigidity and strength in the direction of the fibre, whereas in the crosswise direction, the matrix's stiffness and strength are responsible for the domination of the laminate's mechanical properties. This lamina is hence a highly-orthotropic constituent. (Kim, Lee, & Shin, 2007)

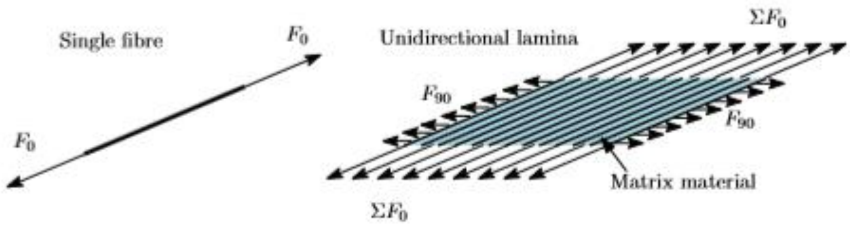

Figure 2.8 Unidirectional Composite Lamina

There could be stacking on top of one another of several of these lamina's, thereby leading to the creation of a laminate that is composite. The purpose for the creation of the laminate is for the continual increase of the stiffness as well as the strength in sequence of the stacking, specific direction or lay-up of the lamina. However, the add-up of constituent sheets of face to the structure of the sandwich proffers additional difficulty to the issue but with an added space design. The face sheets of the constituent could then be engineered for the optimization of the component's directional properties. The load carrying structure of a train's car body of high-speed, which has the responsibility of carrying several diverse loads at different directions is essential to have a lay-up that is quite balanced.

2.7 Rail Vehicle Design

Rail vehicles are comparatively heavy as to when compared with other means of transportation. Additionally, rail cars cost per kg is high. Some of the causes for its high price are each customer's individual design and short series. Another contribution to the high cost is the railways standard load assumptions that are conservative. In contemporary time, there is existence of enough knowledge with regards to manufacturing likelihoods and properties of the structure of a sandwich. In view of this, the car-body of a sandwich or the mixture of aluminum/steel car-body coupled with the design of sandwich are all seen to be more reasonable substitute to normal design of aluminum or steel.

The body of the car must need to meet-up with several conditions, including conditions for safety which are set-up for derailment, fire, scenarios of crash, tunnel's pressure waves, impacts of projectiles and etc. Also, the body of the car must be in line with the precise profile for construction of the line in operation. It must be adequately strong so as not to lead to failure in the course of cyclic loading or typical load.

A running train alongside a track is among the dynamically and statically complex systems in engineering. However, the system consists of a lot of bodies which also makes it to have so much degrees of freedom .Also, the connection of the bodies that's brings about the make-up of the vehicle could be done in several means and there is a link of a moving interface to the track from the vehicle. It is important to state that this interface comprises of the wheel-tread's complicated geometry, the head of the rail as well as the frictional forces of non-conservativeness which are generated as a result of contacted area's relative motion. It is important to make a good design, simulation and analysis of a template if we want to improve, for instance the railway parameters in order to make it more comfortable for the passengers. (Wennberg, 2011)

As it is known, the element of most-importance for any train is the structure of its body. All diverse constituents are connected by the body of the car. It holds the drive-train and of major essentiality carries the passengers and cargo as well as ensures their protection There's need for rigidity of the structure of the body for purpose of supporting stress and weight, as well as a secure joining of all the constituents. The body structure consist of the major structure for carrying load over all suspension units of trucks. It comprises all constituents that are joined to this structure as well as gives direct contribution to its stability, strength and stiffness.

The car-body of rail vehicles is referred to: a structure for carrying load, windows, doors, inner parts with seats, inner-linings, ambient lighting, ventilation and etc. The technical equipment used for braking, propulsion, etc. is not part of the car-body as it is usually attached to the bogie. Sometimes the concept of load carrying structure of the vehicle is stated as follows. The car-body should be complete structurally, comprising of flooring if it has been made use of as an aspect of essential structure of the car-body but will exclude some items like: interior and exterior trim, doors, windows, lights, seats, lining of the interior, insulation or any additional materials that would obscure any structural-member of the body of the car from view. Under floor, roof and ceiling mounted apparatus shall be installed or corresponding distributed weights at each of their locations.

A railway vehicle must be certified before being put forth into service. Also there must be performance of dynamic as well as static tests in accordance to international standards in the course of the process of certification. However, there could be discovery of some rail vehicular structures ability to crash, static stress tests' requirements, standards, and specifications. Within the scope of the standard of the body of a car, the provision of a unified basis for the purpose of the vehicles body's structural design is intended as well. Also, the requirement for the loading of the design structure of the vehicle's body as well as testing are on the basis of experiences that are proven with support from published information and evaluated data for experimentation.

Furthermore, measurements for experimentation and numerical approaches are being employed for the determination of the railway vehicle's static behaviors. It is noteworthy to state that measurements taken during experimentation consumes a lot of time, are costly and can't be made use of at every stage in the design phase. Therefore, the numerical techniques used in contemporary times are very vital tools needed for the static analysis of railway-based vehicles. Even though there are no aforementioned negative consequences of the methods for experimentation, however the verification of the experiments for purpose of obtaining results that are realistic is very mandatory. The FE approach is a very influential tool for analyzing numerical engineering-based analysis, and it is extensively made use of in analyzing the static stress of railway-based vehicles.

Half-width or half-lengthened and half-width or full-lengthened techniques for modeling are employed for the determination of a vehicle's vibration, static structural, depending on its symmetry. However, full-lengthened or half-widened techniques for modeling could be employed for just specific kinds of simple loading of static structure like that of conditions for loading static symmetrical tensions and can't be validated for complicated loading of static structures as well as the conditions for loading dynamically. In view of this, simulations with full length are essential for the purpose of validating designs as well as the provision of the highest probable accuracy.

Furthermore, as a means of obtaining the behavioral structure of the railway-based vehicles, i.e. the distribution of strain and stress, diverse situations of static loadings which were defined in (EN, 2010) can be used in the finite element analyses. Also, in the measurement of experimentation that needs to undergo validation, majority of the normal references which are usually taken into consideration are for static analysis and for dynamic analysis. The Finite element approach is employed for assessing the dynamic as well as the static behavior of the structure of the railway-based vehicles. More so, the models with full lengthened detailed railway-based vehicles are made use of in all finite element analysis. However, in this thesis and putting the afore-mentioned issues into consideration, it can be stated that stress analysis and deformation of structures for the railway passengers are completed. Full-lengthened comprehensive and validated models of the finite element are made use of in the assessment of behavioral static structure of the railway-based vehicles. As a means of obtaining the railway-based vehicle’s static structure behavior, diverse scenarios of case loadings as defined in the standards of EN15663 were employed.

Within the scope of this thesis, structural analysis of the rail vehicle body and finding of the maximum stress and the deflection of the body and modal analysis to determine the structure behavior in dynamic conditions was done by using the material of steel (st36).

2.8 Car body description

The car-body shall be a lightweight integrated structure designed in harmony with the trucks and the coupler or draft gear system in regards to vibration damping and collision resistance. Emphasis shall be placed on a structural design which allows maximum energy absorption in a collision by means of plastic deformation and transferring of minimum forces to the passenger. Modular car body repair elements shall be used appropriately to simplify collision repair.

The car body for each car type shall be arranged as a single car with end vestibules, having a side doorway across from each other at each end of the car, as well as a body end door at each end of the car. One end of each cab shall be dedicated as the Operator's cab. The car-body shell will be designed as a girder that has been modified, making use of the floor and roof as members of the chord, joined together at the sides, which is responsible for carrying the shear. Car roof framing, side sills and side sheeting shall be suitably designed and constructed for installation of passenger side entrance doorways.

All car types supplied shall be of identical design and construction, except for the special requirements of the car end of the cab and food service car window arrangement. The maximum amount of parts commonality between all car types is desired. Each of the side doorways, with the exception of the one at the end of the cab car, shall have single stream combination low level and high level station platform boarding capability. Each of the doorways at the cab car's cab end shall have a single stream high level station platform boarding capability. Individual doorway dimensions are identified. Each car shall be completely equipped for two-way operation independently. The car shall have a pleasing, modern, clean aerodynamic appearance, require minimum maintenance and are structurally able to withstand damage, suitable for easy structural repair and designed the minimize passenger injuries in the event of a mishap.

All connections that are fastened mechanically will be designed through the use of factor of safety 2.0 based upon the fastener's load proof. Furthermore, the friction of the Clamping force would be overlooked in the process of designing and analyzing of connections that are fastened mechanically. Self-tapping screws shall not be used for structural connections. The structure of the car will not have any holes been tapped. Plates meant for tapping might be made use of but should be of greater or same thickness than that of the bolt's diameter, of which the plate meant for tapping is planned and there shall be drilling of a hole for clearance in the bolt's structure. Furthermore, the design of the plates for tapping will in accordance to the exact standards for strength of the corresponding nut.

The design of the car body of contemporary rail-vehicles are as structures of lighter weight with the sole purpose of minimizing mass size and in extension, the demand for energy needed for operation. The crucial conditions for the design of structures are made known by the major static load. (Kozek, Benatzky, Schirrer, & Stribersky, 2011). On a general note, structures of railway-based vehicles comprises of beams, shells and plates. The way these members behave has a direct impact on the dynamic as well as the static structure behavior of these vehicle. The design of the bodily structure of railway-based vehicles is dependent on their subjected loads as well as the features of the materials that were used in manufacturing them (C.Baykasoglu, 2012). Moreover, the comfort of the ride comes up to be an issue of much importance due to the fact that if they get softer, there will be additional exhibition of lesser Eigen frequencies which could indicate some significant effect in the comfort of the ride's perception.

There are diverse impacts made by the reduction in the weight of the railway-based vehicles which are:

I. One of the outcome is the conservation of energy. It has been shown by simulations as to the fact that the savings potential via vehicle mass sizes that are lessened are dominated by the service profile's features. Furthermore, a specific savings with high potentials coupled with the profiles of shorter distance service amidst speeds of reduced maximum and stations exists. It is important to note that if there is an increase in the maximum speed, the energy's proportion required for the overcoming of the resistance in aerodynamic rises up and therefore the savings potential decreases.

