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School Of Mechanical and Industrial Engineering

Modeling and Structural Analysis of railway Vehicle body with Finite Element method

By

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Declaration

I hereby declare that the work which is been presented in this thesis entitled, Modeling and Structural Analysis of railway vehicle body with Finite Element method is original work of my own, has not been presented for master's degree of any other university and all the resources of material used for this thesis have been properly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

__________________________ __________________________________

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Dedication

To my beloved family, for their immeasurable support, encouragement, and patience.

ABSTRACT

A train running along a track is one of the most complicated dynamic and static systems in engineering due to having various nature of contacting wheel and rail. The railway vehicle structures generally have the main components of shells, center sill, under frame, and beams, and behavior of these members directly affects static and dynamic structural behaviors of these vehicles. The central structural design Requirements are given by the main static and dynamic loads. The purpose of the study is to model and analyze a rail vehicle carbody structure that solves the issue of strength and comfort. Modern rail vehicles passenger carbodies are designed as lightweight structures with the aim to minimize mass and thus operational energy demand. At the same time the vehicle carbody shall be designed as stiff as possible to withstand exceptional loads. The output of the analysis shows that the maximum deflection occurs at midway of the span of the length and the selected sections for the different components of the rail vehicle are capable of carrying the intended purpose. In addition, the first six natural frequencies are calculated using ANSYS design and modeling software. The frequency is compared to the sensitivity range of human being in vertical ride comfort. The design and analysis is became an input to Railway Corporation and local manufacturer's that has plant to substitute import by local manufacturing of passenger rail vehicle car bodies.

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List of Symbols

m_1	Design mass of rail vehicle car body without the bogie
m_2	Mass of a single bogie
m_1'	Dead weight of vehicle in working order
m_3	Mass of normal design payload
m_4	Mass of exceptional payload
m_w	Mass of wheel
g	Acceleration due to gravity
σ_{all}	Allowable working stress
σ_y	Yield stress
Z	Section modulus
M	Bending moment
M_{max}	Maximum bending moment
f	Frequency
F_{pa}	Compressive force at passage ways and access area
A_{pa}	Area of access and passageways
F_{cv}	Superposition of compressive and vertical load
F_{tv}	Superposition of vertical and tensile load
P_{cv}	Pressure due to superposition of compressive &tensile load
P_{tv}	Pressure due to superposition of compressive& vertical load
R_2	Reaction force at point 2 bolster support
R_3	Reaction force at point 3 bolster support
L_1	Length of the support between bolster
L_2	Length of the support between bolster

CHAPTER-ONE

1. Introduction

1.1 Background

Rail cars are relatively heavy in comparison to other transportation modes. As an example, the weight per seat is around three times higher for rail vehicles than for buses. The rail vehicles of car body refers to the load carrying structure, including doors, windows, and access panels shall be watertight and shall not be subject to water leakage when operating at maximum speeds under extreme weather conditions.

The technical equipment for propulsion, braking etc. is not definition not include in the carbody, even though this equipment usually is attached or hinged with carbody. Sometimes the concept of car body is limited to only the load carrying structure of the vehicle. [1]

The strength of the complete car body and it's structural elements shall comply with, and be designed to equal or exceed, the FRA requirements of 49 CFR 238 Subpart C, APTA SS-C&S-034-99 Rev 2 and any other applicable requirements in the CFR. The carbody structural sections shall be fabricated using Engineer accepted fixtures to ensure dimensional accuracy and repeatability. Car bodies of modern rail vehicles are designed as lightweight 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 for the use phase: a weight increase for the car-body of one tone implies an increase for the primary energy demand of 0.0259kWh/tonne.km. Considering this energy issue over the use phase, the composite scenarios do represent a good design option. The central structural design requirements are given by the main static and dynamic loads. The carbody first natural frequencies at AW_0, AW_1, AW_2 and AW_3 shall all be greater than 10 Hertz. The second level floor, center vestibules, and floor panels shall not vibrate in the above conditions in a way that affects the life of the vehicle or contributes to ride quality that is uncomfortable for passengers.

Railway vehicle structure generally consists of shells, plates and beams and behavior of these members directly affect static and dynamic structure the vehicle. The structural design of railway vehicle bodies depends on the loads they are subject to and the characteristics of the materials they are manufactured from. [2]

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 intercommunication between cars.The design should, furthermore, be reasonably easy to manufacture and maintains. For high speed trains it is important to have a good aerodynamic design with, for example a stretched front, smooth outer surface, enclosed undercarriage, etc. During operation the car body is continuously excited due to the dynamic interaction between track, wheels, bogie and car body. [1]

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 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 a low sound level. Beside these requirements, the car body is also the operators face outward, placing high requirements on exterior and interior design. The car body must meet the requirements of safety requirement setup for crash scenarios, derailment, fire, pressure waves in tunnels, etc. The car body must also be within the specification construction profile of the operational line, it must be strong enough as not to fail during typical maximum loads or during cyclic loading.

Within the scope of standard, it is intended to provide a uniform basis for structural design of the vehicle body. The loading requirement for the vehicle body structure design and testing are based on proven experience supported by the evaluation of experimental data and published information.[2]

After the railway vehicle is manufactured it must 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 a static strain 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 tests should be run during actual operation over the revenue tracks. The static test can be completed at suitable maintenance facility. To test those condition: numerical method and experimental measurements used to determine static and dynamic behavior of railways vehicle. Experimental measurements are very time consuming, expensive and they cannot be used at all stages of the design. Hence, today numerical methods are important tools in static and dynamic analysis of railway vehicle. Although numerical simulation doesn't have aforementioned disadvantages of experimental method, they must be verified by experiments to obtain realistic results. [5]

Engineers have two tools to assess vibration: measurements and simulation. Simulation based on rail vehicle dynamics model offer a possibility to predict ride comfort, but in order to reliable, the simulation models must be validated. Therefore it needs for validated methods in analyzing and modeling the structural statics and dynamics of the car body. The subject of "car body and passengers in rail vehicle dynamics" deals with the areas of rail-vehicle dynamics, structural dynamics, ride comfort, human body dynamics and seating dynamics.

Rail-vehicle dynamics is a subject of its own and the study of rail-vehicle dynamics dates back to the 19th century of more recent date is the study of rail vehicle dynamics base on simulation and applied to ride comfort, which began in the late 1960s with the advent of sufficiently powerful computers. Many of the computer simulation for rail-vehicle dynamics that are commercially available today have roots in that time. The simulation has been developed in industry, as well as at universities. [2]

Car body vibration can be reduced either by focusing on the structural stiffness of the system or by optimizing the damping components. There are several studies 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. Modern general-purpose software for the simulation of railway vehicle system has included features that enable efficient dynamic analysis of the railway vehicles. 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. [5]
Finite element analysis method is used to evaluate the static and dynamic structural behavior of railway vehicles. Full length detailed railway vehicle models are used in all finite element method analysis, finite element method models should be validated against experimental measurements; most common-base references that are taken into account are ULC CODE OR 577 and ERRI B12/RP17. [4]

1.2. Statement of problem

The structural analysis of railway car body is very complex 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 car body loads, maintenance and operation of existing railway vehicles. In our country such modern rail vehicles are new technology so that the analysis will help to solve the problem and also becomes an input for the futures vehicles. In this paper the impacts of car body load on the strength of the material, components of the vehicle body, property of the material for vehicle body are considered.

1.3. Objective of the study

1.3.1 General objective

The objective of this research is to study passenger rail vehicle by model and analyze the structural analysis of railway transport system of car body and identifying the effects of applied loads on the strength of material.

1.3.2 Specific objective

The specific objectives of the proposed research are listed below, which are also the expected major contributions:

- Modeling the vehicle body
- Determine the load and stress on the vehicle body,
- Static and dynamic simulation car body using finite element method.
- Selecting of the appropriate materials to the car body based on its weight, cost, strength and availability.

1.4. Scope and limitation of the study

1.4.1 The scope of the research:-

- Construction of 3D model of vehicle using software catia
- Finite element model (meshing of geometry model).
- To do finite element analysis of vehicle body.
- Finite element analysis using ANSYS version 14.5 software on static structural and modal analysis.
- Interpreting of the result and conclusion.

1.4.2. Limitation of the research:-

Some of the limitation that might be encountered when conducting the research includes. Ignoring the effect of other property like thermal analysis and vibration of at curve and being theoretical only without practical testing in the work shop. In general, this research may require ample time.

1.5. Research Methodology

In general the study of this paper is carried out through in the way of

1. **Literature review:** A lot of paper and journal has been read up and a part of it has been considered in this project and also from different manufacturer catalogues by reliable websites, and other relevant literature is done.
2. **Data collection:** reading the standards rail vehicle design and collecting the specifications of the body components has been taken from Ethiopian rail Ways Corporation.
3. **Modeling of the structure:** this is made by using the data recorded from the standards and collected data with CATIAV5-R20 software is used to build the 3D model.
4. **Finite element (FE) analysis:** analyzing of structure for the required results using ANSYS Workbench14.5 software. Finally, the vehicle structure will be analyzed based on the Ansys result of static and dynamic analysis. I.e. stress, displacement, mode shape etc.

1.6. Organization of the research

The research is organized in six chapters. The first chapter is the introduction part which states the background of the research, statement of problem, objective, and scope, limitation of the study and methodology of the research.

Chapter two discusses Literature review on the structural analysis of rail vehicle car body. On chapter three describes the theoretical basis and Definition of the main element or parts of rail vehicle car body, models and analytical approaches will be discussed in this part of the study. And also the alternative materials used and their general properties are briefly described.

Chapter four shows the 3D modeling of vehicle car body and the mathematical and finite element modeling. Multi body models representing different modes of a rail vehicle structure are presented. Chapter five discussed data analysis and simulation result interpretation of the result. This is done using numerical approach. Conclusion and recommendation of the research will be discussed and forwarded in chapter six.

CHAPTER TWO

2. Literature survey

2.1 Introduction

The design of vehicle body has been evolved from a simple, all steel structure that meets the basic requirement of strength and functionality, to the current day complex and efficient structure. Lightweight composite materials, such as glass-fiber reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Today, design procedures of vehicles body that ensures reliability and road worthinessis well established. However, as a result of advancements in the areas of material, production methods, computational and design tools, optimization technique, etc, further improvement on vehicle structural design is still an active topic of research.

2.2 Literature review

In the eighteenth century, workers from different mining areas in Europe found that loaded wagons moved more easily if the wheels were turning guided by a rail made of metal plates, because in this way reduced friction. The lanes for cars only served to move the product to the nearest waterway, which was then the main form of transporting large volumes. The start of the Industrial Revolution in Europe in the early nineteenth century demanded more effective ways of bringing raw materials to the new factories and moved from such finished products.[7]

The two mechanical principles, guiding wheels and use of motive power, were combined for the first time by the English mining engineer Richard Trevithick, who on February 24, 1804 succeeded in adapting the steam engine, used since the early eighteenth century to pump water, to pull of a locomotive was run at a speed of 8 km / h pulling five wagons, loaded with 10 tons of steel and 70 men on a road 15 km from the smelting of Pen-y-Darren, in South Wales.

Two decades passed during which they developed the cast-iron rails that supported the weight of a steam locomotive. The power required to pull trains, rather than one or two cars, secured by placing a steam locomotive on two or more axles with wheels attached by rods.

Finally, in 1825 was opened to the public the first steam railway: a set of wagons pulled by a locomotive used this power, covering the distance between the English towns of Stockton and Darlington Five years later it was opened on Liverpool- Manchester flight Which said regular traffic of goods and passengers between the two locations, the locomotive, the famous Rocket, was built by the said Stephenson. With appropriate improvements, the prototype would be used in future machines. A mid-nineteenth century were built many miles of track, around 1850 the steam railway had reached every continent[8].

The first trains that used power from the late nineteenth century, the first railway of its kind were launched in 1881, near Berlin. However, the first regular rail service was the one who joined in 1895 Baltimore and Ohio in the United States.

Fig.2.1 The First regular rail service[6]

From the literature Beatriz tena Villar the bodies that make up the vehicle can be connected in various ways and a moving interface links the vehicle to the track. This interface involves the complex geometry of the wheel tread and the rail head and non-conservative frictional forces generated by relative motion in the contact area. 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, to amplify the velocity or to decrease the pollution. In order to make this kind of design, simulation and analysis railway, it is possible to use the great amount of software available. ADAMS/ Rail will be used to perform.

ADAMS/Rail is a specialized environment for modeling rail vehicles. It allows you to create virtual prototypes of rail vehicle, and analyze the virtual prototypes much like it would analyze the physical prototypes.

ADAMS/Rail has two modes:

- **Standard Interface-** It is possible to use it when working with existing templates to create and analyze your rail models.
- **Template Builder-** If it have expert user privileges, it is possible to use ADAMS/Rail Template Builder to create new templates to be used in the ADAMS/Rail Standard Interface.

Using ADAMS/Rail, it can quickly create assemblies of rail vehicles, and then analyze them to understand their performance and behavior.
There is a possiblity to create assemblies in ADAMS/Rail by defining vehicle subsystems, such as front and rear bogies (including wheel sets, bogie frames, primary and secondary suspensions, dampers, and anti-roll bars) and bodies. It bases these subsystems on their corresponding standard ADAMS/Rail templates.

Once it creates the assembly model, ADAMS / Rail to analyze prototypes virtual as it be would use a physical prototype.

This simulation software can run a variety of analysis, where in necessary to specify:

- The name of the model.
- Data specific on the type of analysis desired.
- The additional property files that describe the information Admasor Rail needs to carry out the simulation, for example, file that defines the wheel / rail contact.

The main analyses that can be done with the program are:

- **Preload Analysis**: Used to understand the forces of preload on the vehicle suspension, therefore, often it used to check that the applied forces are equal to those obtained after the analysis run static.
- **Linear Analysis**: This analysis is used to calculate the eigen modes of vibration of railway vehicle for this; the program restricts movement of wheels and wheels with respect to ground by fixed joints.

- **Stability Analysis**: It allows study the stability of the assembly, by analysis for different speeds and configurations of contact wheel-rail. This information can be used to determine the speed critical vehicle.
- **Dynamic Analysis**: It possible to use dynamic analysis to determine the curve behavior, the derailment, the study of comfort and stability.

Once the appropriate simulations is known, it is necessary to use a software, it is called ADAMS/Postprocessor, with this software it is possible to see the graphic representation as well as working with them. After Design, Simulation, Analysis (Preload, Linear, Stability and Dynamic), and study the results and once done every conclusion for each analysis it can summarize:

- In the Preload analysis is observed that the vehicle is symmetrically, something essential.
- Later, it made Linear Analysis; here it checked with engine values and mode of vibrations, that the vehicle is stable.
- After that, it prepared Stability Analysis, with this analysis it was calculated the critical velocity and the natural frequency (both values are very fine).
- And finally, the last analysis is the dynamic, in this analysis it was checked with graphics, the force, the displacement and other important parameters, every parameters studied are well.

Sidhuetal. (2003) made a study on shape optimization of vehicle for improved safety and reliability. HEEDS (Hierarchical Evolutionary Engineering Design System) software package was used as optimization technique. Using ABAQUS and HEEDS optimization environment, this process has been applied to several automotive lower compartment rail designs. Results showed thatsignificantgainsinperformancealongwithupto20%reductions in mass were achieved.

Rail-vehicle dynamics is a subject of its own and the study of rail-vehicle dynamics dates back to the 19th century of more recent date is the study of rail vehicle dynamics base on simulation and applied to ride comfort, which began in the late 1960s with the advent of sufficiently powerful computers. Many of the computer simulation for rail-vehicle dynamics that are commercially available today have roots in that time. The simulation has been developed in industry, as well as at universities. [2]

Hengjun ZhuJiangtian Yang at the Beijing Jiaotong University Qiqihar,China Beijing, China in 2007 by modeling approach to study the characteristic of railroad carbody, which is based on the experimental and numerical modal analyses. In order to reduce the carbody's weight, an optimal design was developed. The strength, stiffness and the models of the carbody were calculated and compared by means of finite element method. The lightening plan is successfully applied to new car design, and is adopted by road tests.

It is done by applying two sets of loading conditions:-

Case 1: the pulling force in the longitudinal direction is 2250kN, vertical direction static loading, vertical direction dynamic loading, lateral direction force, torsion loading and the pressure of bulk cargo on the wall is considered;

Case 2: the pushing force in the longitudinal direction is 2500 kN, vertical direction static loading, inertia force and the pressure of bulk cargo on the wall were considered;

The material of carbody is weathering steel Q450NQR1. The working stress is 281 MPa in the first case and 380MPa in the second case. The deformation of the carbody under the first set of loading conditions. It can be found that the deformation of the sidewalls is large. The maximum deflection is 7.597 mm, and position is on the central line of the sidewall, where the height is 0.65 m from the floor.

A fundamental theoretical study is performed for the computation of the fatigue damage of the main structures of a road vehicle running on a randomly profiled road by Gobbiand Mastinu (1998). They considered a simple quarter car vehicle model. The expected fatigue damage was analyzed according to Miner's rule and Rain-Flow counting employing Rychlik method. The research show vehicle parameters have an influence on fatigue damage.

CHAPER THREE

3.1. Theoretical basis

A train running along a track is one of the most complicated dynamically and statically systems in engineering. Many bodies comprise the system and so it has many degrees of freedom. The bodies that make up the vehicle can be connected in various ways and a moving interface links the vehicle to the track. This interface involves the complex geometry of the wheel tread and the rail head and non-conservative frictional forces generated by relative motion in the contact area. 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, to amplify the velocity or to decrease the pollution.[7]

It is useful to use a template to research into this kind of project: it is much cheaper, easier and quicker than doing it with a real model. The core element of any train is the body structure. The car body connects all the different components; its houses the drive train and most importantly carries and protects passengers and cargo. The body structure needs to be rigid to support weight and stress and to securely tie together all the components. The body structure consists of the main load carrying structure above all truck suspension units. It includes all components that are connected to this structure and contribute directly to its strength, stiffness and stability.

The car body of rail vehicles refers to the load carrying structure, doors, windows, interior with seats etc., inner lining and so-called comfort systems for lighting, heat, ventilation and sanitation. The technical equipment for propulsion, braking etc. is not definition not include in the car body, even though this equipment usually is attached or hinged with carboy. Sometimes the concept of car body is limited to only the load carrying structure of the vehicle. The car body shall be structurally complete, including flooring if used as part of the primary car body structure, but shall exclude such items as exterior and interior trim, windows, doors, seats, lights, insulation, interior lining, or any other materials that will obscure any structural member of the car body from view. Under floor, roof and ceiling mounted apparatus shall be installed or equivalent weights distributed at their respective locations.