II. Secondly, effects could be seen from the decrease in the damage of the rail as well as the optimization of structure with super standard in accordance to the load of the axle.

With reference to the distribution in weight, there could be a split of the railway-based vehicle into car-body, equipment and bogies. As a result of the complexity of the equipment's systems, coupled with the need in addressing several sub-systems disparately, and also because of the too much conditions and security relevance of the bogies, there is a limit in the saving potential of their weight. The global weight saving resultant potential of the rail vehicle equipment is limited. Analysis have shown that a rough car-body's mass is usually accounted for up to 15 – 30% of the empty weight of the vehicle. Notwithstanding, the body structure of the car interacts with parameters of diverse kinds. Therefore, this implies that the structure of the car-body has a direct effect on the saving potentials of the parameter's weight. Development in the field of railway goes in particular through decreasing the weight of rolling stock vehicles car body structure.

Thus, the car-body's optimization of weight comes up to be a very important topic. However, as a generic standard in the design of vehicles based on the rolling stock, the usage of the principles of lightweight are indispensable. Such principles are split into the following:

a. lightweight optimization of shape and form.

b. lightweight material usage.

c. lightweight optimization based on system and function (system configuration of lightweight)

2.9 Parts of passenger rail vehicle car body

Passenger car body consists of the following main parts. (Koenig & Friedrich, 2011)

2.9.1 Under frame

The under frame shall consist of an essential unit with extensions from both ends of the car and will compose of the side sill, floor beams, bearers of the cross, floor pans, end sill, transition members, posts for collision, and the center sill. However, the sides by the side should be made from floor beams of side by side sill continuity, if the sill at the center is not integrated in the design. Also, the sills at the side and center will be braced by cross-side members. Importantly, the design of the under frame structure will be for purpose of meeting all applicable rules of FRA, the necessities of the AAR and the standards of APTA accordingly.

2.9.2 Center Sill

The center sill is the major load carrying plate form that comprises two longitudinal frames running alongside the car body's length, bolsters, side sill, floor beams and cross bearers. Therefore, the primary component of the under frame is the center sill. As the vehicle is supported about two bogie bolsters at 12.2m for the case study, it can be simplified to a simple supported beam and hand calculation results will dictate the approximate size of the center sill section to be used. Hence, it will be used as an input for finite element analysis. The critical loading case for the rail vehicle under frame is the combined compressive and vertical load which is the biggest of all the loading scenarios.

2.9.3 Cross bearers

There are transverse sections that are integral part of the body frame. They are manufactured from 5mm thick bent to a U-profile and welded to the web sides of the under frame and external side frame. They are spaced to a dimension that suits the plate sheeting and these members are supposed to carry distributed load coming out from passengers. Optimization of the cross bearers is possible due to the fact that bending moments decrease as we go far away from the longitudinal center sill.

2.9.4 Side sill

The external limiting size of the rail vehicle car platform is the side sill. Its production is similar to that of the end sill and cross bearer. They are manufactured by sheering and bending a 5mm thick mild steel and formed to a C-profile along the length of the rail vehicle car body and are used as a base to the side wall posts. Side sills are not only structural component rather they have to be aesthetically attractive as they are they exposed surface of the rail vehicle car body.

2.9.5 Front and Rear sill

Rear and front sills are welded to the side sill along the lateral direction. The house spring loaded draw bar used for coupling two car bodies together. Name plate, reflectors, electrical light system is installed on to this frames. It is the first to be exposed during crash and shall be reinforced by a collision post extended from itself with the under frame.

2.9.6 Side wall

The side wall structural member has columns and girts designed to carry the load from the roof and passenger luggage. Moreover, it should be strong enough to maintain the shape of the rail vehicle car without deformation during jacking and lifting. It also has door and window frames. Side wall should give proper ergonomics to passenger boarding the train and allow comfortable environment during different climate condition.

2.9.7 Collision posts

The APTA standard gives an outline of the smallest necessities needed for the design of the structure for colliding the posts at the end-point of occupied vehicles. However, a vehicle’s end-point that is designed for the purpose of leading a train should be responsible for the protection of the vehicle’s occupant’s right from the objects’ intrusion that gets the train struck in a situation of collision. Due to such reasons, in order for such vehicles to have lead ends, some necessities for higher strength are needed. Such standard’s necessities are aimed at resulting in the absorption of energy at the structure’s end over the under frame. Thus, needed necessities required by colliding posts of the subsequent segments comprises the absorption of a significant quantity of energy by the post via the undergoing of deformation that is critical without either the post failing or even its connections in the course of an overloaded condition.

2.9.8 Couplers

A coupler does three things: connects one car with another, holds the connection and then disconnects the two cars if made use of, also, couplers of the APTA RP-M-003 of Type H, couplers that are semi-permanent, and the interlocking couplers of the AAR Type F standard might be seen as to have the ability to provide the resistance that has been overturned, the needed climb, and the bypass, provided that the below further conditions are satisfied:

a. The arrangement of the structure shall comprise of a carrier coupler which is designed with the sole aim of resisting vertically download thrust of the 450KN all from the shank of the coupler at any probable coupler's position horizontally. The benchmark for accepting in such situation will be that the carrier coupler is not permanently deformed, as well as the bodily structure of the supporting car and connections for intervention.

b. Furthermore, they shall be an inclusion of the buffer beam by the arrangement of the structure across the coupler, which is to be designed with the aim of making sure the 450KN is resisted in an upward thrust vertically for any position of the coupler horizontally. However, the benchmark for such situation's acceptance will be that the beam of the buffer is not permanently deformed, as well as the bodily structure of the supporting car and connections for intervention.

2.9.9 Horizontal Framing Members

There might be connections by the corner posts and the collisions at the frame's end horizontally via an inter-coastal as this is important for the resisting of the design loads lateral components. Furthermore, the head of a structure might be made use of for the connection of the corner posts and the collision tops. A member of the horizontal structure amidst the corner-post as well as the post of colliding shall be included by the framing of the cab-end at a corresponding height on each side all through the windshield's bottom. The shelf of the structure shall also be in support of a load not smaller than 67KN, which could be applied transversely at any point to the member on its span, all without any of the structure of the vehicles been permanently deformed. (Kayran & Aydıncak)

The car body structure is made from Aluminum extrusions, magnesium and composite materials. Moreover, due to the fact that the train's total weight is a crucial parameter used in the process of authorizing the railway-based vehicle, principles regarding light weight have been put into consideration during the car-body structural design. Railway vehicle bodies shall be able to endure consistently the maximum loads with their required conditions for operation and attain the needed service life based on the normal conditions for operation with enough survival likelihood. The capability of the railway vehicle body to sustain required loads without permanent deformation and fracture. The centric requirements needed for the design of the structure are given through the major static loads.

2.10 Category passenger rail vehicles

To this group belong all types of railway vehicles which are for the purpose of passenger's transportation, with ranges from major line vehicles, urban transit stock, suburban transit stock all through the tramways. However, the vehicles meant for passengers' have been split into five(5) categories of the structure's design which comprises of the allocation of all vehicles.

According to European norm for design, there are five categories of rail vehicles, with an indication of the types of vehicle generally associated with each other.

a. Category P-I (Coaches)

b. Category P-II (Fixed units and coaches)

c. Category P-III (Underground, rapid transit vehicles and light rail car)

d. Category P-IV (light duty metro and heavy duty tramway vehicles)

e. Category P-V (Trams)

As a general requirement, rail vehicle car body should have limited weight. As a result of the weight of trains, forces are being exerted on the infrastructure which ends up in the tracts been worn out. There is also an increase of the wear by the high weight on the axles, wheels, brakes, shock absorbers, among others. The body of the car ought to be adequately stiff. From the angle of safety, there should be no flexing of the car-body out of the track gauge while operation is ongoing or showing of vertical displacement that are significant because of the load of passengers.

Different research has been done on the materials used for the rail vehicles to get the materials advantage to minimized the stress, vibration, minimize the material deformation and other related to maximize the static nature of the rail car and are also done to reduce the weight of the vehicle body.

2.11 Definition of design masses

For the case under consideration the dead weight of the vehicle (Bogie + car) is 46ton and the mass of 272 passengers is 19040 kg.

2.11.1 Deadweight

The dead weight of the vehicle in working order is the mass of the structure, bogies, staff and consumables together.

2.11.2 Consumables

It is the weight of sand, water, catering materials, fuel, food and beverages including water for drinking and cooking, clean water of wash basin supply reservoirs and of toilet supply reservoirs.

2.11.3 Standing area

According to EN15663, the calculation of the area meant for standing is being done with tip-up seats and foldable tables in positions that have been closed by taking into account half the projected area of internal stairways. The Standing area doesn't include:

a. Projected area of normal seats (including back and arm rests) on the floors plus a 300mm deep area for the feet of the seated passengers, which extends over a full width of seat.

b. Projected areas of fixed tables on the floors.

c. Area restricted to drivers and other train crew areas where standing is prohibited.

d. Steps and other areas that are only used when boarding or alighting.

e. Areas, except stair ways, that due to their limited dimensions (width or length under 300mm), are unsuitable for standing.

f. Areas which are used for toilets, washing areas or similar.

2.12 Design loads

This is to define load requirements to be used for the design of heavy rail transit vehicles, including static loads representing normal and exceptional conditions. The structure of the car body shall be completely assembled with the loads of all equipment included before the specified loads are applied. Each specified force shall be applied over the minimum area necessary to limit local yielding or buckling, with its center of action at the location specified.

Rail vehicle, except on passenger carrying locomotives with damages that are non-structural in occupied area is restricted to the members framing and sheathing of roof. The deforming of the framing and sheathing of roof is permitted to the level needed in allowing the vehicle to have a uniform direct support on the end-frames and side-frames top chords. For instances like this, and whichever is less, the stress allowed for the car-body's occupied zones structure will be one half of the crucial buckling stress or one half of the yield.

The design of the non-passenger train which carries locomotives with equipment hoods that are not structural shall be in a way that the operator of the cab will be able to maintain a volume that is survivable, in the case of a rollover. Furthermore, the calculation and layout will be shown by the manufacturer (either the finite element or classic approach) that there is a capability of the locomotives to be able to rest up-side down at two or additional contact points and at the same time maintaining in a simultaneous way, the survivable volume of gas within the cab's operator. The contact point might be a main equipment piece (e.g. the transformer and the dieseling in), one platforms endpoint or the other (based on the gravity center's location) or addition of structural members for purpose of the requirement's satisfaction. The enclosure of the deforming of an equipment as well as the sheathing roof of the cab's operator is permitted to a certain point needed to allow the support of the vehicle as described earlier. Additionally, this structural members allowed stress which is being added precisely to the structure for the case of this load, will be one out of half of the crucial buckling stresses or one out of half of yields. However, there shall be determination of the structural members' applied load from a calculation balance that is static while there is a turning upside-down of the locomotive, assuming that just the adjacent of the truck to the cab's operator remains in attachment to the structure. (Jones, 2011)

Table 2.2 Definition of mass cases for different rail vehicle categories

Definition	Symbol	Description
Design mass of the vehicle body in working order	m_1	The design mass of the vehicle body in working order according to EN 15663 without bogie mass.
Design mass of one bogie or running gear	m_2	Mass of all equipment below and including the body suspension. The mass of linking elements between vehicle body and bogie or running gear is apportioned between m1 and m2.
Normal design payload	m_3	The mass of the normal design payload as specified in EN15663
Exceptional payload	m_4	The mass of the exceptional payload as specified in EN15663

CHAPTER 3: METHODOLOGY

3.1 Design Flow Chart

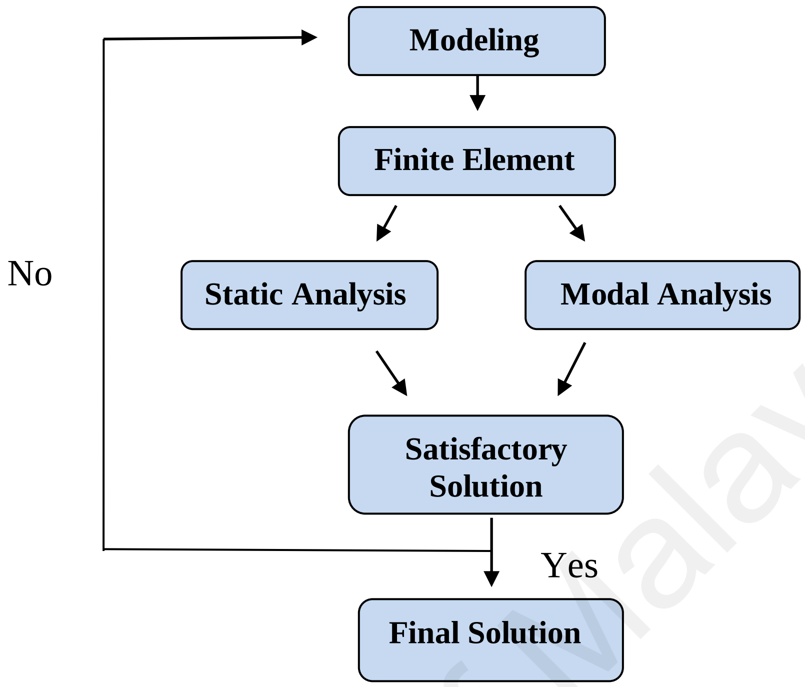

Figure 3.1 Design Flow Chart

3.2 Design Parameters

To define the car body structure, a structural model was created using ANSYS 16.0 Design Modeler. The intention of the structural modeling is to describe the primary car body structure prior to formal stress analysis and structural drawings being produced. With the understanding of how finite element software functions, a FEA model must consist of detailed parameters such as dimensions, loads, constraints and mesh selection.

In this research, category P-III (Light Rail Vehicle) is considered. The main parameters of the car body resembles the parameters of a prototype design that is being developed for an upcoming railway line. However, due to copy right and legality matters, the manufacturer and modal of the rail vehicle are kept confidential. The main dimensions of the adapted rail vehicle design are tabulated below:

Type	Passenger coach
Design speed	90km/h
Gauge	1435mm
Car body length	17800 mm
Car body width	2564mm
Car body height	3536mm
Door height	2400mm
Door width	1600mm
Min. curve radius	80m
Couple height	660mm from T.O.R
Bogie weight	13t
Distance between bogies	12200mm
Max passenger capacity	272P

Table 3.1 Rail Vehicle Dimensions

For a passenger coach, the high overall weight is a collective weight of interior, exterior, under frame equipment, bogies, luggage and passenger weight. Bogies are commonly made up of several components such as bogie frame, wheel set, gearbox, brake disc and traction motor which adds up to the weight. It is often quite hard to keep accurate records of all the pertinent masses and positions. Commonly, the mass of the equipment is merged to the metal structure model.

This research is conducted with a fixed set of under frame equipment to identify its effect on the car body structure when combined with passenger weight. The outcome of the analysis will determine the suitability of these set of under frame equipment to be designed as part of this rail vehicle. The set of under frame equipment is made up of several components which has its own weight. The proposed list of under frame equipment is tabulated below:

Equipment	Qty.	Weight (kg)
Flange lubrication tank	1	15
Battery	1	900
Additional reservoir of air spring	1	67
Brake control unit	2	58
High voltage box	1	580
Overvoltage protection	1	85
Shed receptacle	1	2
Fuse box	4	3
Main air reserved module	1	170
	Total:	**1947**

Table 3.2 Under Frame Equipment Details

3.2.1 Calculations

The carrying capacity of the rail vehicle is 272 passengers and the weight of each passenger is assumed to be 70kg.

a. The total area of load applied is 17.8m long and 0.831m wide

A_{pa} = 17.8m x 0.831m

= 14.79m^2

b. Compressive force at passage ways and access areas is:

F_{pa} = 4people x A_{pa} x 70kg

= 4141.2 kg

c. For this design, the maximum pressure is contributed from vertical and compressive load acting over the whole under frame area of 17.8m length and 2.564m wide.

$$F_{cv} = \frac{35.8+12.345}{4} = 12.03 \text{ ton per axle}$$

This result is consistent to the specification axle load of <13ton

3.3 Model (Geometry)

The adopted design of rail vehicle car body was modeled using ANSYS Design Modeler. The structural sketch includes a longitudinal dimension of the car body and a longitudinal dimension of the under frame. The under frame part of the car body comprises of two longitudinal I-beam (Center sill) which serves as a major load bearing structure. The center sill is further reinforced with five (5) cross beams placed horizontally as shown in exploded figure below. The car body is designed with two doorways and three window openings on each side. The roof structure of the car body shows a 50mm depression for mounting of two air-conditioning units.

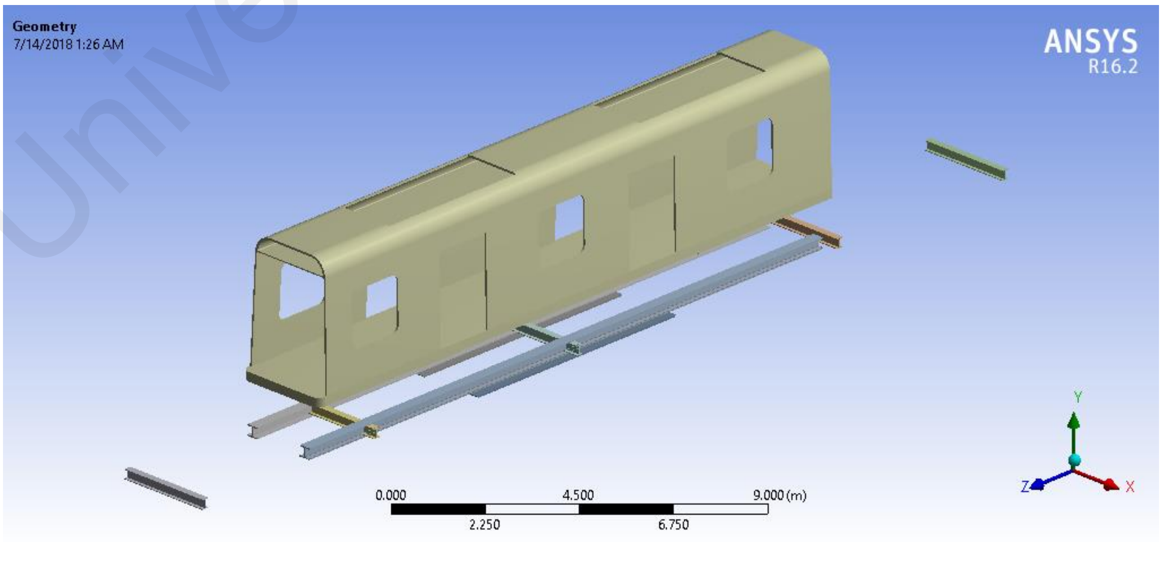

Figure 3.2 Car body Model

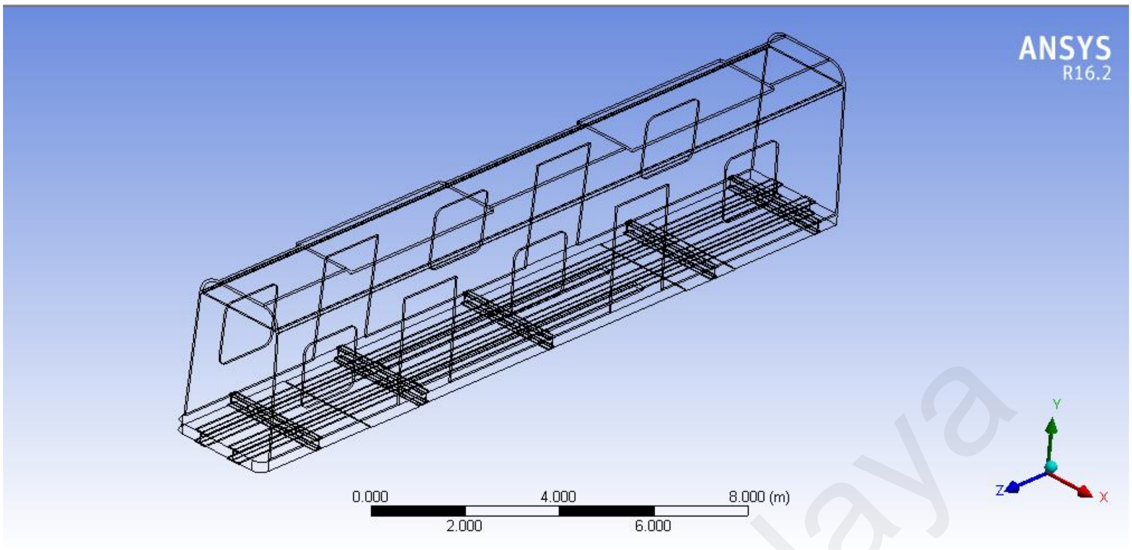

Figure 3.3 Car body Model (Wireframe)

3.4 Meshing

Meshing is a crucial part of FEA to determine how precise the end result of the simulation is. In the meshing section, the geometry is split into numerous cells called nodes and elements. When the mesh sizing is decreased, the results accurateness increases. This may take extra time and RAM (Random Access Memory) to run the solver. For this design, Relevance center and smoothing were set to fine with sizing of 0.1m. The result in this meshing produced 219377 nodes and 83637 elements for the rail vehicle car body structure.