Before putting a railway vehicle into service, it must 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 structures can be found. Within the scope car body standard, it is intended to provide a uniform basis for structural design of the vehicle body. The loading requirement for the vehicle body structure design and testing are based on proven experience supported by the evaluation of experimental data and published information.

Numerical methods and experimental measurements are used to determine the static behavior of railway vehicles. Experimental measurements are very time consuming, expensive and they cannot be used at all stages of design. Hence, today numerical methods are important tools in static analyses of railway vehicles. Although numerical simulations do not have aforementioned disadvantages of experimental methods, they must be verified by experiments to obtain realistic results. FE method is a powerful numerical engineering analysis tool, and widely used in static stress analyses of railway vehicles.

Half-width or half-length and half-width or full-length modeling approaches are used to determine static structural, vibration depending on the symmetry of vehicle. Nevertheless, half- width or full-length and modeling approaches can be used only for certain types of simple static structural loading such as static symmetrical compression and symmetrical tension loading conditions and cannot be validated for complex static structural loading and dynamic loading conditions. Hence, full-length simulations are important for the validation of designs and to provide the greatest possible accuracy.

To obtain static structural behavior of the railway vehicles, i.e. stress and strain distribution, different static loading cases defined in [1] can be used in finite element analyses. Be validated against experimental measurements; most common-base references that are taken into account are for static analysis and for dynamic analysis. Finite element method is used to assess the static and dynamic structural behavior of railway vehicles. Full length detailed railway vehicle models are used in all finite element analysis. In this thesis considering the above mentioned issues, analyses of stress and deformation of railway passenger structures are completed. Full-length detailed and validated finite element models are used to assess static structural behaviors of the railway vehicles. To obtain static structural behavior of the railway vehicles, different static loading cases defined in EN15663standards are used.

Within the scope of this thesis structurally analyzed the rail vehicle body and find the maximum stress and the deflection of the body and also parameterized study was done by using the material the steel(st36)

3.2. Car body description

The carbody 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, transferring minimum forces to the passenger. Modular carbody repair elements shall be used as appropriate to simplify collision repair.

The carbody 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, and a body end door at each end of the car. One end of each Cab car shall contain a dedicated Operator's cab. The carbody shell shall be designed as a modified girder, using the roof and the floor as the chord members, connected by the sides, which carry the shear. Car roof framing, side sills, and side sheeting shall be suitably designed and constructed for installation of passenger side entrance doorways.[6]

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

All mechanically fastened connections shall be designed using a factor of safety of 2.0 based upon the proof load of the fastener. Clamping force friction shall be ignored in the design and analysis of mechanically-fastened connections. Self-tapping screws shall not be used for structural connections. There shall be no tapped holes in car structure. Tapping plates may be used, attached to the car structure with mechanical fasteners. The tapping plate must be equal to or greater in thickness than the diameter of the bolt, for which the tapping plate is intended, and a clearance hole shall be drilled in the structure for the bolt. Tapping plates shall be designed to the same strength standards as the equivalent nut.

Car bodies of modern rail vehicles are designed as lightweight structures with the aim to minimize mass and thus operational energy demand. The central structural design requirements are given by the main static load [8].Railway vehicle structures generally consist of shells, plates and beams and behavior of these members directly affect static and dynamic structure behaviors of these vehicle. The structural design of railway vehicle bodies depends on the loads they are subject to and the characteristics of the materials they are manufactured from [5]. However, ride comfort becomes an increasingly important issue because the softer, more compliant structure exhibits low Eigen frequencies that significantly affect perceived ride comfort.

The weight reduction of railway vehicles has different impacts.

- One result is the energy saving. Simulations have shown that the potential for savings through reduction of vehicle mass is dominated by the characteristics of the service profile. There is a particularly high potential for savings with service profiles that have short distances between the stations and low maximum speeds. As the maximum speed increases, the proportion of energy needed to overcome aerodynamic resistance increases and the potential for savings goes down.
- Second effects can be seen in the reduction of rail damage and superstructure optimization according to the axle load.

In terms of weight distribution, a railway carriage can be divided into equipment, bogies and car body. Due to the equipment systems complexity and necessity to address the various subsystems separately and due to the bogies many and security-relevant a requirement, their weight saving potential is limited.The global weight saving potential resulting ofthe rail vehicle equipment is limited. Analysis showed that the mass of the rough car body normally accounts for 15% to 30% of the vehicle's empty weight. Nonetheless the car body structure is in an interaction with different parameters. This means the car body structure has a direct influence on the weight saving potential of these parameters. Development in the field of railways goes in particular through decreasing the weight of rolling stock vehicles car body structure [8].

Therefore, car body weight optimization becomes a significant topic. As a general rule, in rolling stock vehicle design the use of lightweight principles is indispensable.

The principles can be divided into:

- using of lightweight material
- function and system lightweight optimization (lightweight system configuration)
- form and shape design lightweight optimization

As specified in specific standards and directives such as DIN EN12663, EN 15227 and UIC 566, the car body is subject to various static and fatigue loads, as well as crash loads.

Currently different concepts of car body are in use.[10]

- Differential concept (metallic framework planked with blank sheets)
- Integral concept (locally reinforced aluminum extruded profiles welded in longitudinal direction)
- Hybrid concept (different sections uses potential of different materials)

The differential body optimization process includes:

1. Space allocation model is defined and properly modeled directly in the topology optimization software
2. Boundary conditions are defined, selected loading according to the applicable standards is applied
3. Topology optimization is performed with the required constraints to reveal the main load paths meeting the criteria defined
4. Resulting topology is interpreted and translated into a framework structure
5. Size optimization is performed in order to obtain correct design dimensioning
6. Resulting framework structure is subjected to finite element method analysis in order to validate the results.

7. Results are used as basis for car body design development with further assistance of finite element method analysis for validation.

A railway carriage can be divided into three main assemblies: the running gears, Car body structure and equipment (like propulsion, interior, car body completion, etc.)

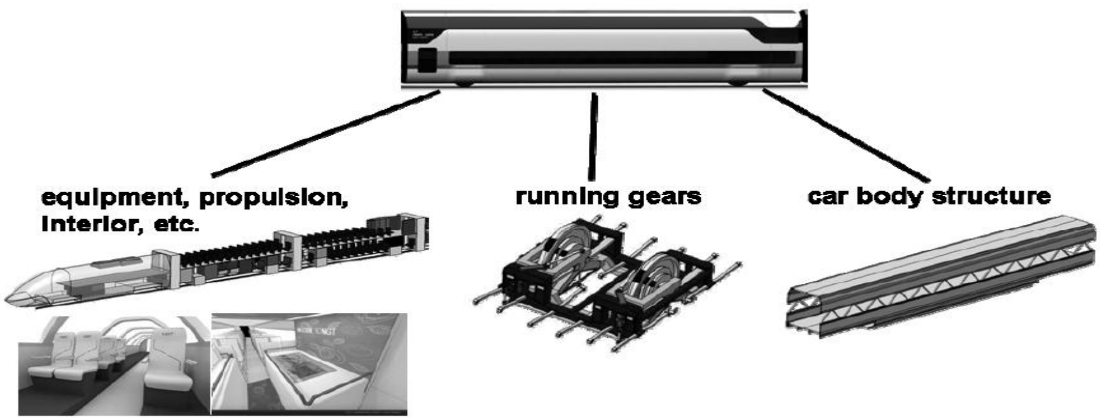


Figure 3.1 Vehicle body carriage subassemblies

3.3. Parts of passenger rail vehicle car body

Passenger car body consists of the following main parts [14]

a) **under frame**

The under frame shall be an integral unit extending from end to end of the car and shall be composed of the center sill , collision posts, end sill, transition members, floor beams, floor pans, cross bearers, and side sills. If the Center sill is not incorporated into the design, the side sills must be made of floor beams that are continuous from side sill-to-side sill. Center and side sills shall be braced by cross members. The under frame structure shall be designed to meet all applicable FRA rules, AAR requirements, and APTA standards.

b) **Center Sill**

The center sill is the major load carrying plate form that comprises two longitudinal frames running along the length of the car body, side sill, bolsters, floor beams and cross bearers. The primary component of the under frame is the center sill. As the vehicle is supported about two bogie bolsters at 11m for the case under this study, it can be simplified to a simply supported beam & 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.

c) **Cross bearers**

These are transverse sections that are integral part of the body frame. They are manufactured from 5mm thick St36 plate 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.

d) **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 shearing and bending a 5mm thick mild steel plate 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 the exposed surface of the rail vehicle car body.

e) **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.

f) Side wall

The side wall structural member has columns and girts designed to carry the load from 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 passengers boarding the train and allow comfortable environment during different climatic condition.

g) Collision posts

The APTA standard outlines the minimum structural design requirements for collision posts at the ends of occupied vehicles. The end of a vehicle that is designed to lead a train must protect occupants of that vehicle from the intrusion of objects the train has struck in a collision. As such, higher strength requirements are necessary for the lead ends of such vehicles.

The requirements of this standard are intended to result in an energy absorbing end structure above the under frame. Therefore, requirements for collision posts in the following sections include the ability of the post to absorb a significant amount of energy by undergoing severe deformation without failure of the post or its connections during an overloading condition.

h) Couplers and drawbars

A coupler does three things: connects one car with another, holds the connection, and then disconnects the two cars If used, drawbars, semi-permanent couplers, standard AAR Type F interlocking couplers, and APTA RP-M-003 Type H tight lock couplers may be considered as providing the required climb, bypass, and overturn resistance if the following additional requirements are met:

i. The structural arrangement shall include a coupler carrier designed to resist the 445KN vertical downward thrust from the coupler shank at any possible horizontal position of the coupler. The acceptance criteria for this condition shall be no permanent deformation of the coupler carrier, supporting car body structure, and intervening connections.
ii. The structural arrangement shall include a buffer beam above the coupler, which shall be designed to resist the 445KN. vertical upward thrust from the coupler for any horizontal

position of the coupler. The acceptance criteria for this condition shall be no permanent deformation of the buffer beam, supporting car body structure, and intervening connections.

i) horizontal Framing Members

End frame collision and corner posts may be connected by horizontal inter coastal as necessary to resist the lateral components of the design loads. In addition, a structural header may be used to connect the tops of the collision and corner posts. Cab-end framing shall include a horizontal structural member between the collision post and corner post on each side at a height equivalent to the bottom of the windshield. The structural shelf shall support a load of not less than 67 kN applied transverse to the member at any point on its span without permanent deformation of any part of the vehicle structure.

j) End frame sheathing

Cab end frame sheathing shall be:

- Equivalent to a 13-mm steel plate with 172-MPa yield strength. Material of higher yield strength may be used to decrease the required thickness of the material provided an equivalent level of strength is maintained.
- Designed to inhibit the entry of fluids into the occupied cab area of the equipment.
- Connected to underlying framing members sufficient to develop the full strength of the sheathing.

The car body structure is made from hollow large scale steel, Aluminum extrusions, magnesium and composite materials. Since the overall weight of the train is a critical parameter for the authorization process of the railway vehicle, light weight principles have been taken into account when designing the car body structure.

Railway vehicle bodies shall withstand the maximum loads consistent with their operational requirements and achieve the required service life under normal operating conditions with an adequate probability of survival. The capability of the railway vehicle body to sustain required loads without permanent deformation and fracture [11].The central structural design requirements are given by the main static loads.

2.4. Category passenger rail vehicles

To this group belong all types of railway vehicles intended for the transport of passengers, ranging from main line vehicles, suburban and urban transit stock to tramways. Passenger vehicles are divided into five structural design categories into which all vehicles may be allocated.

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:[3]

a) Category P-I e.g. coaches;
b) Category P-II e.g. fixed units and coaches;
c) Category P-III e.g. underground, rapid transit vehicles and light railcar;
d) Category P-IV e.g. light duty metro and heavy duty tramway vehicles;
e) Category P-V e.g. tramway vehicles.

As a general requirement; rail vehicle car body should have limited weight. Trains exert forces on the infrastructure due to their weight which results in wear of the tracks. High weight also increases the wear on wheels, axles, brakes, shock absorbers, etc. The car body should also be sufficiently stiff. From a safety perspective the car body should not flex outside the track gauge during operations or show significant vertical displacement due to the passenger load.

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 also done to reduce the weight of the vehicle body.

3.5. Definition of the design masses

For the case under consideration the dead weight of the vehicle (bogie +car) is44.5ton.And the mass of a single 109 Passengers bogie is considered to be 3ton.

a. **Deadweight**

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

b. **Consumables**

It is the weigh to 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.

c. **Standing area**

According to EN15663, the standing area is calculated with tip up seats and folding tables in closed position and by taking in to account half the projected area of internal stairways.

Standing area doesn't include:-

- Projectedareasofnormalseats(includingbacksandarmrests)onthefloors plus a 300mmdeepareafor the feet of the seated passengers, which extends over the full width of the seat;
- Projected areas of fixed tables on the floors
- Area restricted to drivers and other train crew areas where standing is prohibited;
- Steps and other areas that are only used when boarding or alighting;
- Areas, except stair ways, that due to their limited dimensions (width or length under 300mm), are unsuitable for standing;
- Areas which are used for toilets, washing areas or similar.

d. **Luggage area**

According to EN 15663, the luggage area does not include overhead racks.

Table 3.1.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 15663withoutbogie masses.
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 $m_1$and m_2
Normal design Payload	m_3	The mass of the normal design payload as specified in EN 15663.
Exceptional Payload	m_4	The mass of the exceptional payload as specified in EN 15663.

3.6. 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 vehicles, except on passenger carrying locomotives with non-structural equipment hoods, shall be designed to res ton their roofs so that any structural damage in occupied area is limited to roof sheathing and framing members. Deformation to the roof sheathing and framing is allowed to the extent necessary to permit the vehicle to be uniformly supported directly on the top chords of the side frames and end frames. For this condition, the allowable stress for the structure of the occupied zones of the car body shall be one-half yield or one-half the critical buckling stress, whichever is less.

Non-passenger-carrying locomotives with non-structural equipment hoods shall be designed such that in the event of a rollover, the operator’s cab will maintain a survivable volume. The manufacturer shall show by layout and calculation (classic or finite element method) that the locomotive is capable of resting upside down at two or more points of contact while simultaneously maintain in gas survivable volume within the operator’s cab. The points of contact may be a major piece of equipment (for example, the dieseling in and transformer), one end of the plat form or the other (depending on the location of the center of gravity) or structural members added to satisfy this requirement. Deformation of equipment enclosures and operator’s cab roof sheathing is allowed to the extent necessary to permit the vehicle to be supported as described above. The allowable stress for structural members added to the structure specifically for this load case shall be one half yields or one half the critical buckling stresses. The load applied to the structural members shall be determined from a static balance calculation while the locomotive is upside down assuming only the truck adjacent to the operator’s cab is still attached to the structure.[11]

Table 3.2.Load cases for different rail vehicle categories[3]

Category	Exceptional pay load(m_4)	Service(Fatigue)pay load(m_3)
B-I main line passenger rolling stock [1,2,3]	1 passenger per seat 4 passengers per/m^2 in passage ways, access and service areas 300kg/m^2in luggage areas passenger mass=80kg	1 passenger per seat Up to 2 passengers per/m^2in passageways, access and service areas 300kg/m^2in luggage areas passenger mass=80kg
B-II Inner and outer suburban passenger rolling stock [1,2,3]	1 passenger per seat 5-10 passengers per/m^2in passageways, access and service areas. 300kg/m^2in luggage areas passenger mass=70-72kg	1 passenger per seat Up to 6 passengers per/m^2in passageways, access and service areas 300kg/m^2in luggage areas passenger mass=70-72kg
B-III Metro & rapid transit Rolling stock [3,4]	1 passenger per seat 5-10 passengers per/m^2in passageways, access and service areas 300kg/m^2in luggage areas passenger mass=70-72kg	1 passenger per seat Up to 6 passengers per/m^2in passageways, access and service areas 300kg/m^2in luggage areas passenger mass=70-72kg
B-IV Trams	1 passenger per seat 6-8 passengers per/m^2in passageways, access and service areas	1 passenger per seat up to 6 passengers per/m^2in passageways, access and serviceareas300kg/m^2in luggage areas

3.7. Requirements of the materials in vehicle

The materials used in vehicle industry need to full fill several criteria before being approved. Some of the criteria are the results of regulation and legislation with the environmental and safety concerns and some are the requirements of the customers. In many occasions different factors are conflicting and therefore a successful design would only be possible through an optimized and balanced solution.[12]

3.7.1. Lightweight

As there is a high emphasis on greenhouse gas reductions and improving fuel efficiency in the transportation sector, all car manufacturers, suppliers, assemblers, and component producers are investing significantly in lightweight materials Research and Development and commercialization. All are moving towards the objective of increasing the use of lightweight materials and to obtain more market penetration by manufacturing components and vehicle structures made from lightweight materials. Because the single main obstacle in application of lightweight materials is their high cost, priority is given to activities to reduce costs through development of new materials, forming technologies, and manufacturing processes.

Yet the weight reduction is still the most cost-effective means to reduce fuel consumption and greenhouse gases from the transportation sector. It has been estimated that for every 10% of weight eliminated from a vehicle's total weight, fuel economy improves by 7%. This also means that for every kilogram of weight reduced in a vehicle, there is about 20 kg of carbon dioxide reduction. To achieve lightweight construction, without compensating on rigidity, automakers have been investigating the replacement of steel with aluminum, magnesium, composites, and foams. The recycling and recovery of end-of-life vehicles, which involves recovery targets of 85%, are driving the auto industry to adopt lightweight materials technology to meet these recovery targets.[12]

Some of the facts about the lightweight materials are as follows:

- The total global consumption of lightweight materials used in transportation equipment was 42.8 million tons/$80.5 billion in 2006 and will increase to 68.5 million tons/$106.4
- Billion by 2011, at a compound annual growth rate (CAGR) of 9.9% in tonnage terms and 5.7% in value terms between 2006 and 2011.

- High strength steel accounts for the largest percentage of total tons of lightweight materials consumed, followed by aluminum and plastics. In value terms, plastics with their relatively high unit prices are the largest market segment. Aluminum and high strength steel are the second and third largest product segments.
- Motor vehicles, particularly passenger cars and light trucks, are by far the largest end user segment. Shipbuilding was the second largest consumer of lightweight materials, while the aircraft industry ranks second in the value of the lightweight materials consumed.

Rail vehicle manufacturers are investigating the reduction of the weight in a viable economical way. For example study by Lotus Engineering concludes that a vehicle mass improvement of 38%versus a conventional mainstream vehicle can be achieved at only 3% cost. Comparison of weight reduction and associated costs for two future models are shown in Table 2.3. In recent years, the amount of ferrous metal has declined, mostly driven by manufacturers replacing iron with aluminum for engine castings. The percentage of sheet steel per car has also dropped, mainly due to:[13]

- Higher levels of equipment, trim and soundproofing.
- More aluminum used in wheels and suspension parts.
- More mounded plastics, especially under the bonnet.

Table 3.3.Comparison of weight reduction and associated costs for two future models

BaseToyotaVenza Excludingpowertrain		**Lotus Engineering Design**			
System	Weight (kg)	2020Venza		2017Venza	
		%Mass Reduction	%Cost Factor	%Mass Reduction	%Cost Factor
Body	383	42	135	15	98
Closures/Fenders	143	41	76	25	102
Bumpers	18	11	103	11	103
Thermal	9.25	0	100	0	100
Electrical	23.6	36	96	29	95
Interior	252	39	96	27	97
Lighting	9.90	0	100	0	100
Suspension/Chassi	379	43	95	26	100
Glazin	43.7	0	100	0	100
Misc.	30.1	24	99	24	99
Totals	1290	38	103	21	98

3.7.2 Cost

One of the most important consumer driven factors in carbody industry is the cost. Since the cost of a new material is always compared to that presently employed in a product, it is one of the most important variables that determine whether any new material has an opportunity to be selected for a vehicle component. Cost includes three components: actual cost of raw materials, manufacturing value added, and the cost to design and test the product. This test cost can be large since it is only through successful vehicle testing that the product and manufacturing engineers can achieve a 'level of comfort" to choose newer materials for application in a high-volume production program.

Aluminum and magnesium alloys are certainly more costly than the currently used steel and cast irons that they might replace. The ability to approach the total cost of the competition, therefore, must be associated with lower component manufacturing costs. Compared to cast irons and steel, cast aluminum and magnesium components are potentially less costly. This is based on their reduced manufacturing cycle times, better much inability, ability to have thinner and more variable wall dimensions, closer dimensional tolerances, reduced number of assemblies, more easily produced to near net shape (thus decreasing finishing costs, and less costly melting/metal-forming processes).However, wrought aluminum and magnesium components are almost always more costly to produce than their ferrous counterparts. Since cost may be higher, decisions to select light metals must be justified on the basis of improved functionality. Government regulations mandate reductions in exhaust emissions, improved occupant safety, enhanced fuel economy, reductions in workplace emissions, increased safety requirements, for toxic materials handling and disposal.

3.7.3 Safety, crashworthiness

The ability to absorb impact energy and be survivable for the passengers is called the ''crashworthiness'' of the structure in vehicle. There are two important safety concepts in vehicle industry to consider, crashworthiness and penetration resistance. Crashworthiness is defined as the potential of absorption of energy through controlled failure modes and mechanisms that provides a gradual decay in the load profile during absorption. However, penetration resistance is concerned with the total absorption without allowing projectile or fragment penetration.

The current legislation in design of the railway vehicle requires that, in the case of an impact at speeds up to 15.5 m/s (35 mph) with a solid, immovable object, the occupants of the passenger compartment should not experience a resulting force that produces a net deceleration greater than 20g carbon dioxide reduction.

The current trend of materials in car industry is towards replacing metal parts more and more by polymer composites in order to improve the fuel economy and reduce the weight of the vehicles. The behavior of composite failure in compression is the opposite to metals. Most composites are generally characterized by a brittle rather than ductile response to load. While metal structures collapse under crush or impact by buckling and/or folding in accordion type fashion involving extensive plastic deformation, composites fail through a sequence of fracture mechanisms involving fiber fracture, matrix crazing and cracking, fiber-matrix de-bonding, de-lamination and interplay separation. The actual mechanisms and sequence of damage are highly dependent on the geometry of the structure, lamina orientation, and type of trigger and crush speed, all of which can be suitably designed to develop high energy absorbing mechanisms. Several aspects are considered in design for improved crashworthiness including the geometrical and dimensional aspects which have key role in different stages of crash. However the materials deformation and progressive failure behavior in terms of stiffness, yield, strain hardening, elongation and strain at break are also very important in the energy absorption capacity of the vehicle. Their crashworthiness behavior is of fundamental importance in the safety design of the whole vehicle because their plastic collapse is the mechanism that is used to dissipate the kinetic energy of the vehicle in an accident. The mechanism of plastic collapse should be reliable and its evolution during the crash regular so that the desired quantity of absorbed energy, a low load uniformity and the required level of deformation load can be achieved without increasing danger for the vehicle passengers.

3.8. Current materials in use

The current materials used in rail vehicle industry both categories of metals and composites are reviewed. The advantages and disadvantages of each material are discussed. Also the most recent topics of research on development of new compositions, manufacturing and characterizations of these materials for the specific purpose of use in vehicle is presented.[12]

3.8.1 Steel

Advanced iron and steel technologies have seen considerable development over the past decade and are frequently included into new designs and redesigns by all automakers. The steel industry and component suppliers are investing heavily in innovation. The result of the investment is numerous examples of successful, cost-effective use of stainless steel, new formulations of iron, high-strength steels, and an associated variety of new design, fabrication, and assembly techniques. Applications include not only vehicle bodies, but also engine, chassis wheels and many other parts. The usages commonly demonstrate weight reduction plus simultaneous improvements in strength, stiffness, and other structural performance characteristics. Thus, a clear potential exists to affordably make vehicles lighter and safer at the same time.

Mass reduction through advances in the use of iron and steel is significant (ferrous materials), because they are the dominant material (64% of a typical family vehicle). Iron and steel form the critical elements of structure for the vast majority of vehicles, and are low-cost materials with an extensive experience base and familiarity to the industry.

The past several years have seen steady increases in the use of high-strength steels (HSS), many versions of which are referred to as high-strength, low-alloy (HSLA) steels. These materials plus their associated advanced design and fabrication techniques (as well as improved design and fabrication using traditional steels) formed the basis of the American Iron and Steel Institute (AISI) Ultralight Steel Auto Body (ULSAB) series of studies and demonstration projects. The ULSAB car body demonstrated a 19% mass reduction in a body structure that had superior strength and structural performance (including crashworthiness) along with a reduced parts count and net manufacturing cost savings compared to a conventional steel body. Comparable mass reductions and other benefits were achieved for doors, hoods, decklids, and hatchbacks. Improved steel materials and forming processes allow a significant optimization of vehicle body structures and components.
The prime reason for using steel in the body structure of an automotive is its inherent capability to absorb impact energy in a crash situation. This, in combination with the good formability and joining capability, makes these materials often a first choice for the designer of the body-in-white (BIW) structure. In bending and torsion, both material and shape are important parameters for the efficiency of the component to carry the applied load.

For bending, the elastic-plastic transition is a combination of shape and material properties. The strength of a beam under bending is related to the materials yield stress and Young's modulus. The stiffness is correlated to the materials Young's modulus and the shape of the component.

High-strength steel (HSS) is based on alloys that are categorized on the basis of yield strength. Standard HSS has a yield strength between 210 MPa and 550 MPa; ultra-high- strength steel (UHSS) has a yield strength higher than 550 MPa. High-strength steels can cost as much as 50% more than traditional mild steels, but they allow use of lower thicknesses than milder steels for achieving needed part performance specifications. Also, different grades of steel can be combined in tailored blanks, so that the more costly or thicker materials can be placed only where needed. With HSS, there can be a trade- off between strength and formability; in other words, the stronger a steel is, example in resisting stretching (tension), the more difficult it can be to forge into shapes, particularly the stylistically and aerodynamically optimized shapes needed for new vehicles. Steel suppliers are therefore developing steels with a range of properties that give engineers more flexibility in selecting an ideal grade of steel for any given application. Stainless steel is a material of choice due to passivity and resistance to corrosion. Some of the stainless steel grades suggested for rail vehicle are as follows: [19]

a. Duplex austenitic-ferritic stainless steel

The most commonly used duplex grade is 0.02% C – 22% Cr – 5.5% Ni – 3% Mo – 0.15% N alloy, whose standard European designation is X2CrNiMoN22-5–3 / 1.4462.

b. Austenitic stainless steel.

Table 3.4 Specific Strength of Stainless Steels, 6061 Aluminum and High Strength Steel

Property	Duplex Stainless Steel	Austenitic Stainless steel			Aluminum Alloy		High Strength Steel HSLA
		Annealed	C850(2)	C1000(3)	T4(4)	T6(5)	
Density: ρ(g/cm3)	7.8	7.9	7.9	7.9	2.7	2.7	7.83
Yield Stress: σ (N/mm2)	640	370	600	880	130	275	410
Specific Strength (N/mm2/g/cm3)	82	46.8	76	111.4	48.1	100	52.4

The specific stiffness of Stainless Steel is very similar to that of aluminum alloy and the HSLA steel, which means that the three materials can all be considered as “light materials”. The specific strength of the austenitic Stainless Steel in the cold worked condition is much higher than the one for the other materials. The specific strength of different steel and aluminum are compared in the Table 3.4

3.8.2 Aluminum

There are a broad range of opportunities for employing aluminum in rail vehicle power train, chassis, and body structures. The use of aluminum offers considerable potential to reduce the weight of a rail vehicle body. In current steel construction, the vehicle consists of stamped body panels spot welded together (body-in-white) to which stamped steel fenders, doors, hood, and deck lid are bolted. There are two methods of designing and manufacturing an aluminum body structure; one is similar to the current steel construction 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 complex stampings at acceptable economical rates. This involves appreciation of the interaction of the crystallographic texture, sheet thickness and stamping die or lubricant parameters. In addition, the aluminum alloys chosen for exterior panels must have the ability of age hardening to provide suitable strength for dent resistance during the oven paint baking.

In order to use the Aluminum in vehicle intake manifolds and transmission housings, it is essential that material shows the ability to be cast into leak proof components with well-defined inner passages for water and air flow, provides suitable thermal conductivity, and sufficient resistance to the mechanical forces at temperatures near 145’C. On the other hand, the components are exposed to high mechanical stresses from engine vibration and the thermal expansion loads. This can lead to thermal fatigue if the metallurgical structure is not sufficiently small and if the casting contains inclusions, oxide films, and porosity. This has initiated considerable research to aluminum castings with no defects to avoid fatigue and reduced impact resistance. Also control of solidification microstructure, dendrite arm spacing, grain size, and eutectic silicon morphology are the other areas that have become more and more under investigation. In addition to alloy chemistry and melt temperature, dissolved gas and nonmetallic inclusions must be controlled to limit porosity and stress- raising oxide films.

Aluminum usage in automotive applications has grown substantially within past years. A total of about 110 kg of aluminum: vehicle in 1996 is predicted to rise to 250 or 340 kg, with or without taking body panel or structure applications into account. There are strong predictions for aluminum applications in hoods, trunk lids and doors hanging on a steel frame. Recent examples of aluminum applications in vehicles cover power trains, chassis, body structure and air conditioning. Aluminum castings have been applied to various automobile parts for a long period. As a key trend, the material for engine blocks, which is one of the heavier parts, is being switched from cast iron to aluminum resulting in significant weight reduction. Aluminum castings find the most widespread use in automobile. In automotive power train, aluminum castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission (other parts-rear axle, differential housings and drive shafts etc.) For chassis applications, aluminum castings are used for about 40% of wheels, and for brackets, brake components, suspension (control arms, supports), steering components (air bag supports, steering shafts, knuckles, housings, wheels) and instrument panels. Recently, development effort to apply wrought aluminum is becoming more active than applying aluminums castings.

3.8.3 Magnesium

Magnesium, light metal has a density of 1783 kg/m^3, which is two thirds of aluminum and one sixth of steel. That means it is 33% lighter than aluminum and 75% lighter than steel or cast-iron components. The strength-to-weight ratio of magnesium is 158kNm/kg, which is higher than 130kNm/kg for pure aluminum. This high strength-to-weight ratio is the principal driver for the increasing demand of this metal. The purity required for commercial magnesium according to ASTM B92 (2007) for 9980A grade is a minimum of 99.80 wt% Mg, with impurities such as Ca, Al, Si, and Fe below 0.05 wt% each. The corrosion resistance of modern, high-purity magnesium alloys is better than that of conventional aluminum die-cast alloys. As well, porosity-free die-cast AM501 AM60 can achieve 20% elongation, or over three times that of Al A380, leading to higher impact strength; but magnesium components have many mechanical/physical property disadvantages that require unique design for application to vehicle products. Although it’s tensile yield strength is about the same, magnesium has lower ultimate tensile strength, fatigue strength, and creep strength compared to Aluminum. The modulus and hardness of magnesium alloys is lower than aluminum and the thermal expansion coefficient is greater. However, it should be noted that suitable ribbing and supports often can overcome the strength and modulus limitations.[15]

Table 3.5 Properties of Mg, Al, Fe

Property	Magnesium	Aluminum	Iron
Crystal Structure	hcp	FCC	BCC
Density at 200C (g/cm3)	1.74	2.70	7.86
Coefficient of thermal expansion 20-1000C (*106/C)	25.2	23.6	11.7
Elastic modulus (106 MPa)	44.126	68.947	206.842
Tensile strength (MPa)	240	320	350
Melting point (0C)	650	660	1.536

Despite the above issues Magnesium alloys have distinct advantages over aluminum that could not be dismissed. These include better manufacturability, longer die life and faster solidification due to lower latent heat. Therefore more castings can be produced per unit time compared to aluminum. Magnesium components have higher mach inability. Magnesium components can be produced with improved dimensionality and surface quality, and smaller draft angles compared to aluminum.

The capability of magnesium to be hot chamber die cast can reduce casting scrap by reducing dross and can limit gas and oxide inclusions while allowing more consistent melt temperature. A comparison of the properties of the Mg, Al and Fe is made in Table 2.5 above.

Components that form rail vehicle car body structure are created using various manufacturing processes such as casting, extrusion and welded plate's assembly. Various materials are considered; mainly aluminum, steel, magnesium and Glass-Reinforced Plastic (GRP).They are designed and welded in accordance with AWSD15.1, AWSD1.1 for steel, andAWSD1.2for aluminum. Such rail vehicle car bodies are assembled using bolts, rivets and welding which are assessed during FE validation.

In dynamic simulations of railway vehicles, it is desirable to represent the car body structural flexibility by a limited number of degrees of freedom. These rigid body degrees of freedom are:

longitudinal, lateral, vertical, roll, pitch, and yaw motions. The most common way of finding such a representation is to use the body's Eigen modes found from Eigen value analysis of the free body. Then, we get six rigid body modes and a number of structural modes, preferably those with the lowest Eigen frequencies. The carbody vibrations can be divided in two types of modes: rigid and flexible. The rigid body modes that affect vertical ride comfort are bounce, pitch and roll. These modes normally lie in a relatively low frequency range; around 1Hz.The flexible modes are twisting and bending deformations of the carbody due to constraints acting on it. In a first step complete structure of rail vehicle bodies were developed, optimized and evaluated based on global stiffness requirements. The knowledge gained in this step was used as requirements for the strength and stiffness of panels during the continued development of the multi-functional optimization [5].

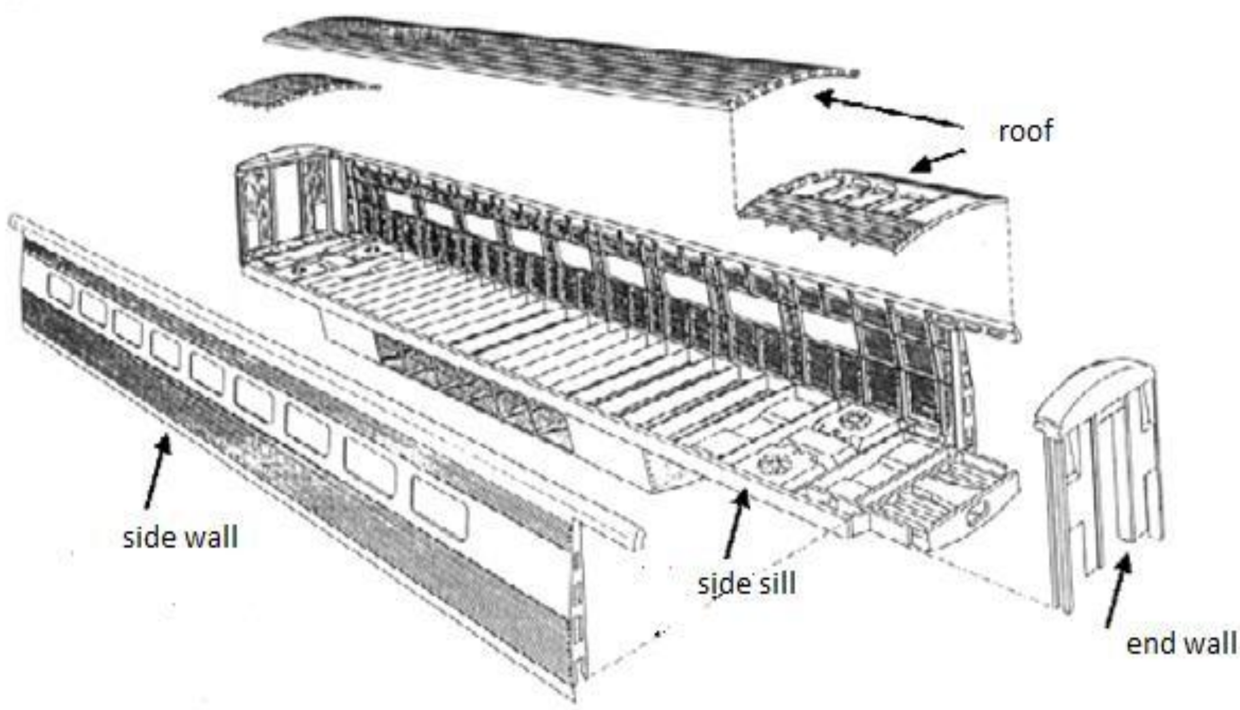


Fig 3.2.Main elements of a passenger rail vehicle structure

Modern multibody dynamics and finite element analysis methods can be used in the investigation of train collisions, crashworthiness and the absorption of energy in the structure. Analyses could range from simplified one-dimensional models used to evaluate interactions between vehicles and study the effects of varying parameters such as the crush strength to detailed three-dimensional finite element crash simulations that can be used as part of the vehicle design process. Multibody dynamics formulations can be in one, two or three dimensions. The one dimensional (1D) models consider the train to be constrained to the longitudinal track line.The two-dimensional (2D) models considers the lateral buckling of the train constructs in the investigation and the three-dimensional (3D) models consider the over-riding of vehicles in a train.

The carbody structure fatigue damage is mainly caused by the vehicle dynamic response, which is usually expressed as stress or strain time history. Stress/Strain calculations for fatigue life estimation can be performed in the time domain or frequency domain. The quasi-static stress method was used to obtain the stress/strain time histories. The detail carbody stress analyses with ANSYS were performed based on multi body system and finite element method. And mode analysis is also performed here. Modal analysis is usually used to determine the natural frequencies and mode shapes of car body structure.