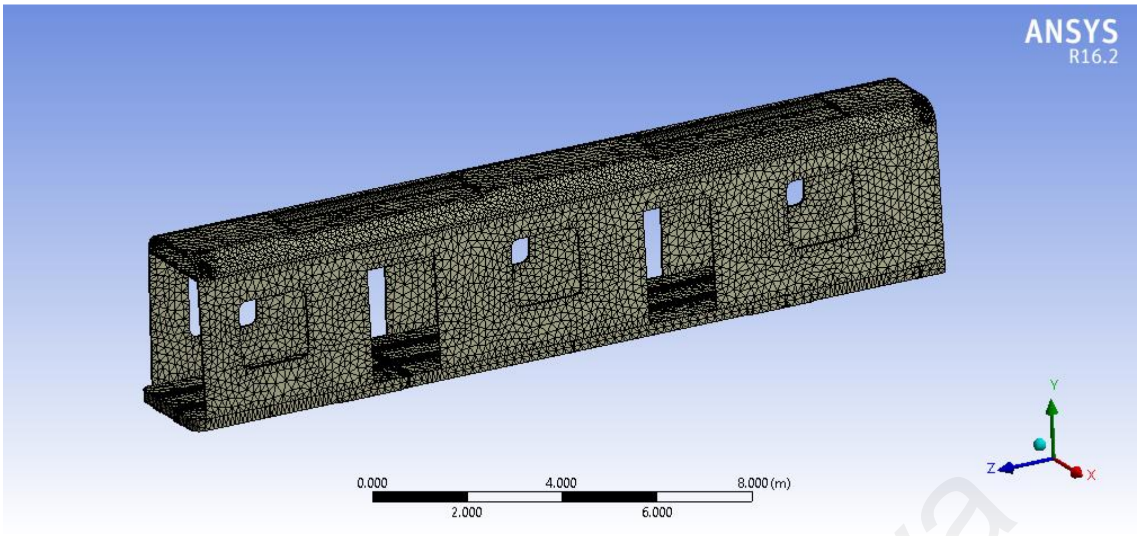

Figure 3.4 Meshing

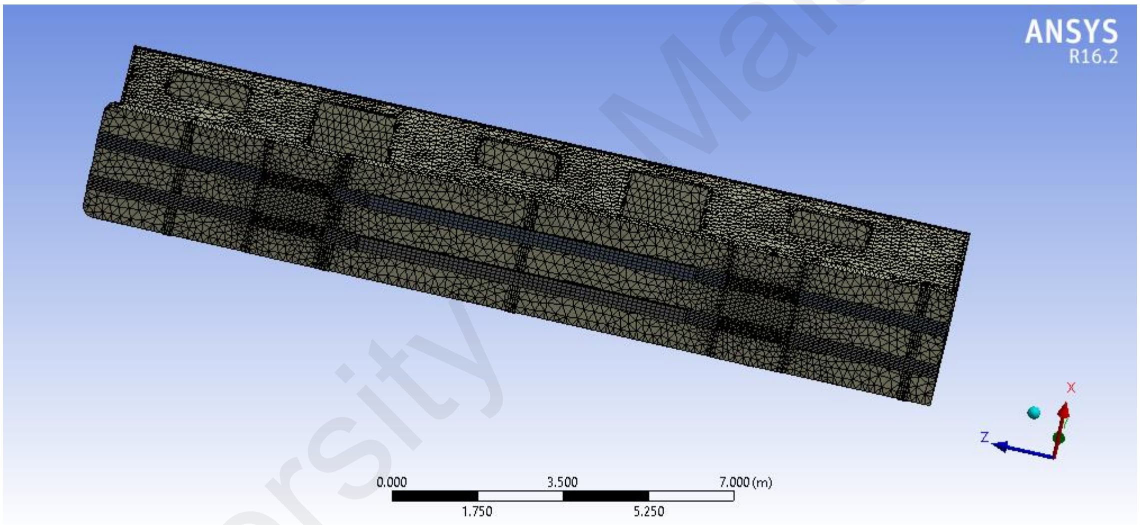

Figure 3.5 Meshing (Bottom)

3.5 Boundary Conditions

3.5.1 Fixed Support

In the setup segment, the boundary conditions are set. For this case, two (2) fixed supports were applied below the car body structure where the bogies shall be mounted.

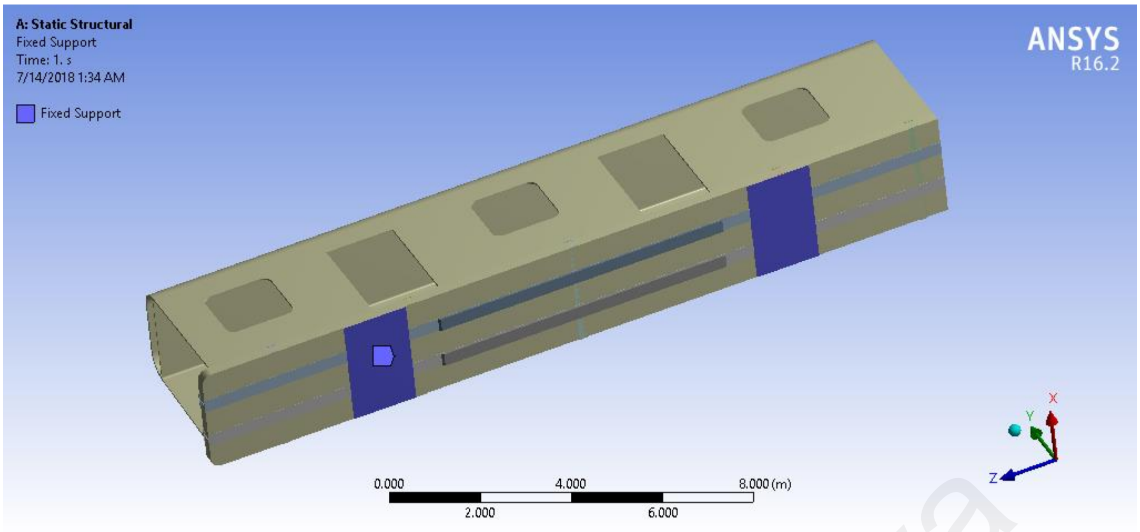

Figure 3.6 Fixed Support

3.5.2 Applied Pressure

As shown in figure above, a total pressure of 21267 Pa was applied on the under frame section. The applied pressure is a sum of passenger weight and the weight of the under frame equipment.

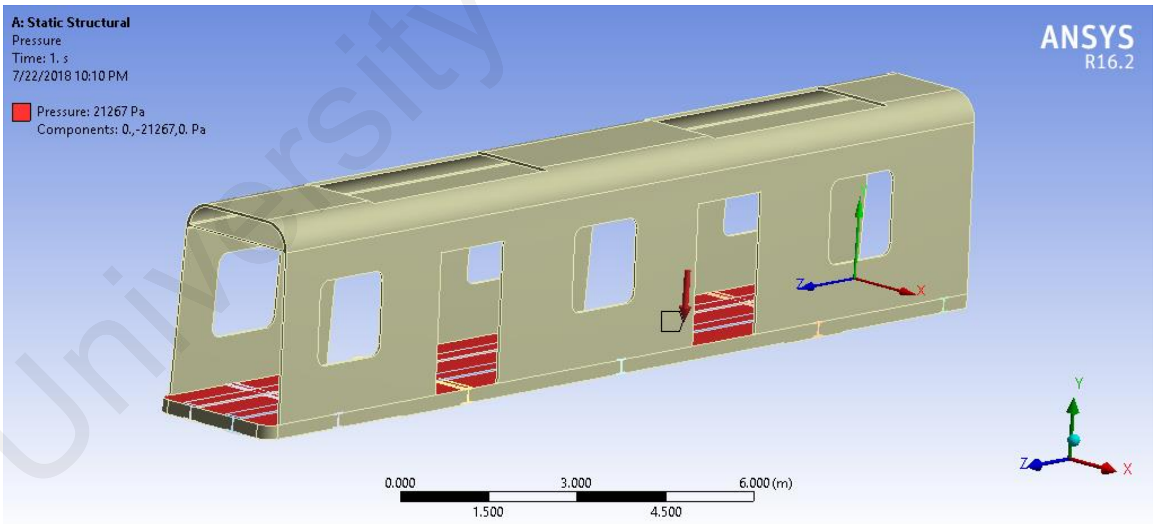

Figure 3.7 Pressure (Loading)

3.6 Difficulties Encountered

The main issue encountered with this model was an unrealistic simulation result which did not match the deformation value. This was however easily resolved by ticking the large deflection box in static structural analysis settings.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Static Results

Static analysis is conducted to determine the response of the rail vehicle car body to steady state loads. The deflections between two nodes are determined using assumed shaped functions. The equation results in nodal translational and rotational displacements. In the carried out analysis, the parameters considered is the stand still condition of the vehicle on a level ground with maximum payload. A distributed pressure of 21267Pa was applied due to combined vertical and compressive load of passenger weight and the under frame equipments mounted on the car body. This causes maximum shear stress on the center sill. The vertical deflection also includes the static deflection of the vehicle structures. The vertical deflection results obtained indicates that the maximum deflection occurs at the centre of the rail vehicle under frame with a deflection of 0.00046207mm as shown in figure 16 and 17. This portrays that static loads including the weight of the vehicle body, the cabin and the engine are taken by the under frames which causes the bending loads in it.