CHAPTER FOUR

3. Model of the rail vehicle body

3.1 Modeling body of vehicle

To define the car body structure, a structural model is developed by using CATIAV5-R20 modeling and analysis ware. This model is import the mode with a file format such as IGES, ACIS, or ParasolidtoANSYS-14.5 for final result analysis. The purpose of the structural sketch is to define the primary car body structure in advance of formal stress analysis and structural drawings. With the basic understanding of how finite element programs work, a finite element model must be created with appropriate parameters such as dimensions, loads, constraints, element choice, mesh selection, etc.

The structural sketch includes a side view; a top view showing one longitudinal dimension of the roof and one longitudinal dimension of the under frame; and typical car body cross-sections. Cross-sections of the structural members, showing the shape, dimensions, material, and thickness of each member is included. The members shown include, to the extent used in the particular design, typical side frame and door frame posts; end, side, draft and center sills; belt, top, and roof rails; collision and corner posts; bolsters, floor beams and cross bearers; roof carlines and purlins ;roof sheathing or corrugation; side frame sheathing or wall corrugation.[18]

A computer aided design (CAD) or finite element (FE) analysis can give the mass, center of gravity position, and mass moments of inertia. However, in most applications the mass of the car body structure is less than half the car body mass. For a coach the additional mass is a result of the interior layout and interior/exterior equipment. For powered vehicles, especially locomotives, the car body also carries some of the traction equipment. Often, it is quite hard to keep accurate records of all the pertinent masses and positions. Usually, the mass of this equipment is merged to the metal structure model. In many vehicles–track dynamics simulations of the payload, i.e., passengers or goods, also needs to be considered. The corresponding mass might also be combined with the car body structure model.

In this project, category P-I(coaches) is considered.

The main dimensions of car body of rail vehicle that are taken from the standard

Table 4.1 Main technical parameters of 28 G hard seated passenger coach

Type	Passenger coach
Design speed	140km/h
Model No	28G orYZ28B
Gauge	1435mm/ standard gauge
Car body length	22535mm
Car body width	2180mm
Min. curve radius	Coupler: 145m
Car body height	2796mm
Height from coupler center to rail roof	880mm
Bogie	209P
Height from coupler center line to top rail	880mm
Fixed distance between two cars	11000mm
Dead weight	≤46t
Axle load	≤17t
Fixed passenger capacity	109P
Bogie mass	3000kg

Length=22535mm

Width=2180mm

Height between under frame to car top=2796 mm

Load to be applied pressure is 29820.32pa

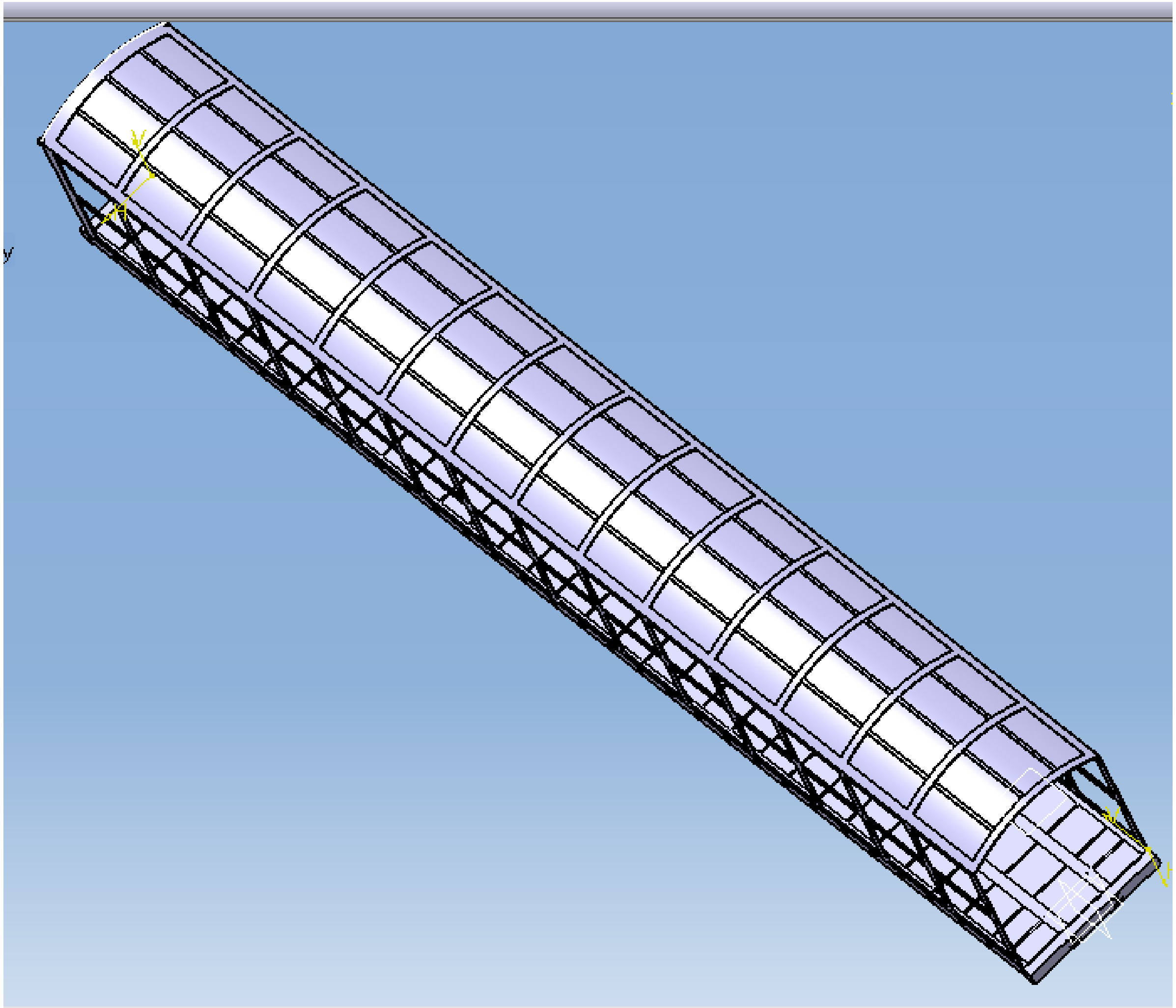


Fig 4.1.model of passenger rail car

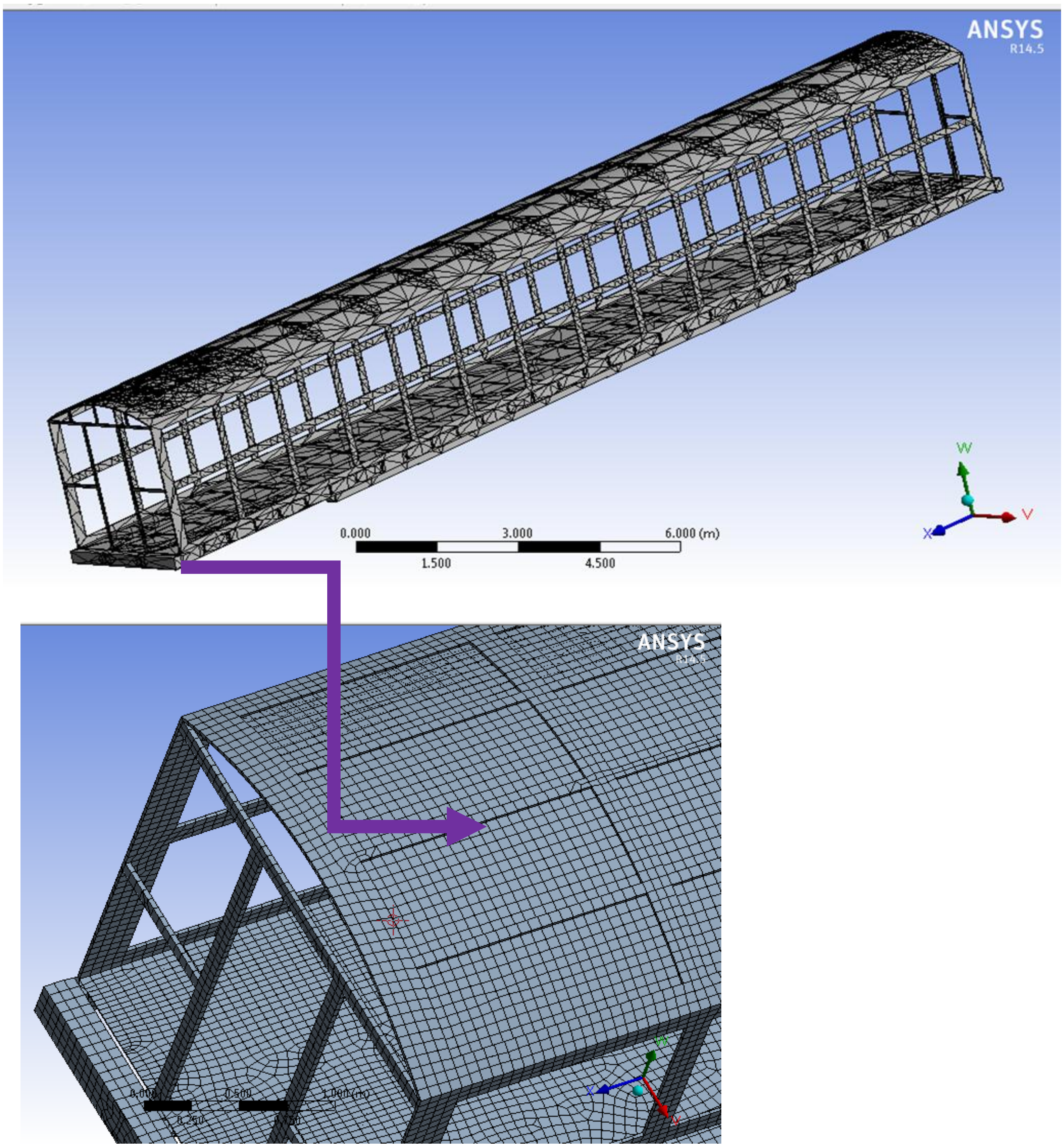


Fig 4.2. Meshed model of a passenger rail vehicle

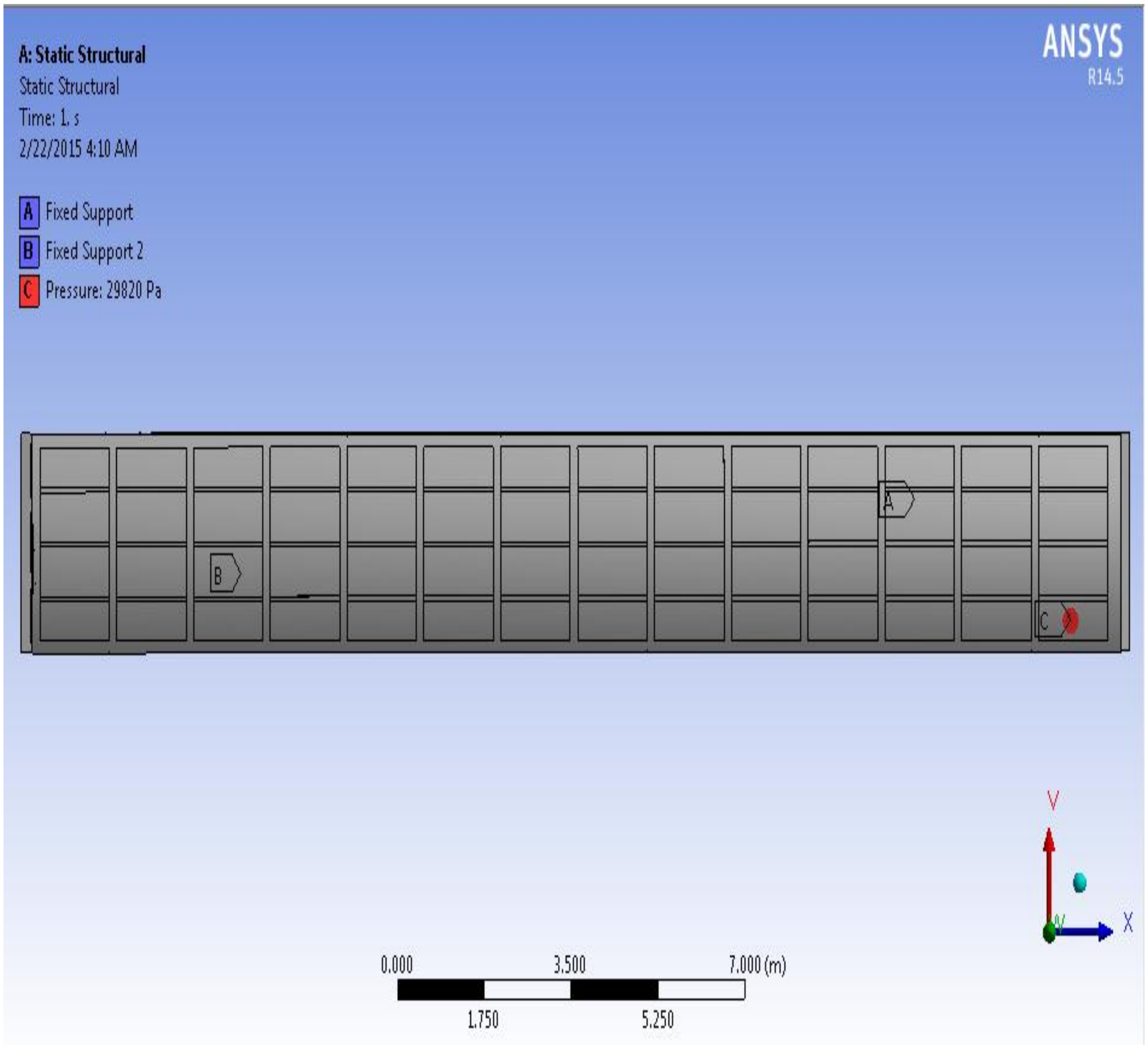


Fig. 4.3. Top view of a passenger Rail vehicle model

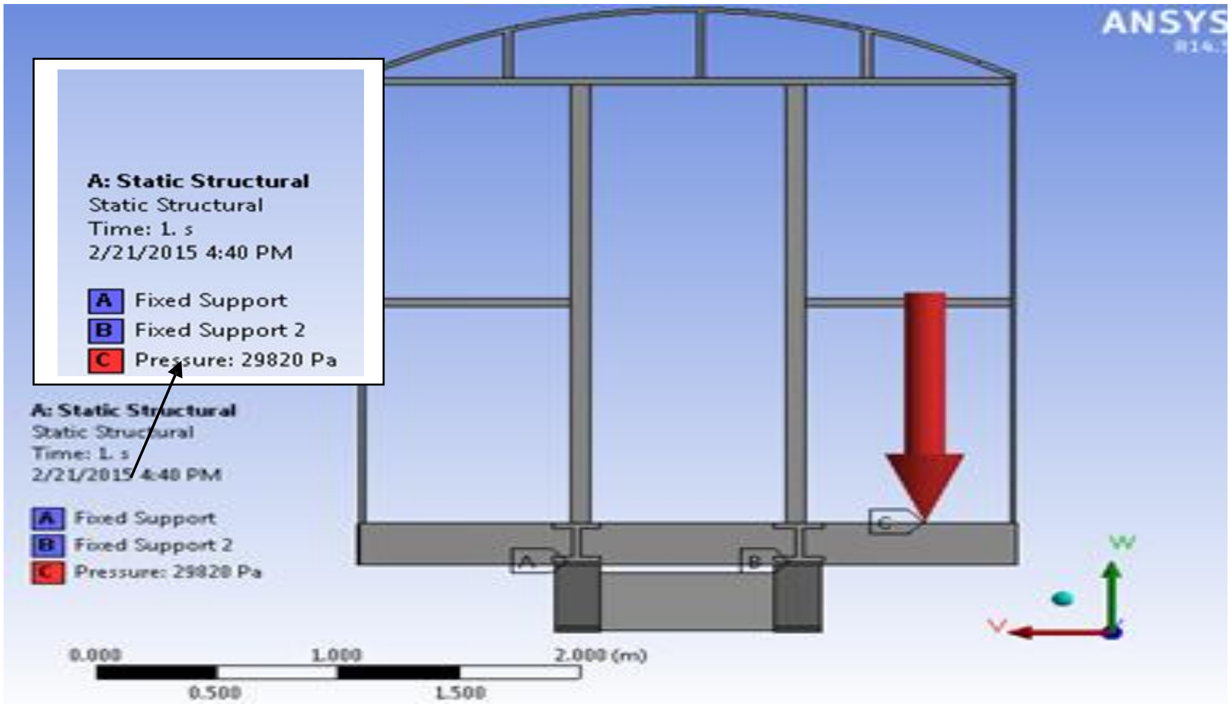


Fig 4.4.Frontal view of a passenger Rail vehicle model,

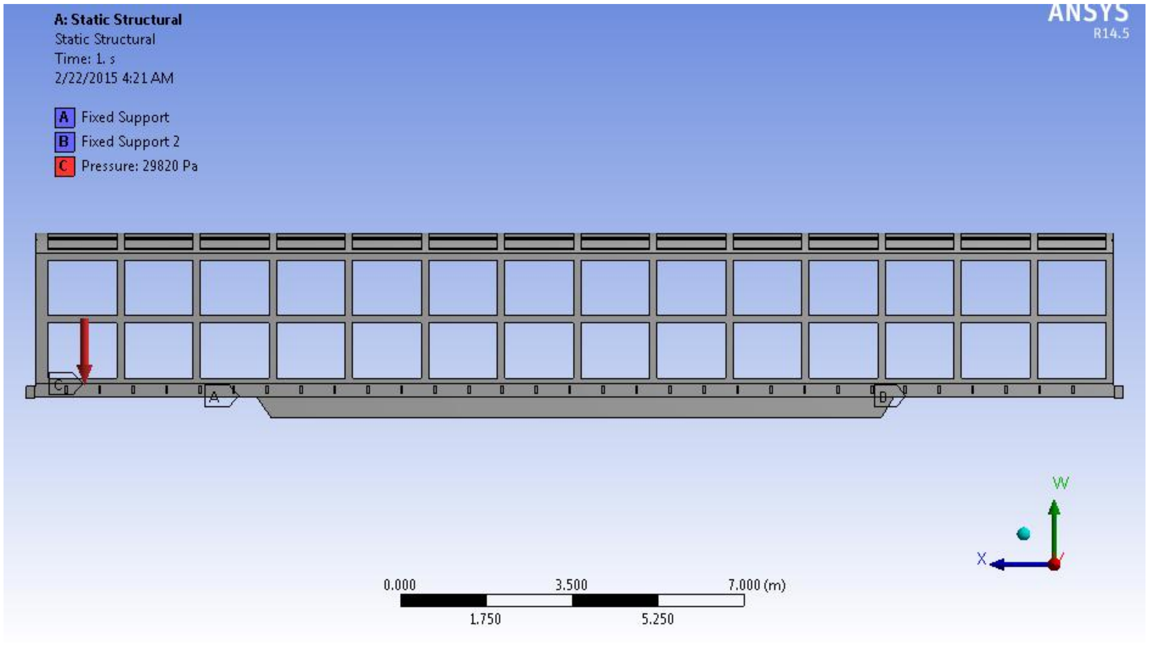


Fig 4.5. Fixed support points at the bogie bolster

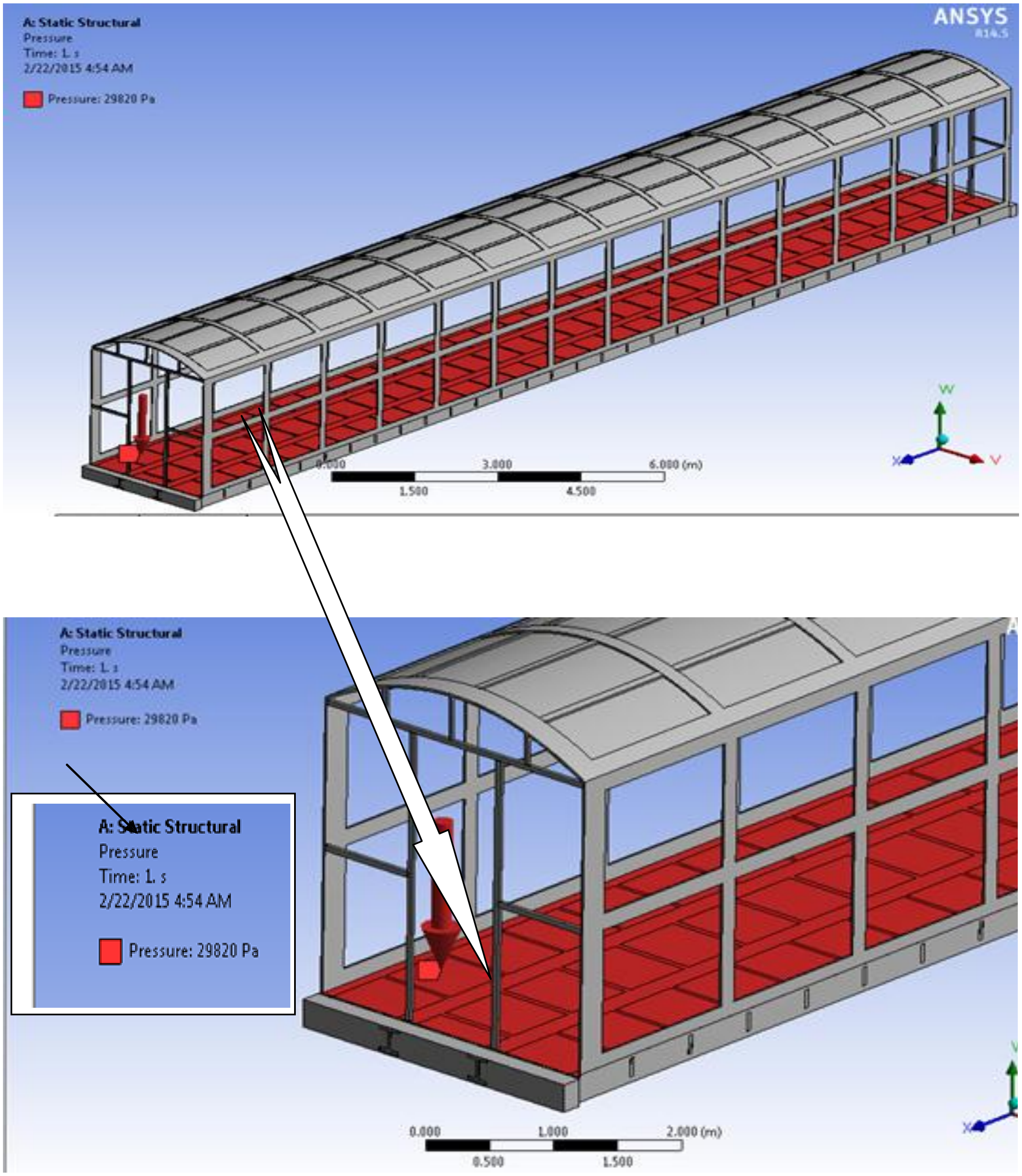


Fig. 4.6 Applied load on the vehicle

CHAPTER FIVE

5. Analysis and results

5.1 Analysis and acceptable standards

For the passenger car categorized under P-I, the load analysis is conducted in accordance to the EN12663-1:2010. All load cases are considered and the design is checked for exceptional loading (m4). This is because the Exceptional load case imposes the maximum load and requires high material strength of the passenger rail vehicle structural components. Different type of the components used in the design of railway bogies and rail vehicle car bodies result in a large variety of modeling methods and element types being employed in the creation of the FE model. The analysis is a solution approach that comprises importing of 3D model from CATIAV5-R20 to ANSYS workbench that is then processed in order to clean up unnecessary details or components. The imported Model is then meshed to act like single entity. Finer mesh and close to exact solution can be achieved by control length mesh size.

5.1.1 Finite element analysis

The finite element method (FEM) is a numerical method seeking an approximated solution of the distribution of field variables in the problem domain that is difficult to obtain analytically. It is done by dividing the problem domain in to several elements. Known physicals are then applied to each small element, each of which usually has a very simple geometry. A continuous function of an unknown field variable is approximated using piece wise linear functions in each sub-domain, called an element formed by nodes. The unknowns are then the discreet values of the field variable at the nodes.

Next, proper principles are followed to establish equations for the elements, after which the elements are ‘tied’ to one another. This process leads to a set of linear algebraic simultaneous equations for the entire system that can be solved easily to yield the required field variable. Traditionally, structures have been analyzed it her as continuous or as discretized (‘lumped’) systems. Some structures, such as uniform beams, can still usefully be treated as continuous systems, but most are now regarded as discrete multi-DOF systems. The finite element method, in fact, can be said to combine both approaches: it is continuous within the elements, but discrete at the global coordinate level.

The general procedure of finite element method for structure analysis is

- Divide structure into pieces(elements with nodes)
- Describe the behavior of the physical quantities on each element
- Assemble the elements at the nodes to form an approximate system of equation for the whole structure.
- Solve the system of equations involving unknown quantities at the nodes (e.g. displacements)
- Calculate the desired quantities(e.g. deformation and stresses) at selected elements

5.1.2 Types of loading

i. Compressive and tensile loading

Rail vehicle mass is split into three categories, mass of the car body, mass of running gear and payload mass as stated in the literature review.A rail vehicle is subjected to a wide range of compressive, tensile, bending and twisting forces. To avoid permanent damage of the rail vehicle during operations it should be designed to withstand the following load cases. However, if technical justification is presented, either higher or lower values may be utilized instead of the ones presented herein. One of the main parameters considered in the design of railway structures is the longitudinal yield strength of the vehicle. This load requirement is important because when vehicles are properly designed to this load, they are protected against large-scale deformation rail vehicles.

The carrying capacity of the vehicleis109 passengers and each passenger is assumed 65kg

1. The total area of load applied is approximately, 20.096m long and.631m wide.

$$A_{pa} = 0.631m * 20.096m$$

Compressive force at passage ways and access areas is:

$F_{pa} = \quad 4\text{persons} * A_{pa} * 65\text{kg}/_{m^2}$

$F_{pa} = 3176.16kg$

Hence the total exceptional load on the rail vehicle car body is:

$m_4 = 12616.16kg$

The expected total dead weight of vehicle and two bogie is 44.5ton from the specification and standard. The vehicle may need to be jacked to a place where it can be maintained or attached to another locomotive. In such case, a hooking point is located in such a way that it will enable the load being carried safely without deformation. This is in accordance to the center of gravity and moment of inertia of the vehicle body being jacked.

ii. lifting criteria

There are two different lifting criteria.

The first lifting case is for example after simple derailments of the rail vehicle were one of the boogies is still on track. During this lift the rare boogie (if it is the front boogie that has derailed) is on the track and the front of the vehicle is lifted, with the front boogie hanging under the car. Also here a dynamic contribution of 1.1g is applied and the vertical load is written as

$F_l = 1.1xg * (m_1 + m_2)$

$F_l = 447.8kN$

This load is uniformly distributed over the floor of the car body. An offset lifting situation should also be considered. In this case one of the four lifting points in the first example is displaced vertically from the other three by 10mm. No permanent deformations should occur during any of these cases.

The second is defined to illustrate a lift in a workshop. The rail vehicle is then raised via specified lifting points. An additional dynamic factor of 1.1g is applied and both boogies are left hanging under the car. The vertical load is then given by empirical relationship of

$F_l = 1.1 * g * (m_1 + 2m_2)$

$F_l = 480.2kN$

Superposition of Static compressive &vertical force of the vehicle structure is

F_{cv} =2501.45kN

The Superposition of Static tensile force &vertical load for the vehicle structure is

$$F_{tv} = 1500kN + g * (m_1 + m_4)$$

$$F_{tv}=2001.45kN$$

Total axle load is therefore; $(\frac{m_1+m_4}{4})$ per axles

For the design, the maximum pressure is contributed from superposition of vertical and Compressive load acting over an area of 22.356m length and 2.723m wide platform.

F_{cv}=29.82kpa

$$F_{cv} = (\frac{38.5+12.616}{4}) = 12.779 \text{ ton per axle}$$

This result is consistent to the specification axle load <17 ton

5.1.3. Structural car body Component design

The main structural components that to being consider in the design of car body are under frame and center sill.

A . Center Sill

The combined load due to Compressive force and vertical force is

$$F_{cv} = 2000kN + g*(m_1 + m_4)$$

$$F_{cv} = 2501.44KN$$

m_4 =Exceptional load for PI

The dead weight of the vehicle in working order is

$$m_1' = m_1 + 2*(m_2)$$

For calculation in this study, m_1 doesn't include the weight of two bogies

$$m_1' = 44.5 ton$$

The dead load of the vehicle in working order without considering the bogie mass is

$$m_1 = m_1' - 2 x m_2 = 44.5 ton - 2*3. ton = 38.5\ ton$$

Assumption:

$\frac{1}{2}$ of this superposed compressive & vertical force is shared among two sides of the vehicle chassis running along the length.

$$\frac{F_{cv}}{2} = 1250.725 kN$$

Load shared by each under frame beams is

$$\frac{F_{cv}}{4} = 625.36 kN$$

This load is considered distributed on the beam that is supported 18m along its span.

The load intensity *(w)* $$w = \frac{625.36\text{kN}}{22.356\text{m}}$$

$$w = 27.97$$

$$\sigma = \frac{M}{Z}$$ where Z is -section modulus of the center sill.

The yield strength of the structural steel beam (St 36) is σy=460Mpa.

The force of reaction at the bogie bolsters centers

$$R_1+R_2=w*(2L_1+L_2)$$

$$R_1 = R_2$$

$$R_1=27.97*11.18kN=R_2$$

$$R_1=312.65kN=R_2$$

This load is considered distributed on the beam that is supported 18m along its span.

The Bending Moment at the two fixed bolster supported is equal and maximum among the section

$$M = w * L_2 * \left(L_1 + \frac{L_2}{2}\right) - R_2 * L_1$$

Where $w=27.97kN$, $L_2 = 16.326m, L_1 = 4.03m$ *and* $R_2 = 312.65kN$

$$M=4307.81kN$$

The maximum deflection is at the center of the beam. i.e. at 11.17m.

$$Z = \frac{M_{\max}}{\sigma_y}$$

$$Z = \frac{4307.81kNM}{460Mpa}$$

$$Z_{\max} = 9364.8cm^3$$

The standard Beam element that has similar characteristics is selected from standard table for metal manufacturer's catalogue. The property of the center sill is summarized in Table 5.1.

To decrease the weight of the car, optimization of the beam is made by reducing the section near the bolster support position. This will enable us to consider a tapper element at the low stressed area.Considering moment at the bogie fixed ends to decrease the section beyond the bogie support on both sides of the vehicle, $M_1 \& M_4 = 0$

$$M = \frac{W * l^2}{2}$$

$$M_{\max} = 227.13kN{-}m$$

$$Z = \frac{227.13}{460Mp} kN{-}m$$

Z=4975.87 m^3. The section modulus required for this bending Z which is less than the specified section

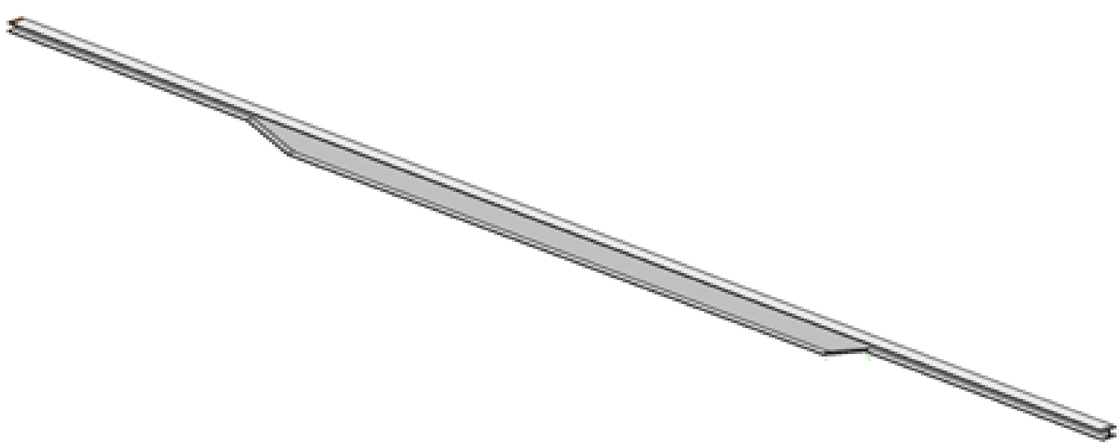
=

The section that has this property and complements with the middle frame is 305x305 column.

Table 5.1 Summary of middle center sill material

Universal beam914x305	
Radius of gyration	
Along x-x	36.78cm
Along y-y	6.42cm
Elastic modulus	210Gpa
Along x-x	10891cm3
Along Y-Y	1014cm3
Mass per meter	289 kg/m
Flange width	307.8mm
Flange thickness	32mm
Web height	926.6mm
Web thickness	19.6mm
Cros-sectonal area	369.8cm2

Universal beam305x305	
Radius of gyration	
Alongx-x	14.2cm
Alongy-y	8.02cm
Elastic modulus	210Gpa
Along x-x	2991cm3
Along Y-Y	1034cm3
Mass per meter	198 kg/m
Flangewidth	314mm
Flangethickness	31.4mm
Web height	339.9mm
Web thickness	19.2mm
Crossectonal area	252.8cm^2



5.1.The designed center sill for the vehicle

5.2. RESULTS

The solution method follows the steps as follow

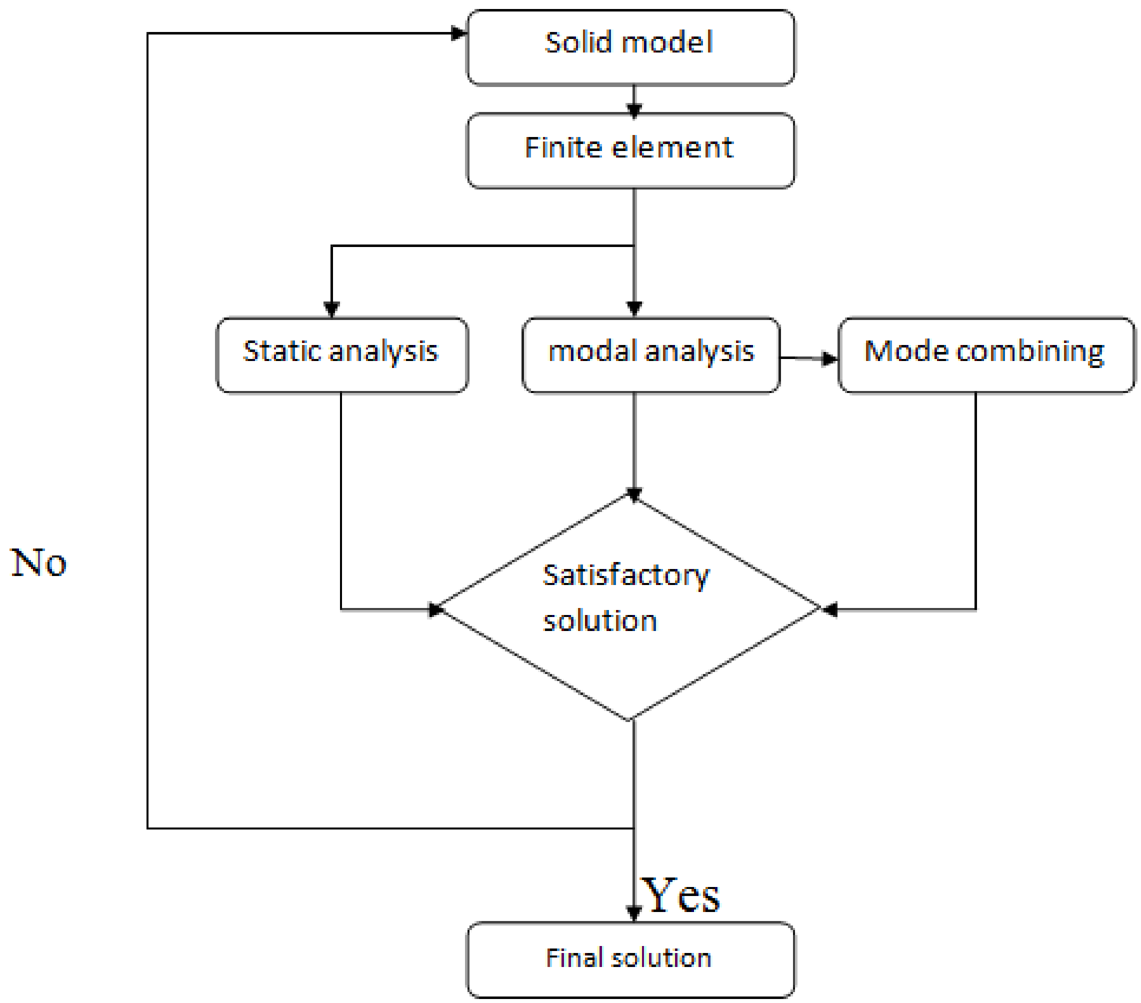


Fig 5.2.Solution method for structural and modal analysis

5.2.1. Static structural results

The static analysis is concerned with determination of the response of the rail vehicle car body to steady state loads. The corresponding stresses and strains are obtained using strain-displacement and strain-+stress (constitutive) relations. The deflections between two nodes are determined using assumed shape functions. The solution to the equation gives nodal translational and rotational displacements.