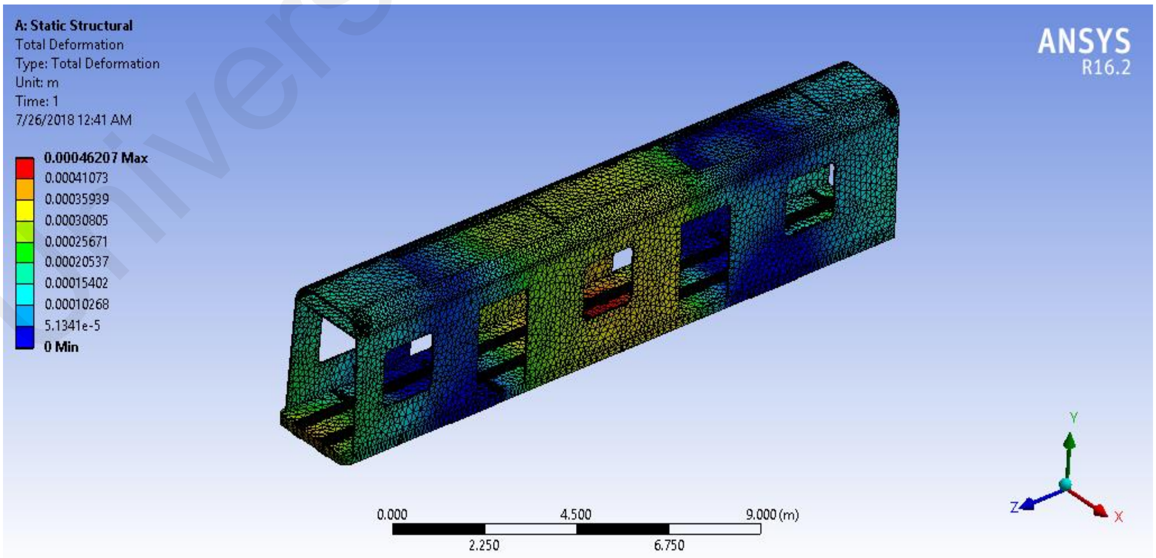

Figure 4.1 Total Deformation Results

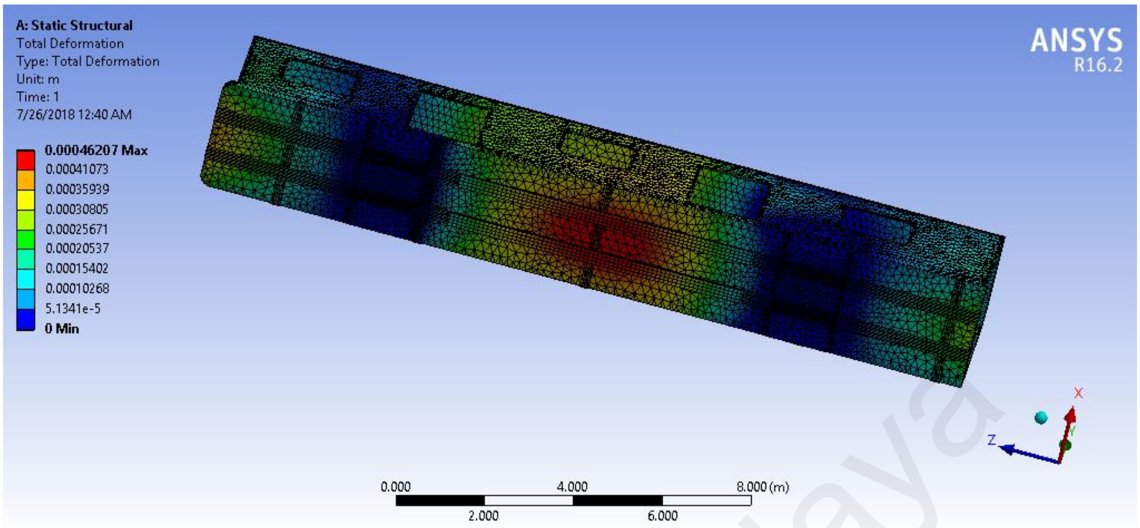

Figure 4.2 Total Deformation (Bottom) Results

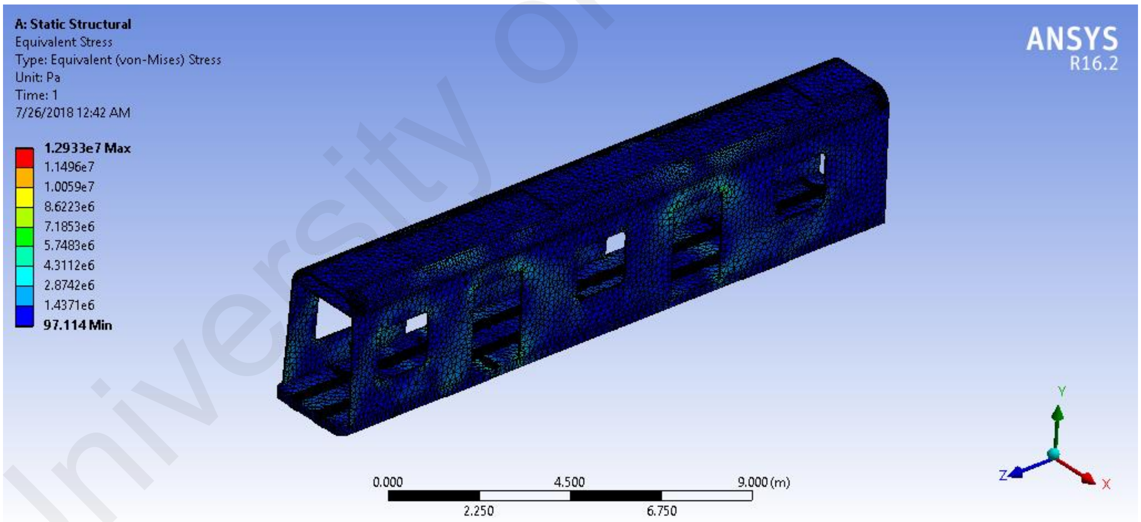

Figure 4.3 Von-Mises Stress distribution Results

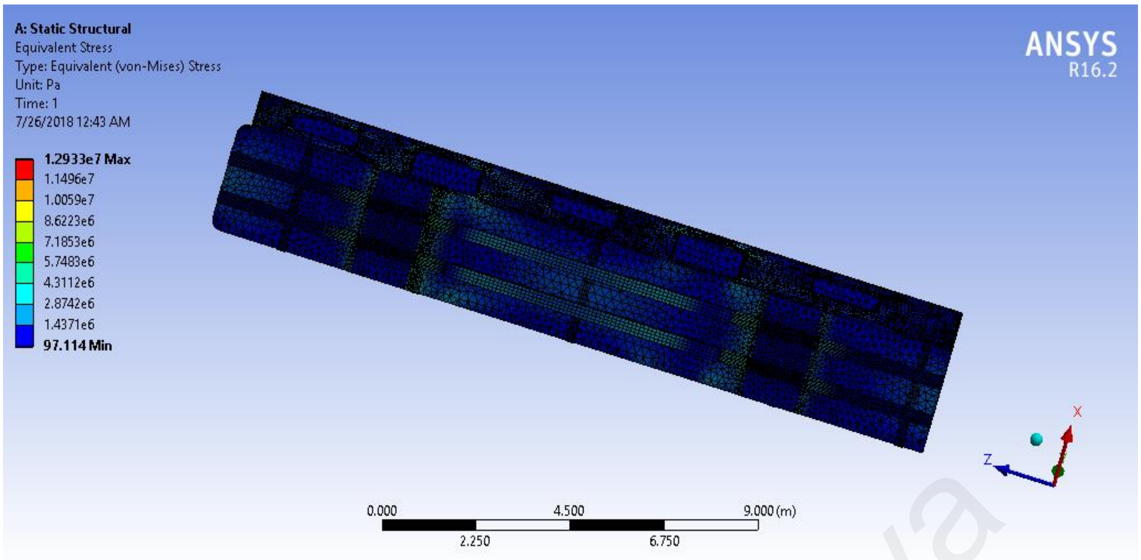

Figure 4.4 Von-Mises (Bottom) Stress distribution Results

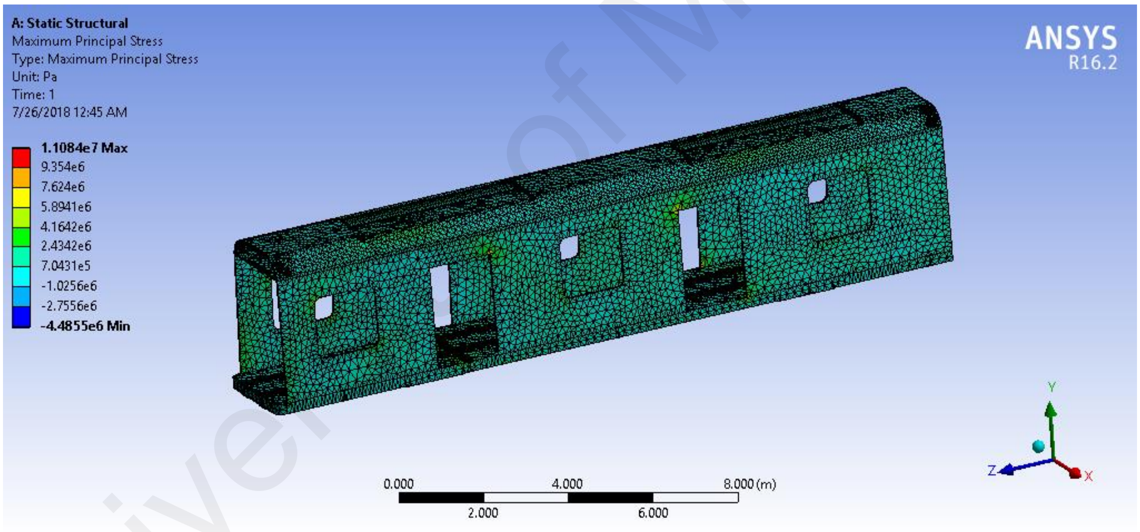

Figure 4.5 Maximum Stress distribution Results

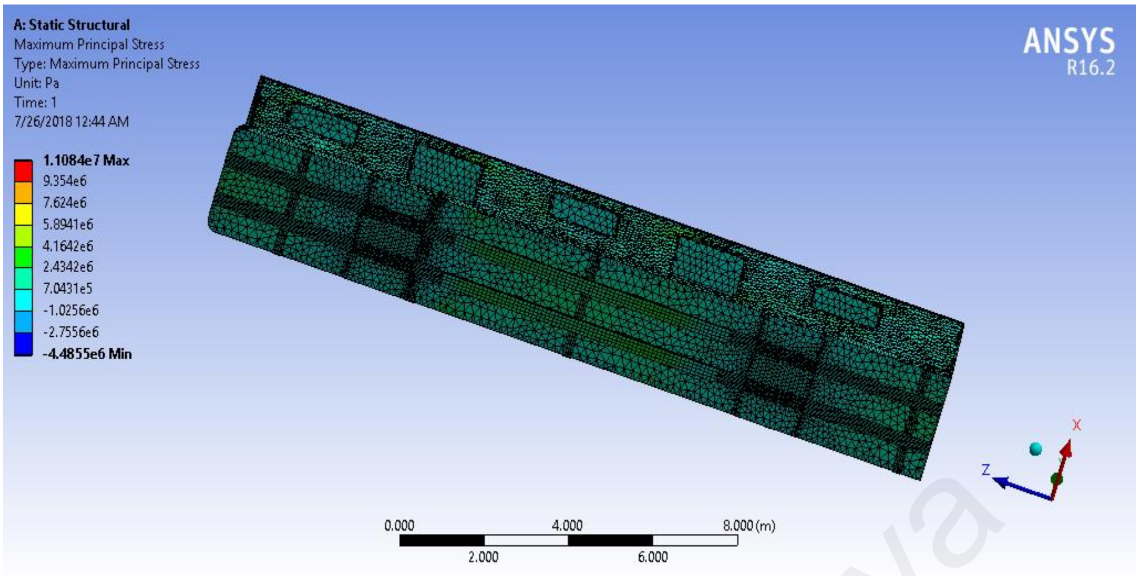

Figure 4.6 Maximum Stress distribution (Bottom) Results

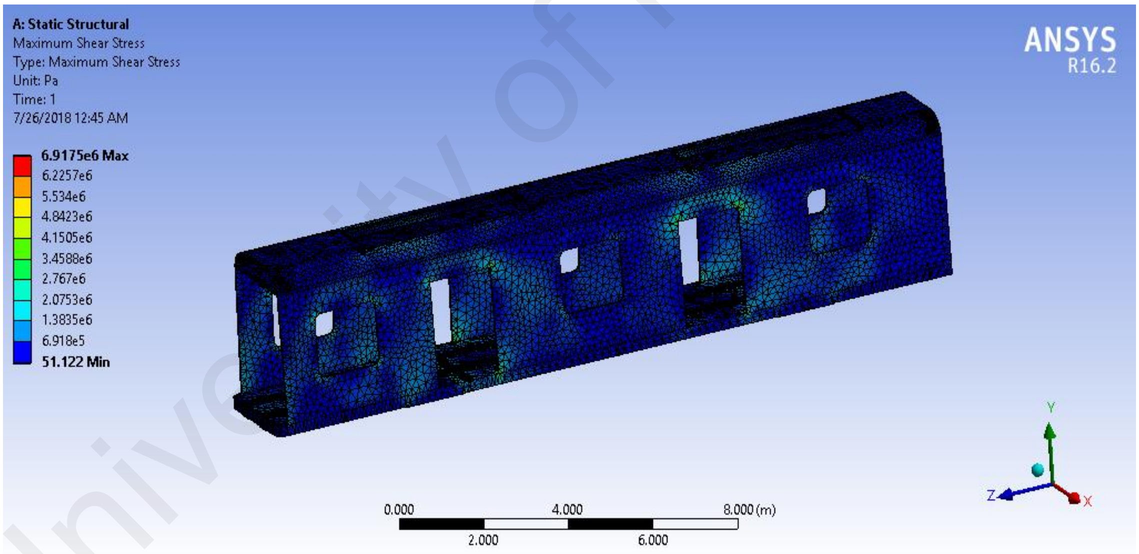

Figure 4.7 Maximum Shear Stress Results

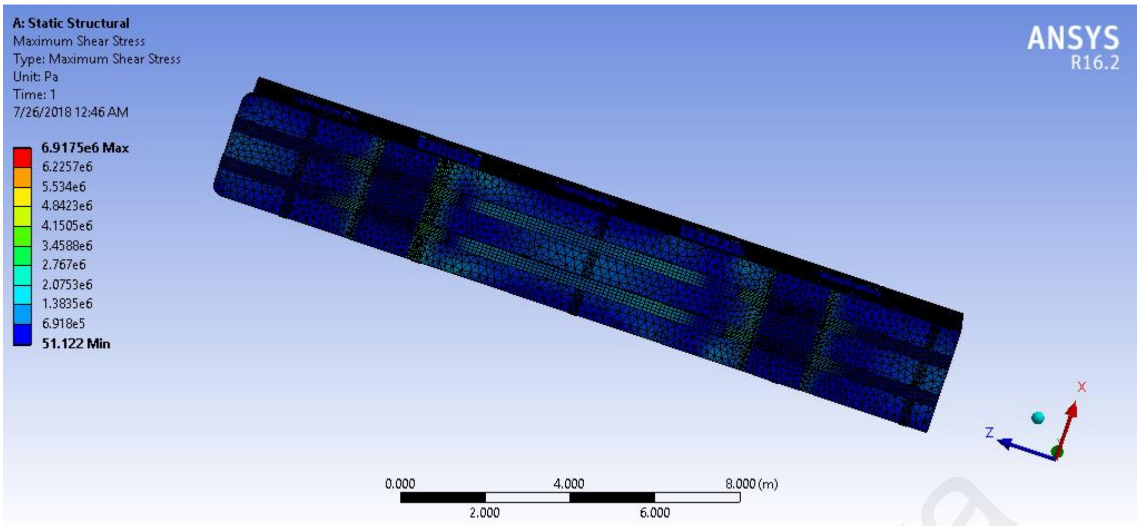

Figure 4.8 Maximum Shear Stress (Bottom) Results

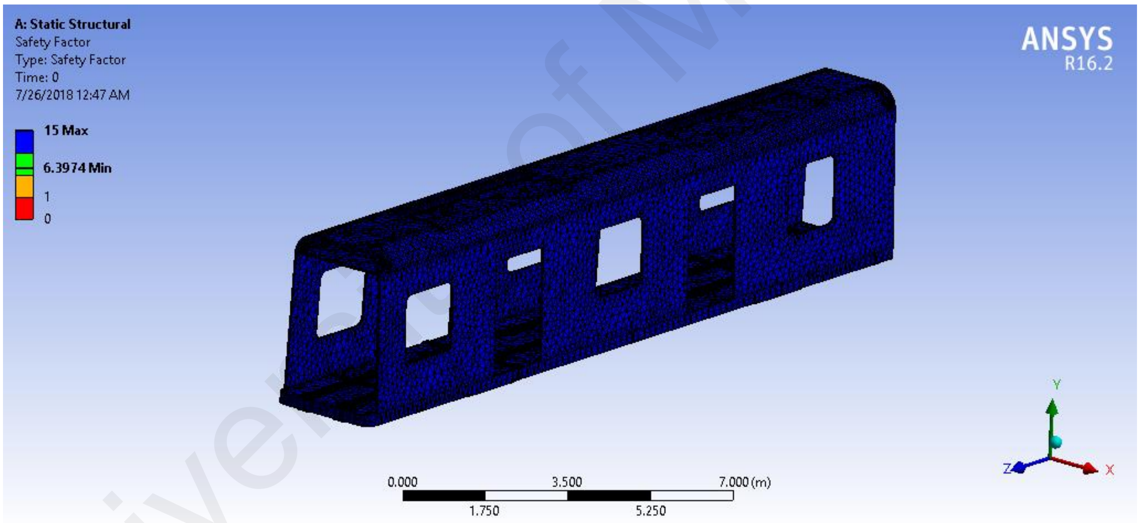

Figure 4.9 Safety Factor Results

Table 4.1 Static Structural Analysis Results

Analysis Type	Results
Total Deformation	0.00046207 (max)
Equivalent von-misses stress	1.293×10^{7} (max)
Maximum Principle Stress	1.1084×10^{7} (max)
Maximum Shear Stress	6.917×10^{6} (max)
Safety Factor	6.3974 (min)

4.2 Modal Analysis Results

A modal analysis was done to determine the vibration characteristics (natural frequencies and mode shapes) of the structure. It also serves as a starting point for more detailed dynamic analysis such as random vibration, transient dynamic analysis, a harmonic response analysis. The natural frequencies and mode shapes are crucial parameters in the design of a structure for dynamic loading conditions. Furthermore, a modal analysis can be done on a pre-stressed structure such as spinning turbine blade.

The objective of the simulation is to predict the behavior of a component or vehicle under a given loading condition before commencement of manufacturing of a prototype. Finite element analysis (FEA) has been an integral part of the design and development process for commercial vehicles for many years. FEA is applied to ensure that all parts, linkages and systems, which make up a vehicle are strong enough to with stand the loads subjected on them. Further to this analysis, the dynamic behavior of vehicles in service has been the result of testing, development and judgment, based on the experience of the design team. This is where the use of multi-body simulation (MBS) comes in play to give real benefits. Where else, finite-element analysis looks at the stresses and deflections of parts, to ensure that they are of high strength for their intended operation, MBS software packages look at the dynamic behavior and interaction of mechanisms and systems, under loads and conditions that replicate real life. Computer simulation brings multiple benefits to the analysis of static and dynamic systems if applied in a proper manner.