In the analysis, the situation considered is the stand still condition of the vehicle on a level road loaded to the maximum payload. The other loads considered include dead weight of the engine, and weight of the vehicle itself. A distributed pressure of 29820.32pa prevails due to a combined vertical and compressive load on the under frame. This creates the maximum stress on the center sill. Particularly, it is maximumat transition points of change in cros-section and near bolster support. The value of stress is 124.57Mpa in this spots and it is less than 460Mpa in other sections. The vertical deflection includes the static deflection of the vehicle structures. The vertical deflection is observed to be maximum at the center of the rail vehicle structural body and the under frame that is 4.289mm. As seen in the figure below, of the other components, the under frame gets highly stressed. This is attribute to the fact that all the static loads including the weight of the vehicle body and the cabin, and the engine are taken by the under frames and this causes bending loads in it.

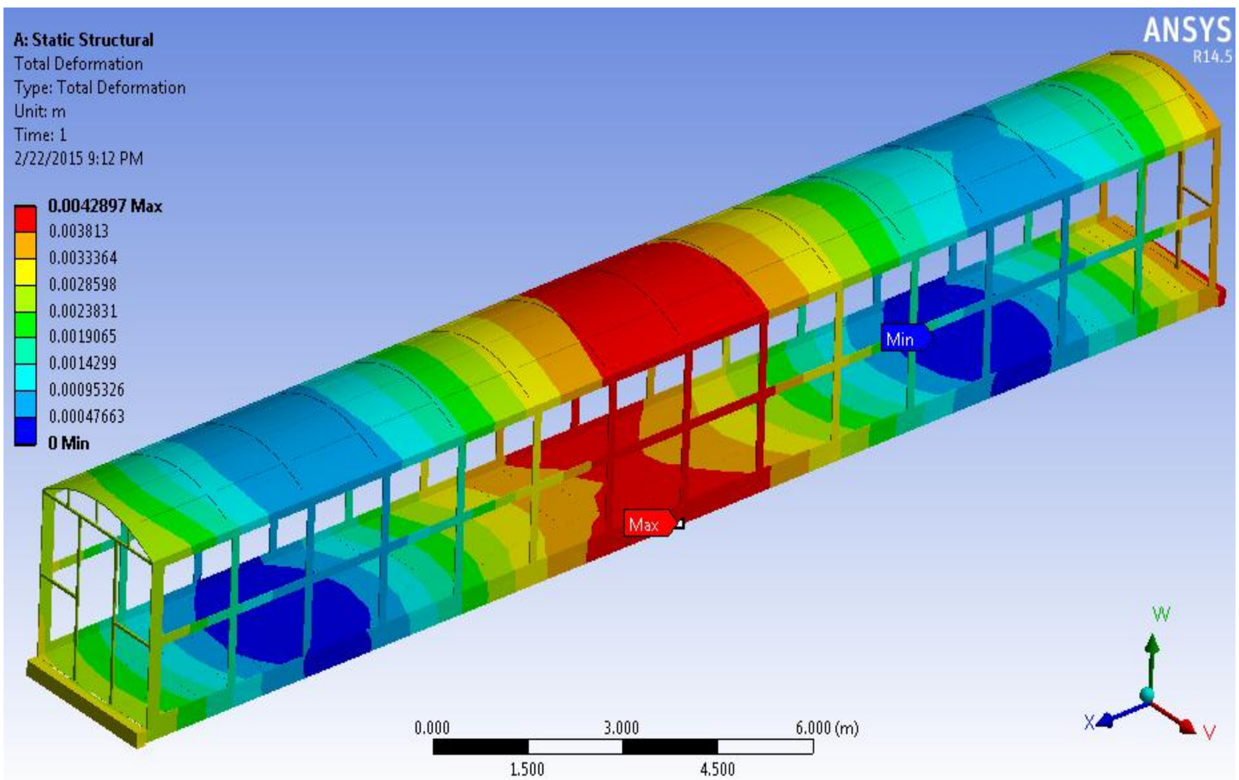


Fig 5.3.Total deformation of passenger rail vehicle

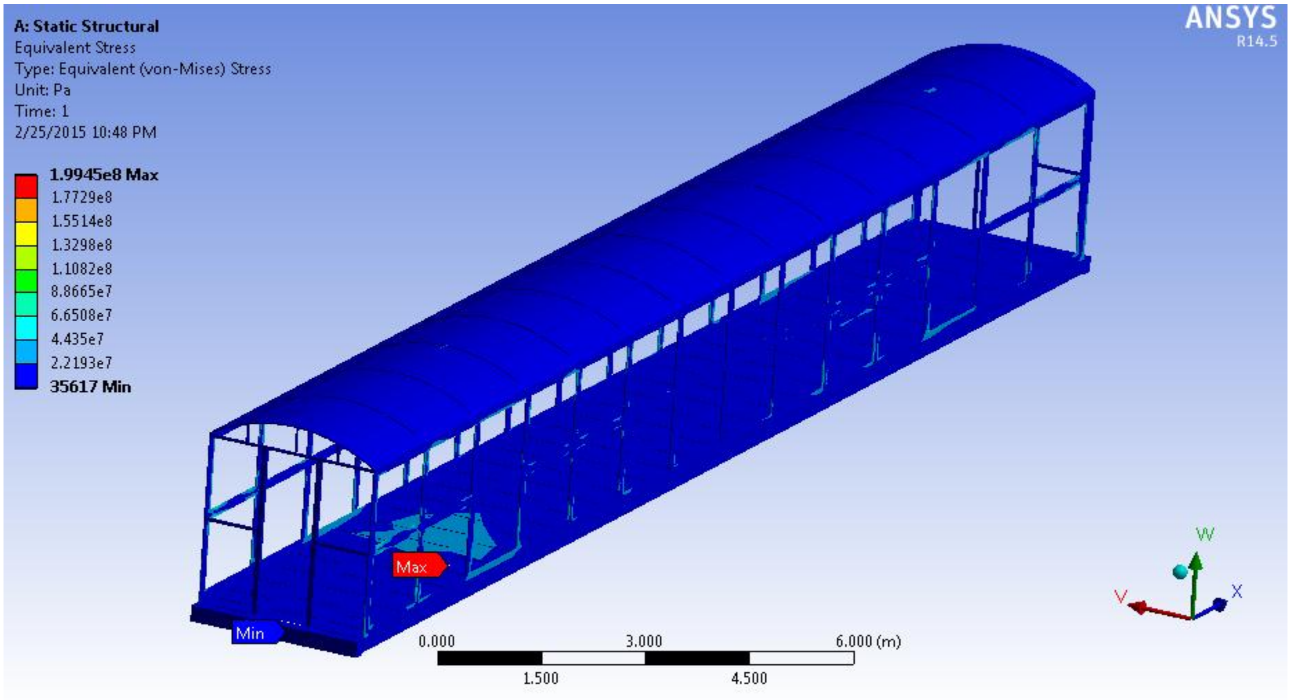


Fig.5.4a.von-miss Stress distribution on rail vehicle car body-Isometric view

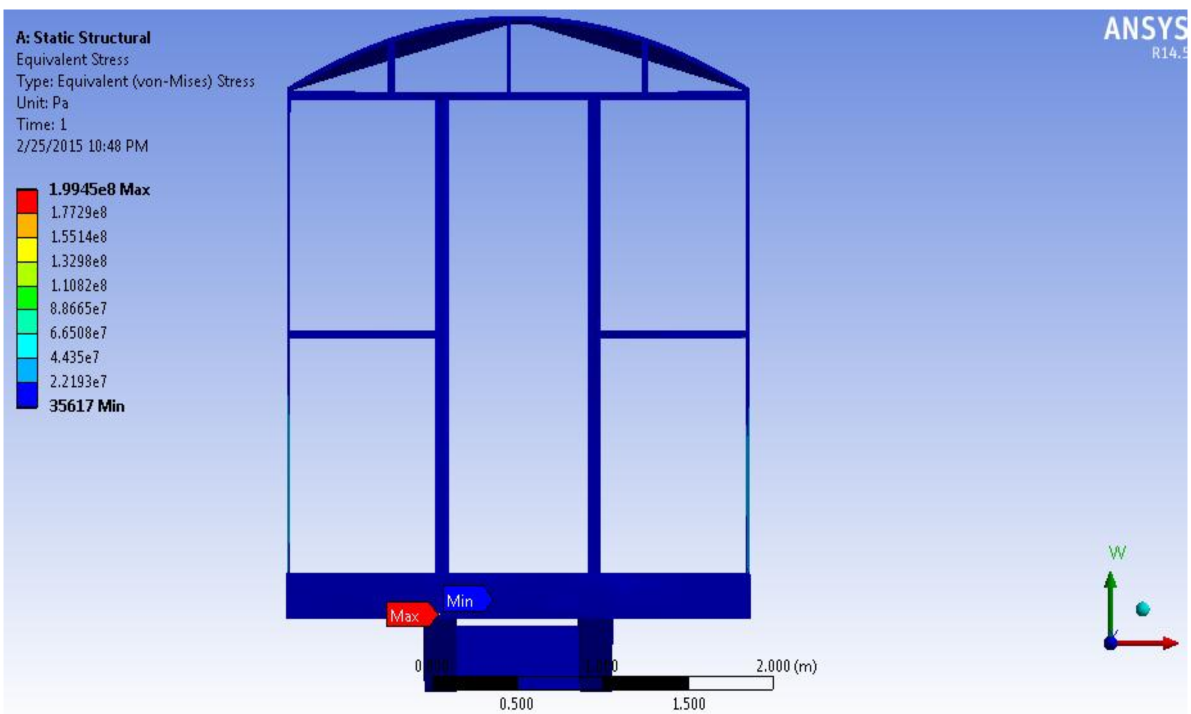


Fig 5.4b.Stress distribution on rail vehicle car body -end view

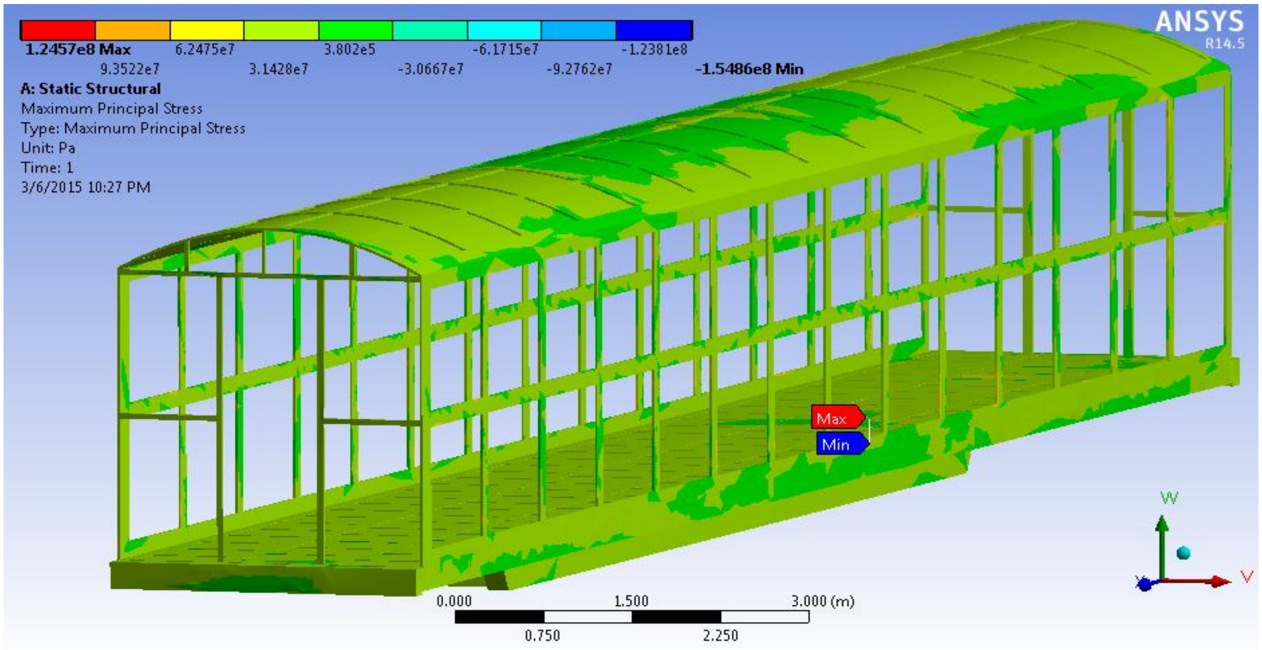


Fig5.5a. Maximum stress distribution on the rail vehicle car body-Isometric view

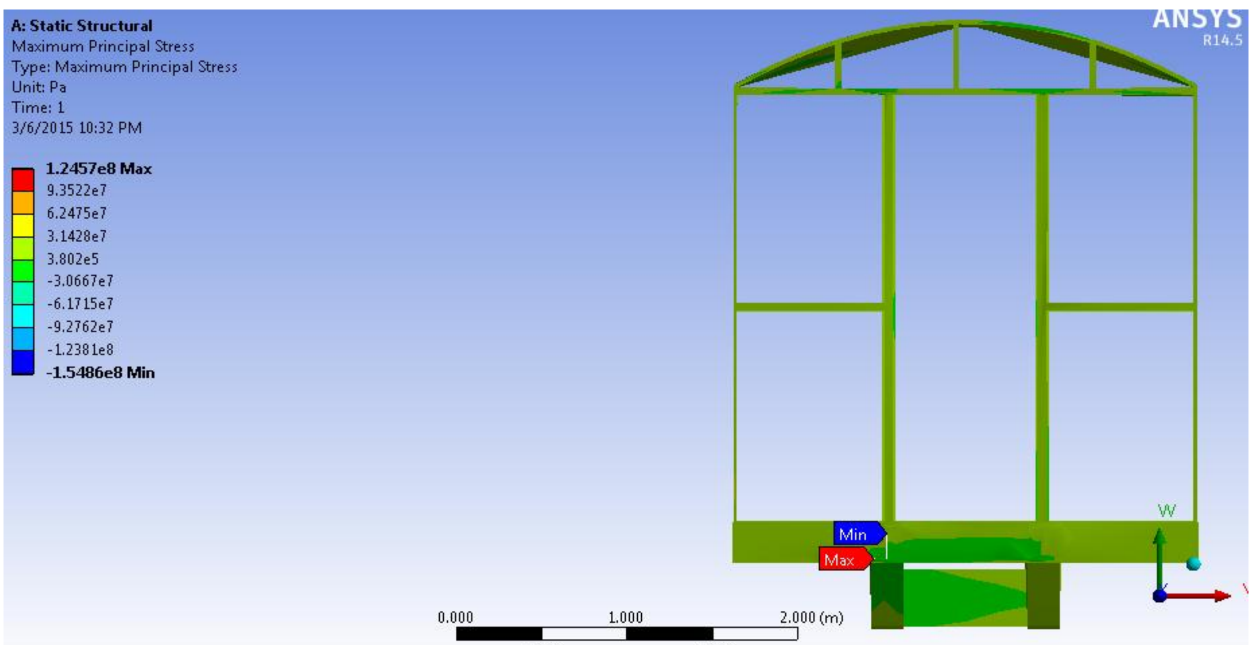


Fig.5.5.b Maximum stress distribution on the rail vehicle car body-front view

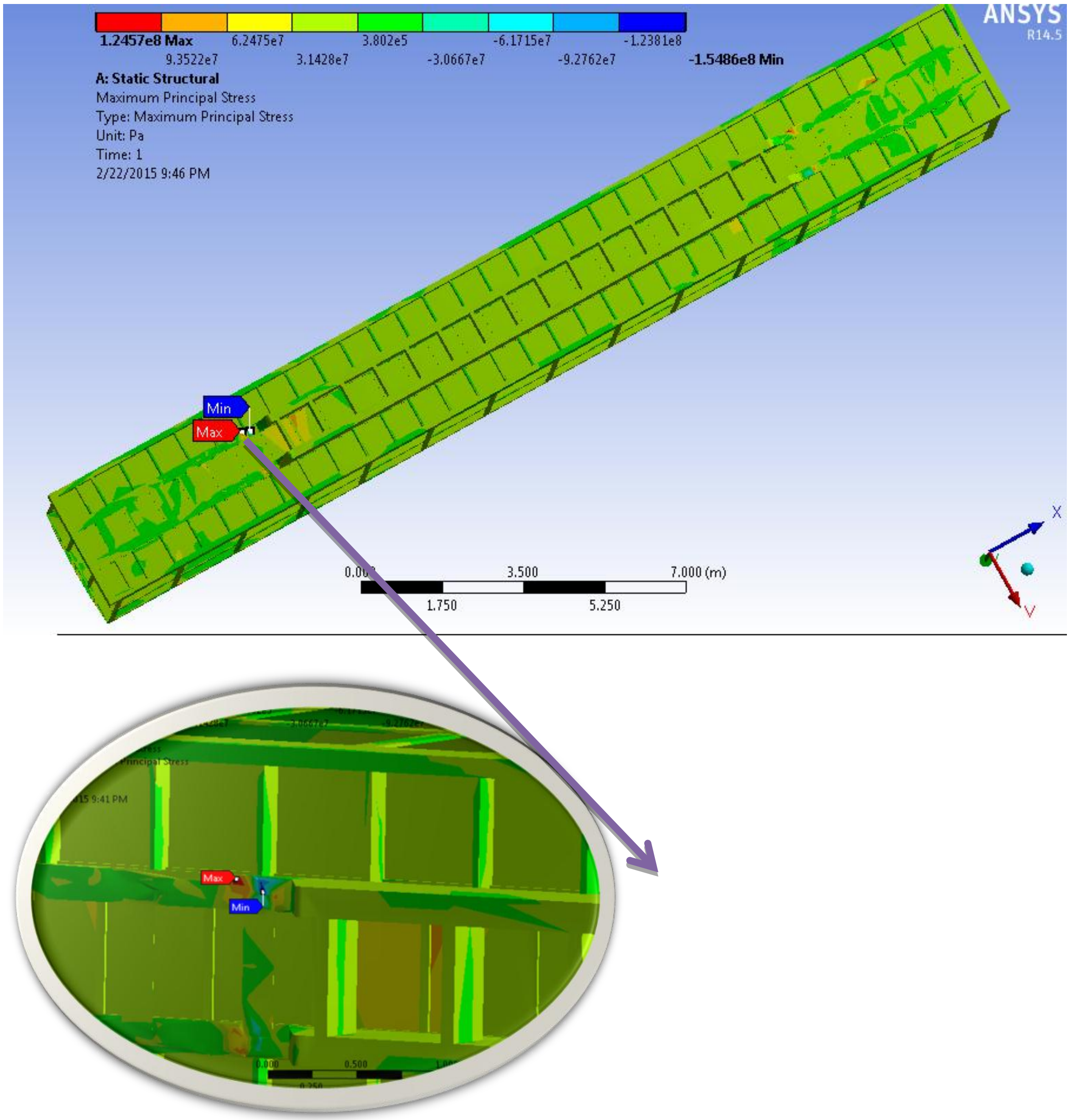


Fig 5.6c.Maximum stress distribution on the rail vehicle car body-bottom view

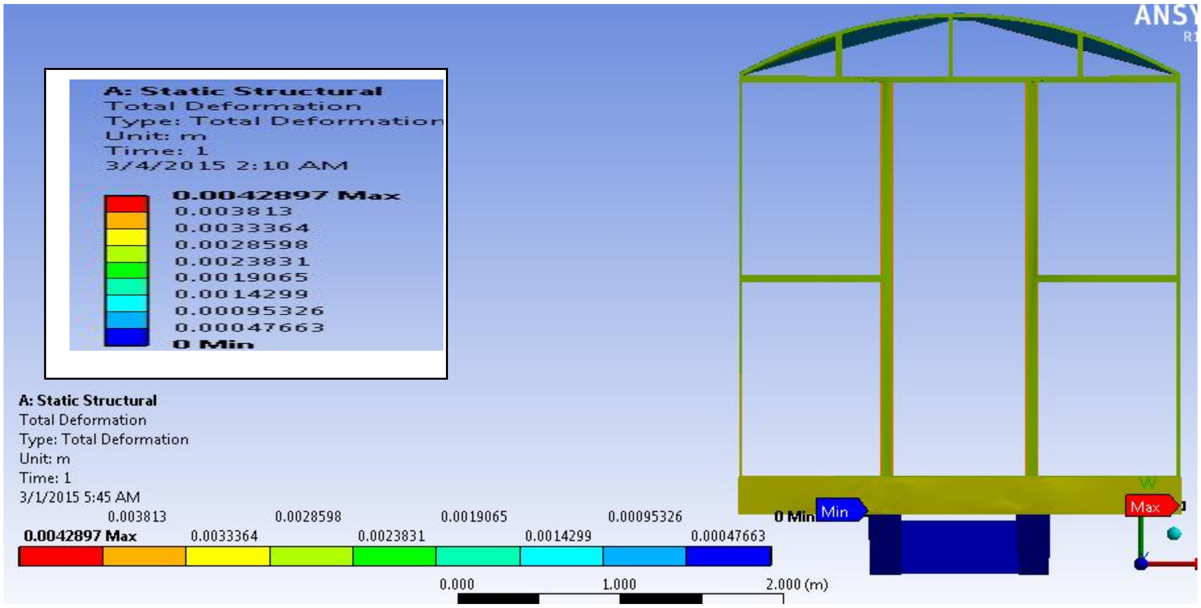


Fig 5.7.Total deformation of Rail vehicle structure-frontal view

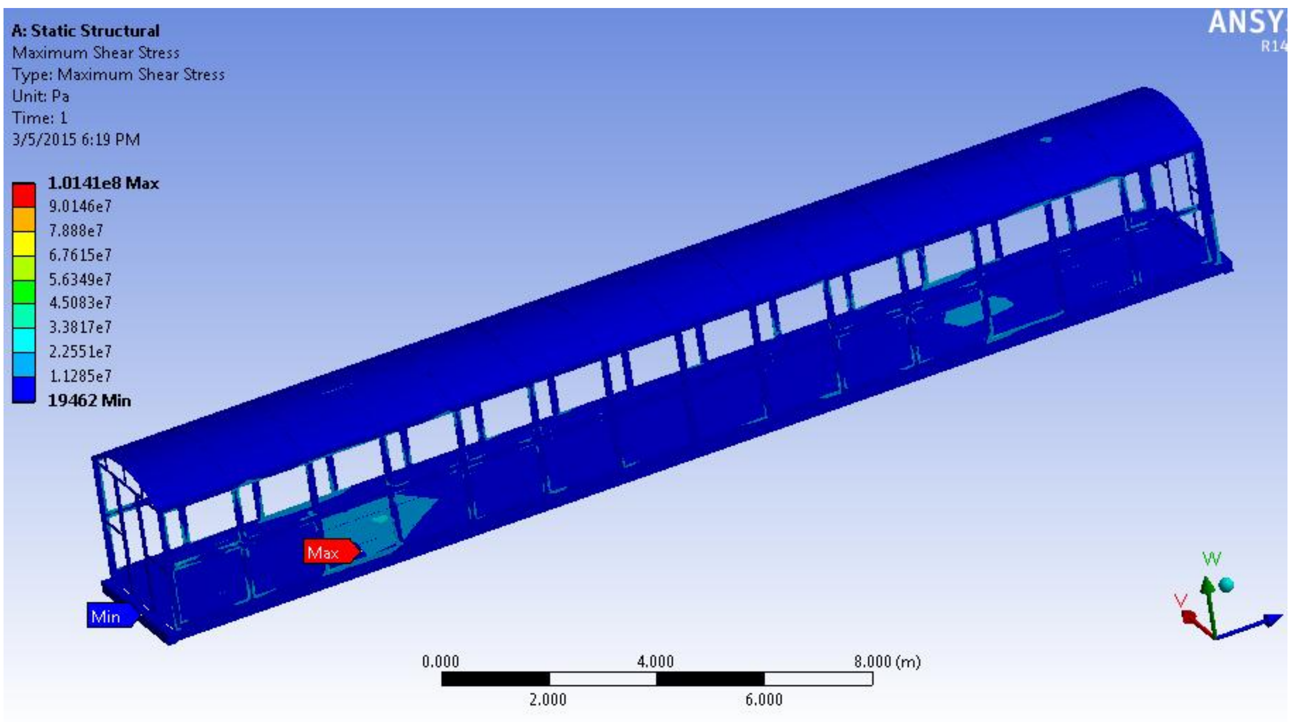


Fig 5.8.Maximum shear stress of rail vehicle car body-Isometric view

5.2.2. Modal analysis results

A modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It can also serve as a starting point for another, more detailed, dynamically is, such as random vibration, transient dynamic analysis, a harmonic response analysis. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. In addition, a modal analysis can be done on a pre-stressed structure, such as a spinning turbine blade.

The intention of computer simulation is to predict the behavior of a component or vehicle under given loading conditions, before manufacture 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 placed on them in service. Beyond this analysis, however, as described previously, the dynamic behaviour 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) software can give real benefits. Whereas finite-element analysis looks at the stresses and deflections of parts, to ensure that they are strong enough for their intended, MBS software packages look at the dynamic behavior and interaction of mechanisms and systems, under loads and conditions that replicate real life. Computer simulation, if applied properly, brings many benefits to the analysis of static and dynamic systems.

The tool, known as modal analysis, has its basis in the fact that every mechanical structure exhibits natural modes of dynamic response and these modes can be readily computed given the elastic and inertia characteristics of the structure.

Modal analysis is performed on finite element models and can be added in the same run to all the other load cases. All fitted structures are designed with sufficient modal separation to avoid coupling. Since the modal analysis can be part of the same run as the linear static analysis, structural optimization can be performed while using design variables from the linear static solution in combination with in normal mode solution.

In rail vehicle modeling often a right handed triad is adopted

X – Longitudinal translation, positive in the forward direction

Y – Lateral translation, positive to the right

Z– Vertical translation, positive downward

T–Rotation about X-axis (roll), positive clockwise

P– Rotation about the Y-axis (pitch), positive clockwise w – rotation about Z axis (yaw), positive clockwise

Typical flexible modes that are interesting when focusing on vertical ride comfort are the first vertical bending mode, first torsion mode (torsional motion along the longitudinal axis) and the first so-called breathing mode, resulting from cross-sectional shear. Normally, the frequencies for the first flexible modes lie in the range of 8–15Hz, however, depending on the vehicle configuration and settings. The higher the eigen frequency, the more complex the mode shapes. To avoid resonance between rail vehicle car body and bogie, the lowest possible bending frequency of the car body is determined by the eigen frequencies of bounce and first bending mode of the bogie.

According to present standards, humans are mainly sensitive to vertical vibrations in the interval of 5 to 15Hz. The sensitivity reaches a maximum approximately at 8Hz. Human beings are sensitive to lateral vibrations in the interval of 1 to 2Hz. Therefore, to secure good ride comfort, it is of importance not to let the eigen frequencies of the rail vehicle car body to coincide with this sensitivity range. As mentioned before, the first vertical bending mode has the largest influence on vertical ride comfort. A theoretical vehicle model with rigid and flexible car body modes is used. When the structural stiffness of the car body is decreased, so are the bending frequencies, and there is a risk of significant vibrations in the rail vehicle car body.

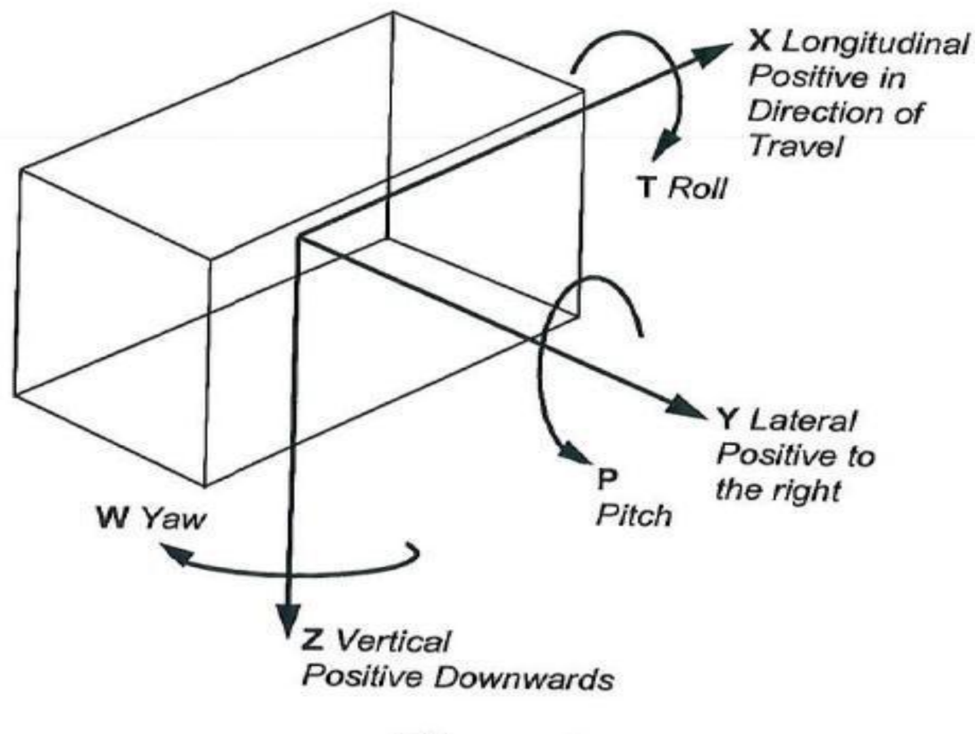


Fig .5.9.Axis system for vibration modes

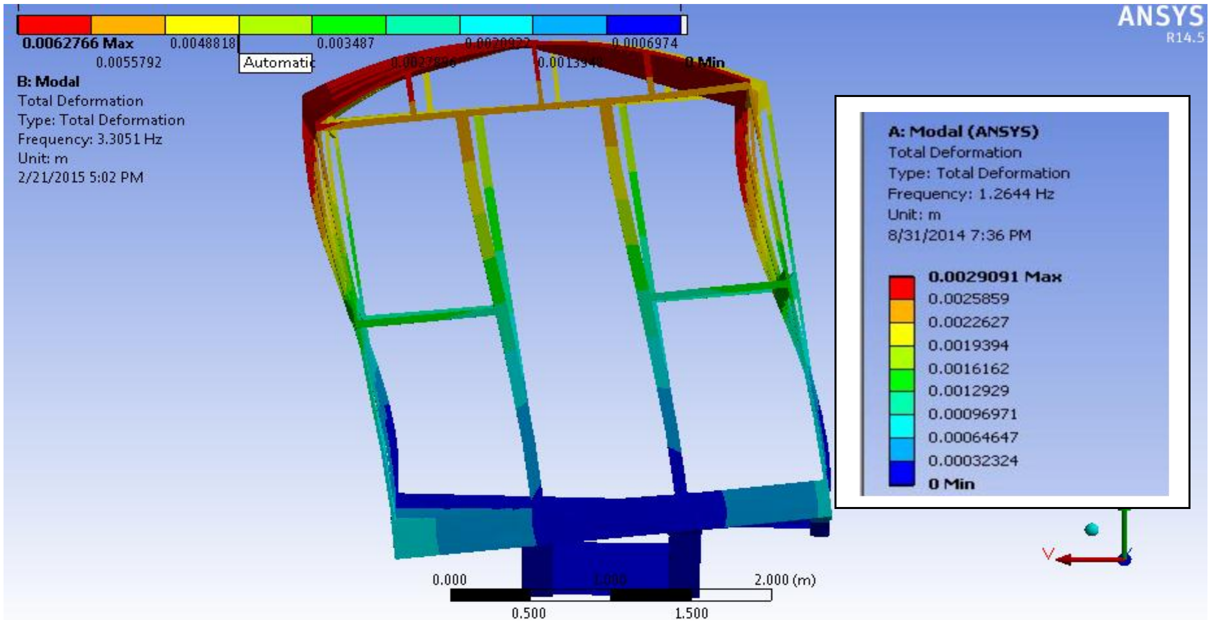
When the rail vehicle car body structure flexibility is modeled in the flexible multi body algorithms using experimentally identified modal characteristics, standard modal analysis techniques can be used to determine the rail vehicle car body modal parameters such as the natural frequencies, mode shapes, and modal damping coefficients.

A detailed rail vehicle car body structure is idealized using the finite element analysis software ANSYS (Version14.5). Finer meshes are used to prevent any possible stress concentration effects. The stress-strain histories at the critical areas of the car body structure are calculated. The modal frequency of the structural body is also obtained using modal analysis techniques.

Results for the Modal analysis of rail vehicle car body structure are listed below. The six lowest mode shapes and undamped frequencies of the studied passenger rail vehicle car body is shown in the table below.

Table 5.2. Modal frequency and displacement of rail vehicle car body

No.	**Mode shape**	**Frequency (Hz)**	**Max. deformation(m)**
1	1stlateral bending	1.2644	0.0029
2	Torsion 1	1.6898	0.0048
3	longitudinal bending	3.501 Hz	0.0028
4	vertical bending	5.84821Hz	0.0042
5	Torsion 2	10.625Hz	0.0064
6	2ndLateral bending2	11.047Hz	0.0071



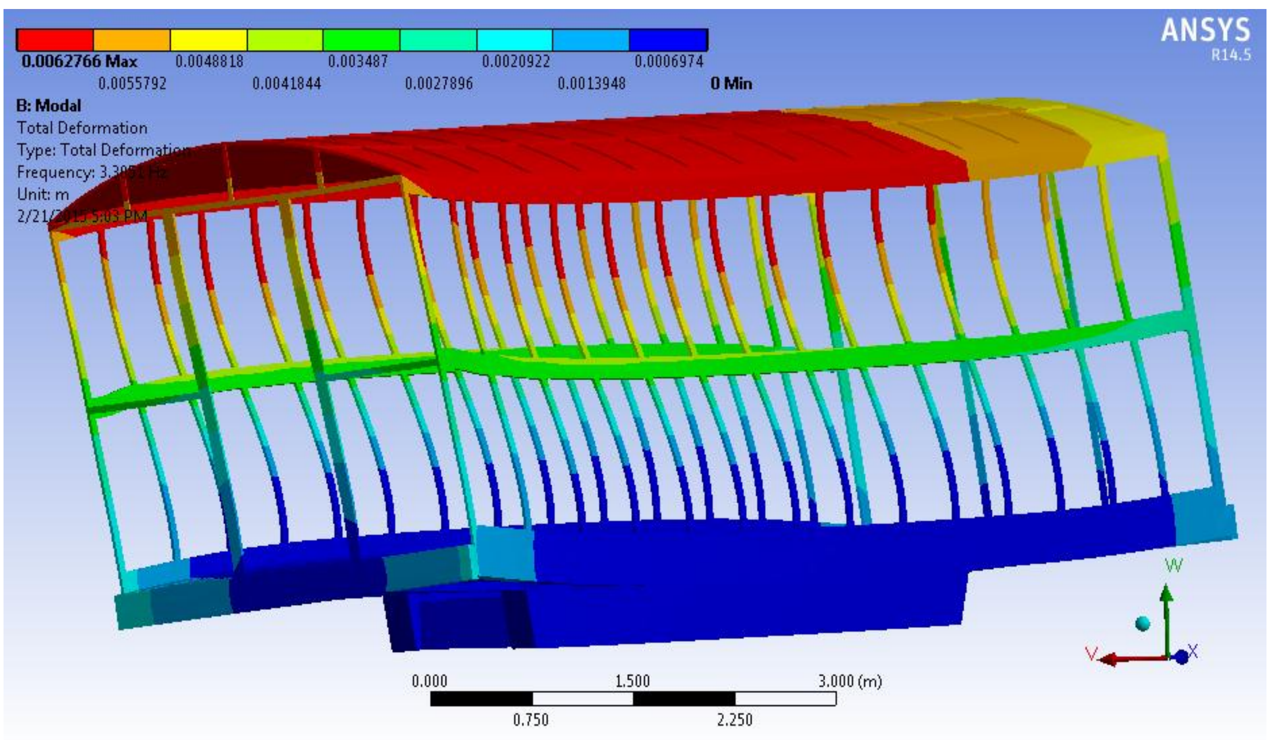


Fig. 5.10.FirstLateral bending mode shape (3.3051Hz)