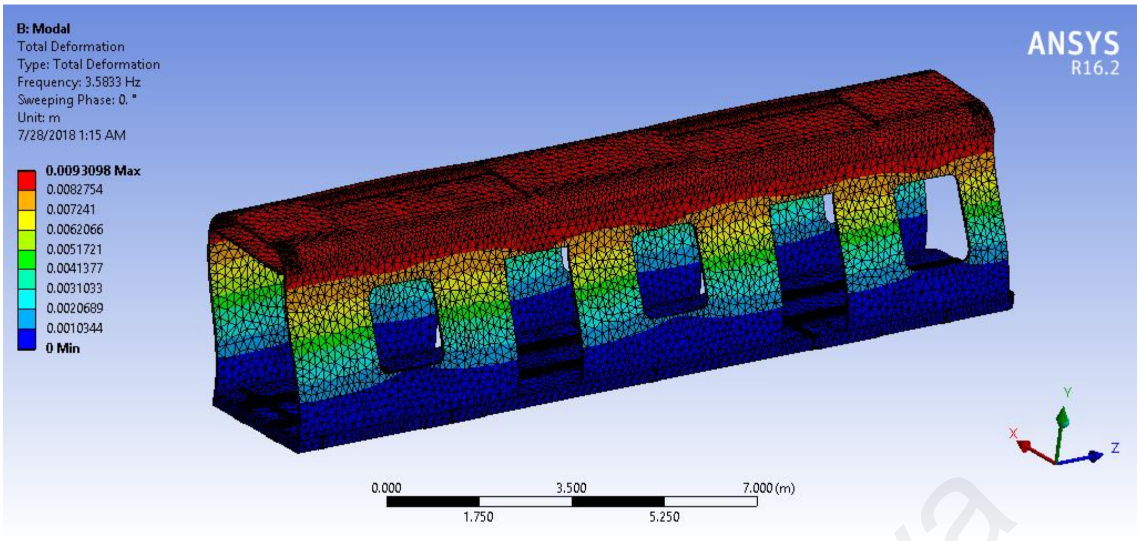

Figure 4.10 Mode Shape 1

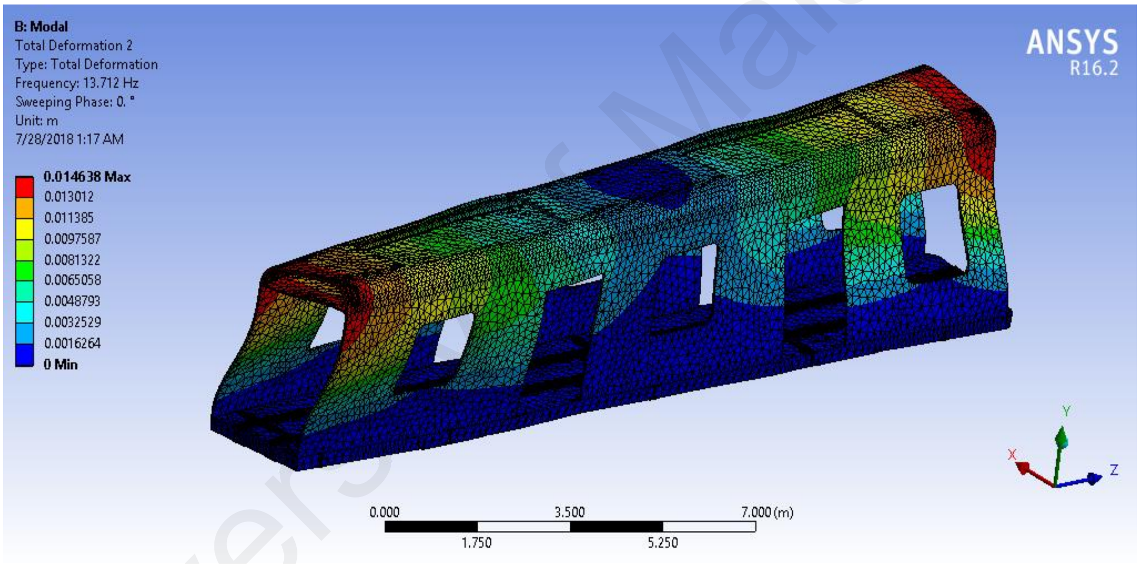

Figure 4.11 Mode Shape 2

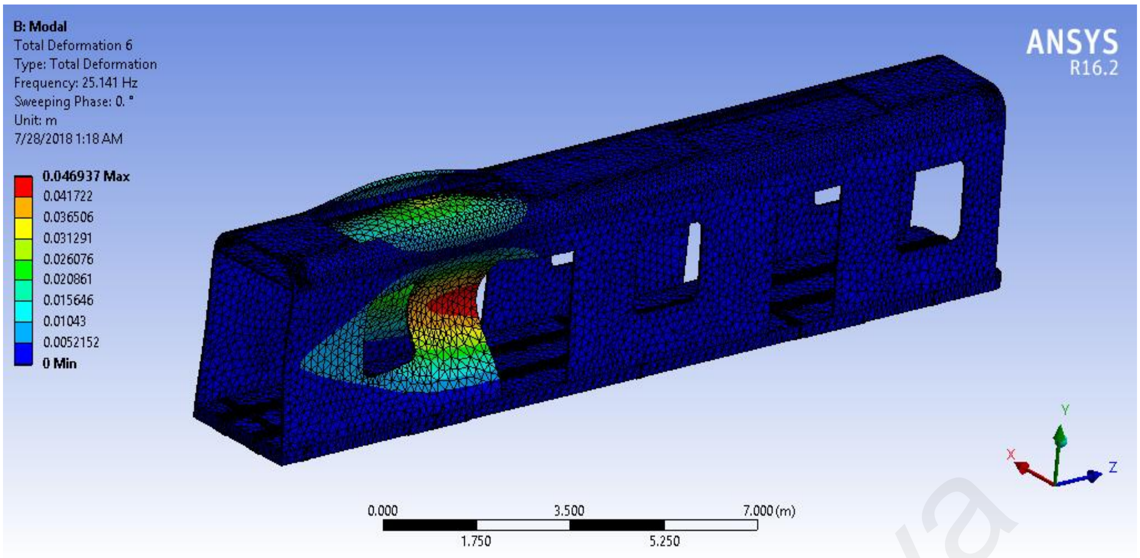

Figure 4.12 Mode Shape 3

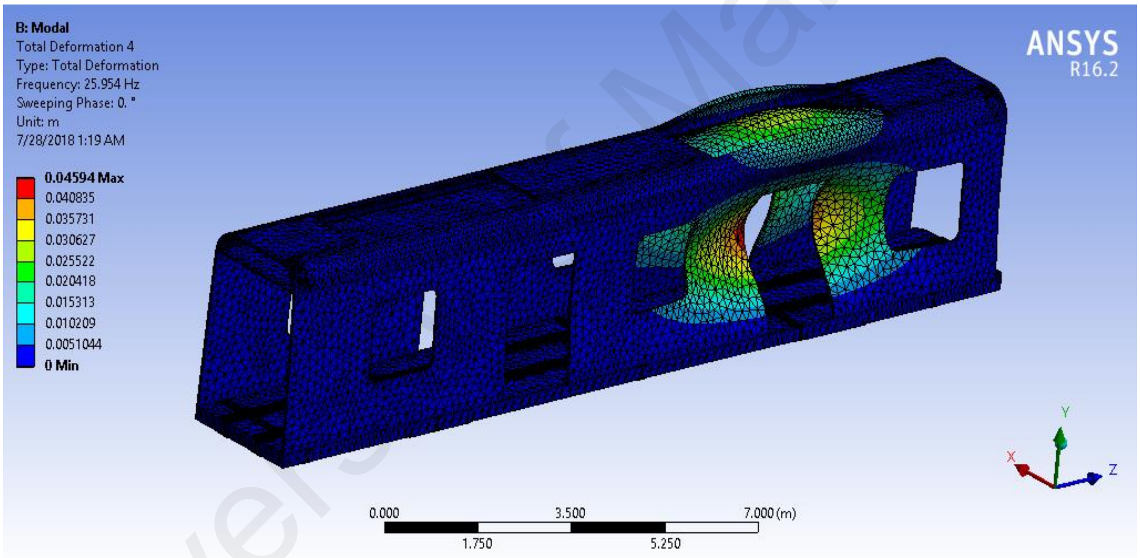

Figure 4.13 Mode Shape 4

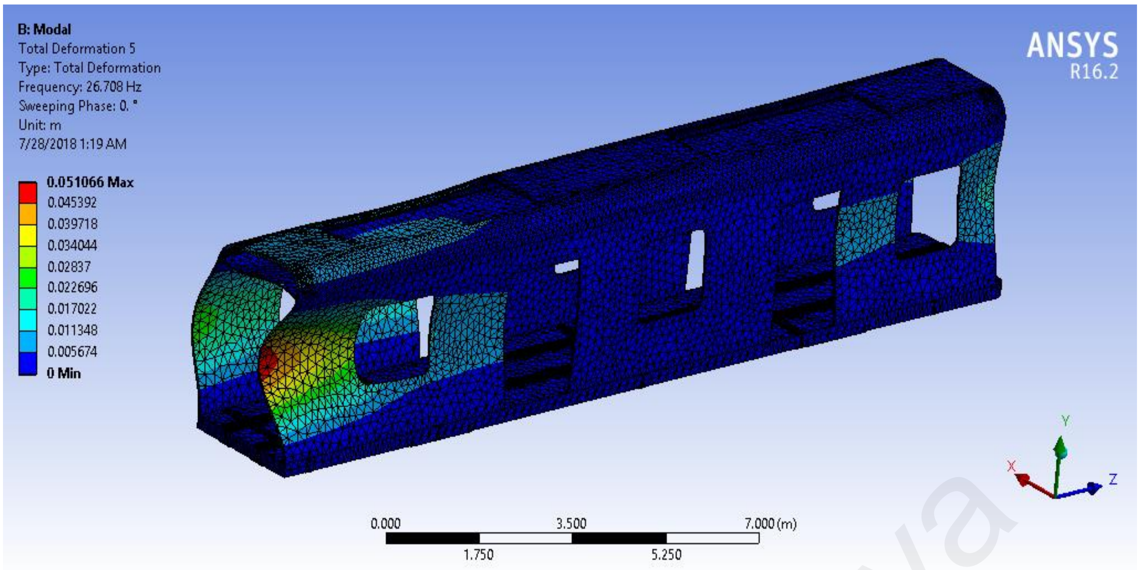

Figure 4.14 Mode Shape 5

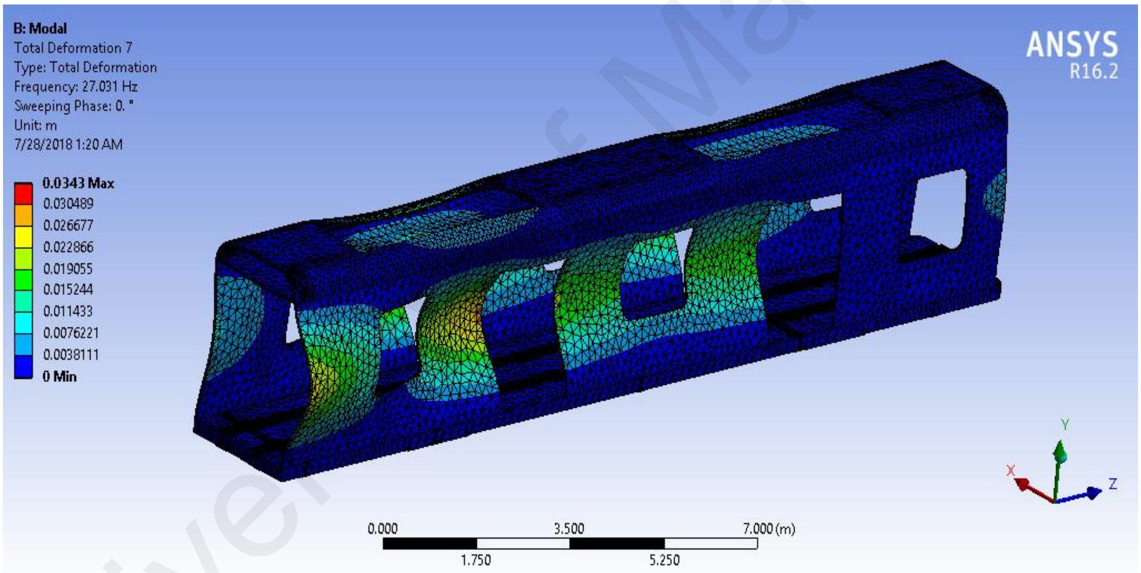

Figure 4.15 Mode Shape 6

Table 4.2 Modal Analysis Results

Mode No.	Mode Shape	Frequency (Hz)	Max. deformation (m)
1	1st lateral bending	3.5833	0.009309
2	Torsion 1	13.712	0.014638
3	Longitudinal bending	25.141	0.046937
4	Vertical bending	25.954	0.045940
5	Torsion 2	26.708	0.051066
6	2nd lateral bending	27.031	0.034300

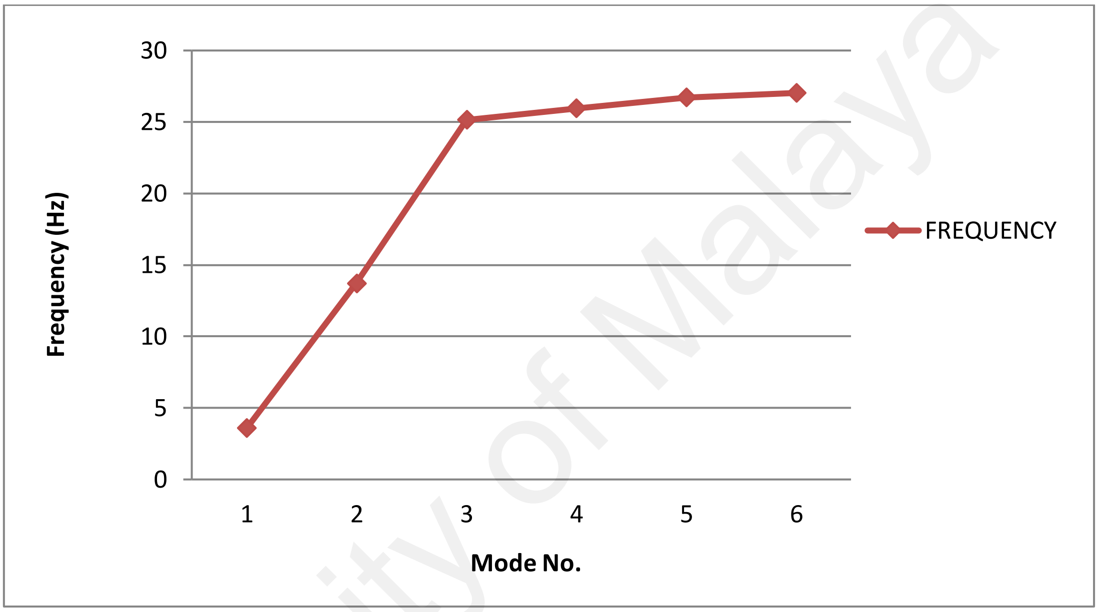

Figure 4.16 Graph of Frequency (Hz) vs Mode no.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

From this study, it can be concluded that:

a. The centre sill of the under frame is affected the most by static loads. The maximum deformation produced is 0.00046207m at the midway span of rail vehicle which is within the allowed range of 1/700-1/1000 for structural beams and members.

b. Passengers boarding this rail vehicle are exposed to a vibration frequency ranging from 3.5833Hz - 27.031Hz. This result is the natural frequency of the vehicle itself and is inevitable. Rigid vibration mode of the first lateral bending with a frequency of 3.5833 is a little concern as it is within the sensitivity range of human beings in ride comfort.

b. The set of proposed under frame equipment is found to be suitable as it does not cause high deflection to the rail vehicle under frame structure with maximum passenger load.

The rail vehicle car body shall be designed as stiff as possible to resist the incoming compressive, vertical, vibration stress and simultaneously provide comfort to the passengers on board. Therefore, appropriate material must be selected. It is recommended to use more strong and lightweight structures which are esthetically, structurally and operationally viable.

The conditions that are taken into account to maximize the stiffness of the car body and to increase the natural frequency of the car body.

a. Make the car body as short as possible. However, this may conflict with the desire to maximize the number to passengers on board.

b. The sheet metal which is attached to the car body structure should be included in the finite element analysis in order to find a more accurate result.

c. Use stiffer car body materials. However, this may conflict with the requirements of lightweight car bodies.

CHAPTER 6: REFERENCES

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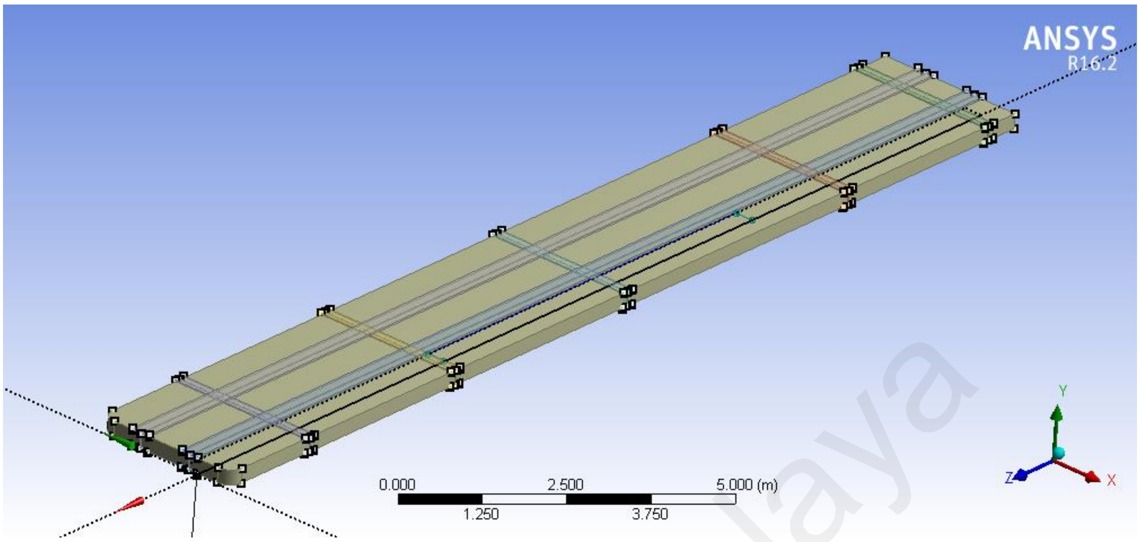
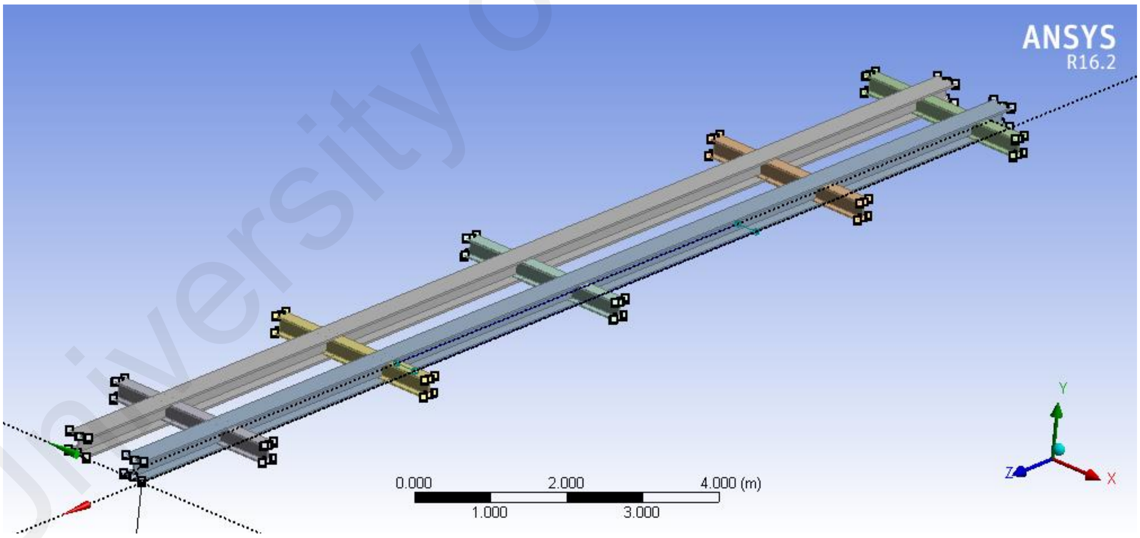
APPENDIX



Underframe model of the rail vehicle



Longitudinal and cross beams of the under frame