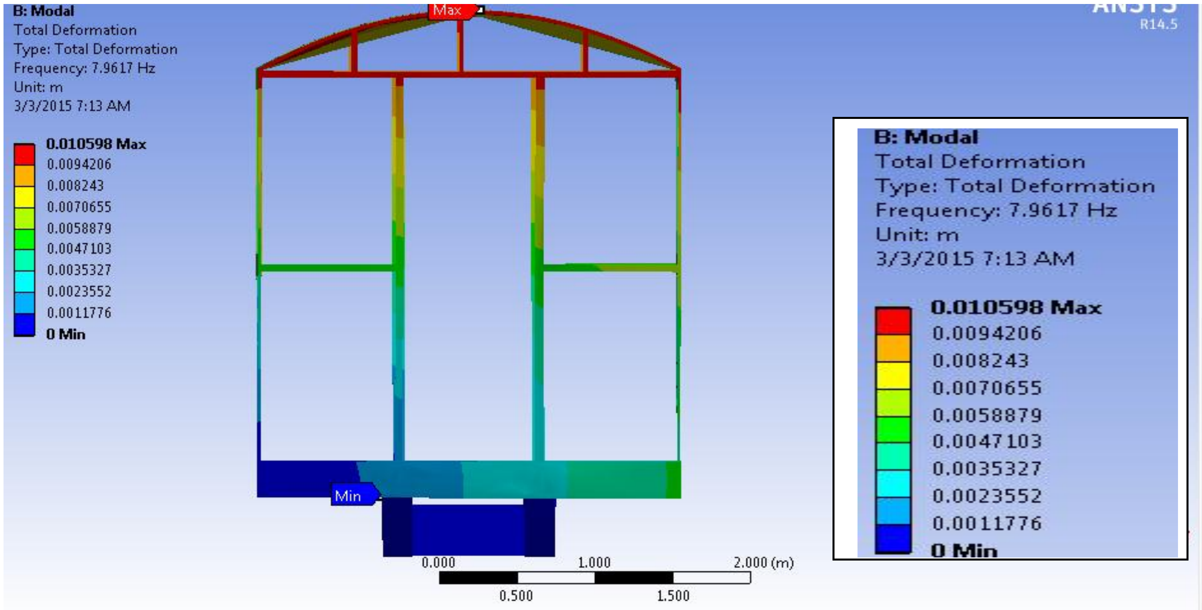


Fig 5.11frontal view first torsion mode (7.9617Hz)

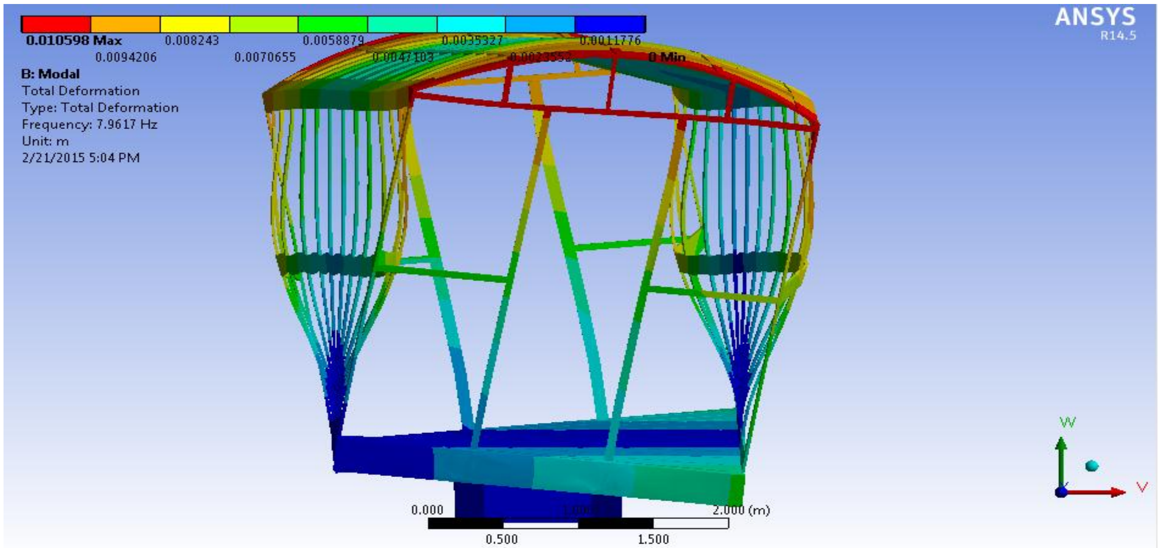


Fig 5.12 First torsion mode (7.9617Hz)

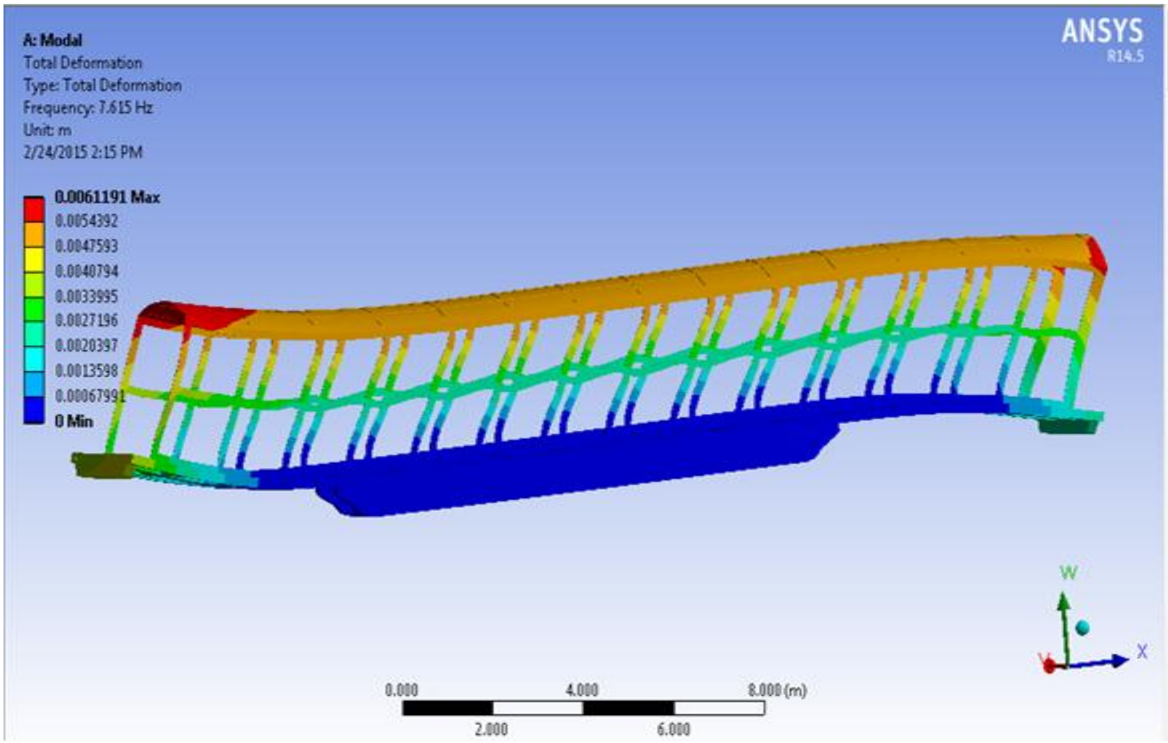


Fig. 5.13.FirstLateral bending mode shape (7.615Hz)

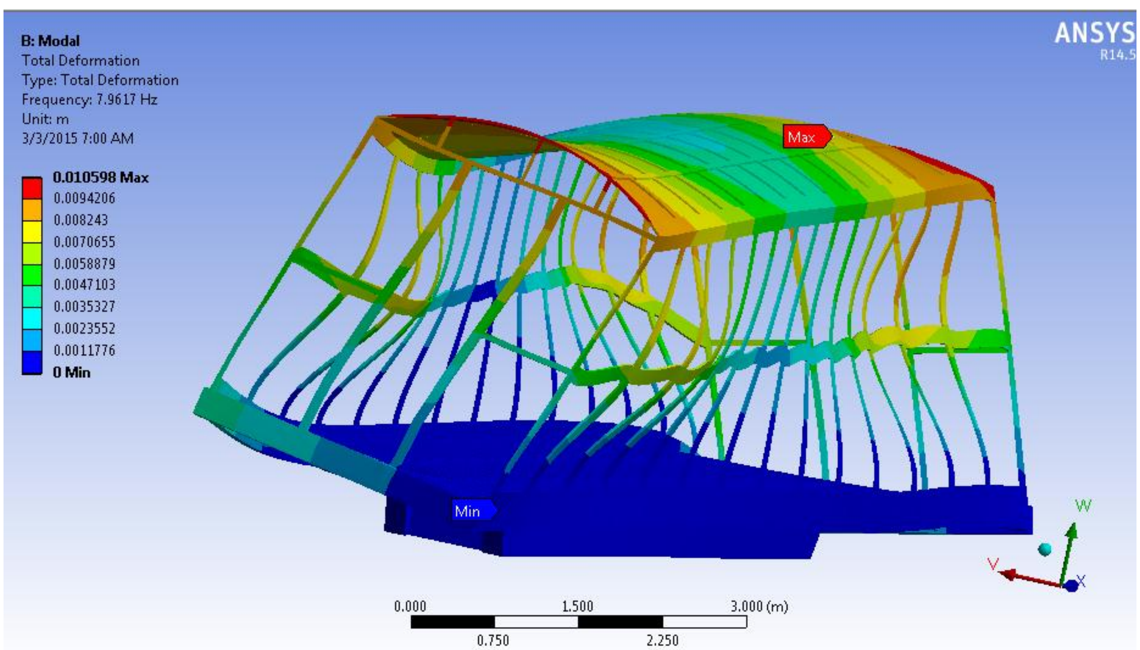


Fig. 5.14.Longitudinal mode shape (7.615Hz)

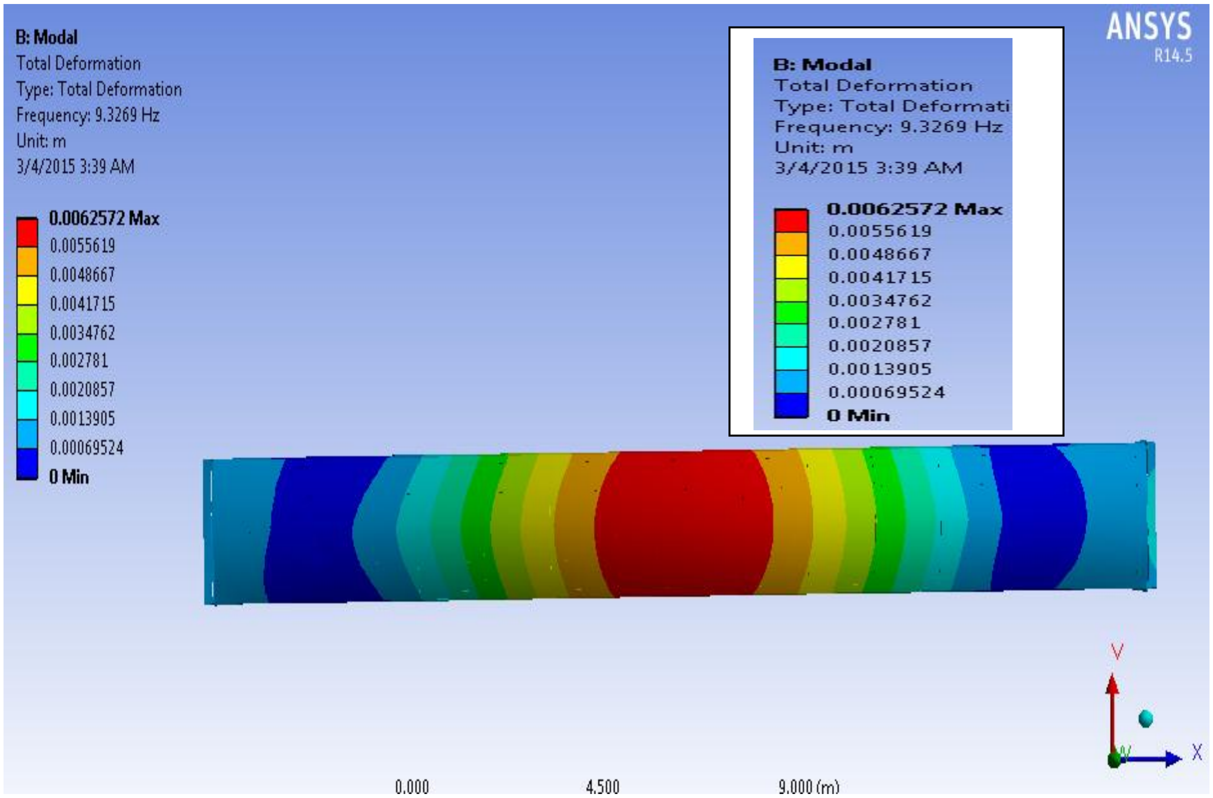


Fig 5.15.First vertical bending (9.3269Hz) top view

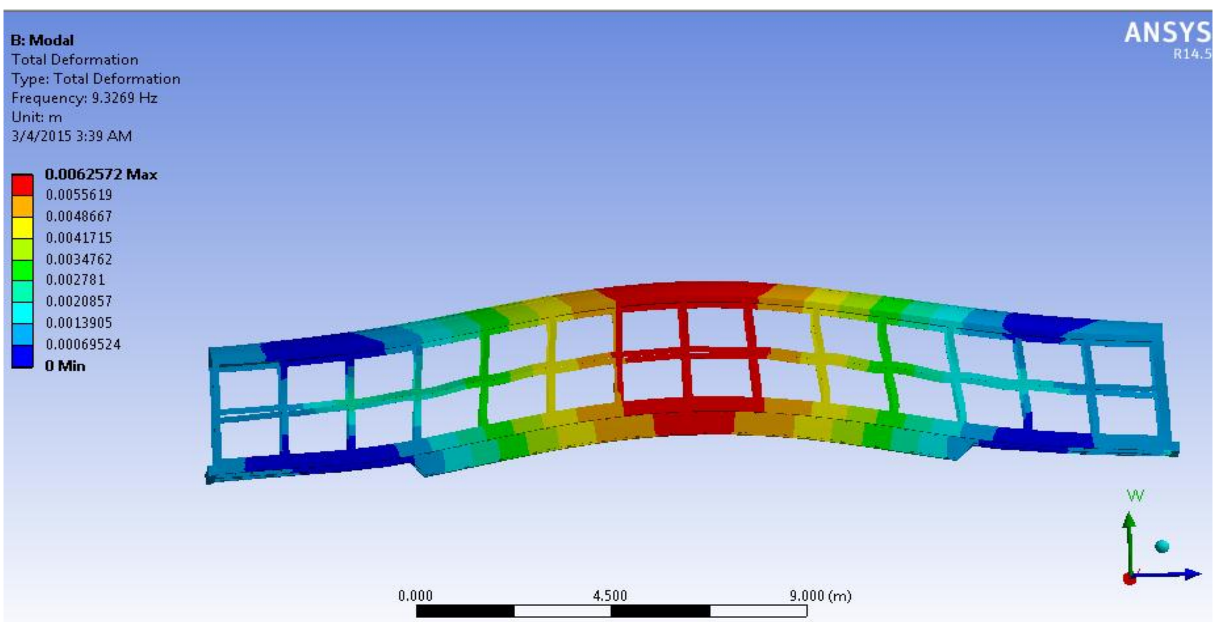


Fig 5.16.First vertical bending (9.3269Hz)

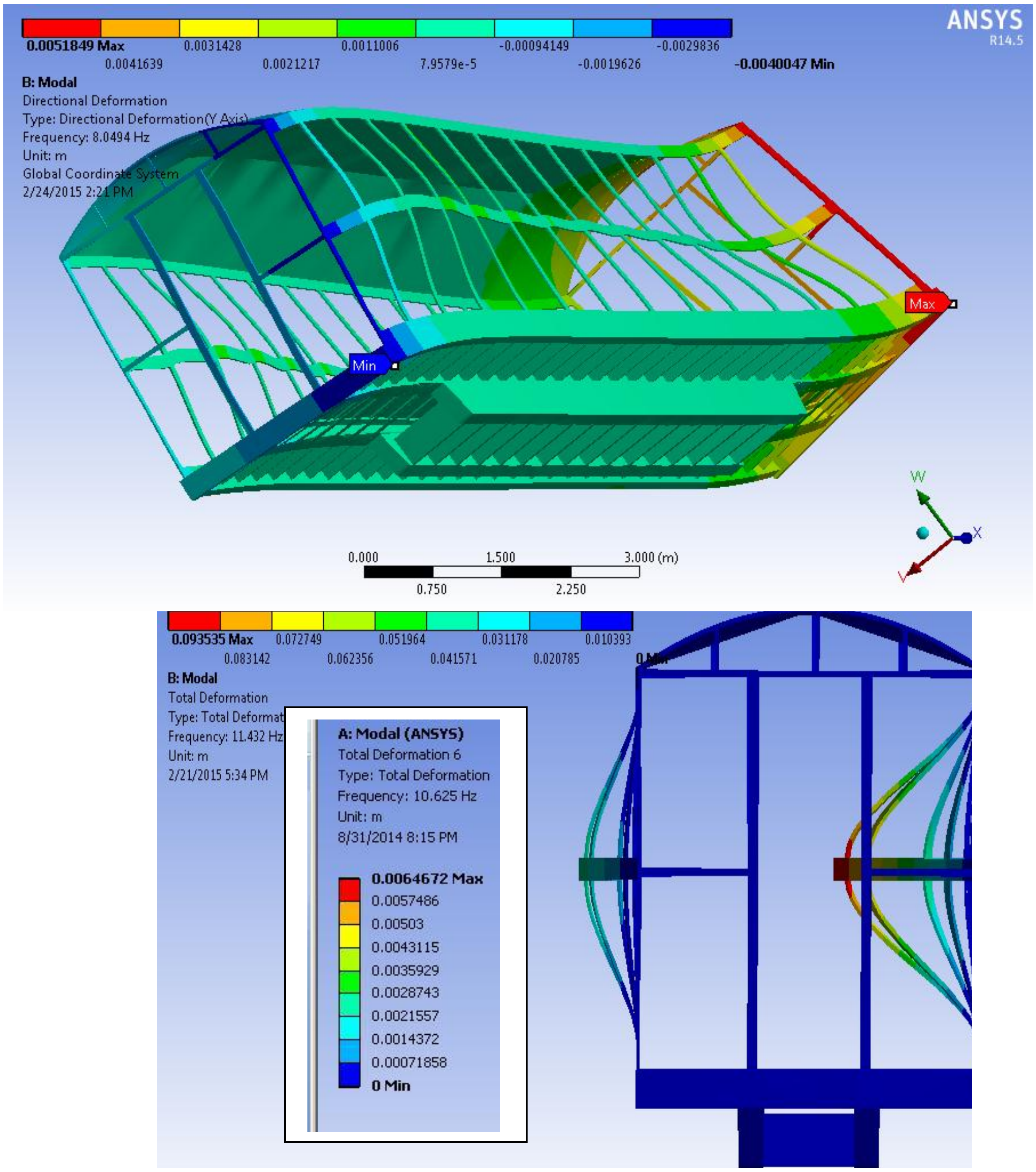
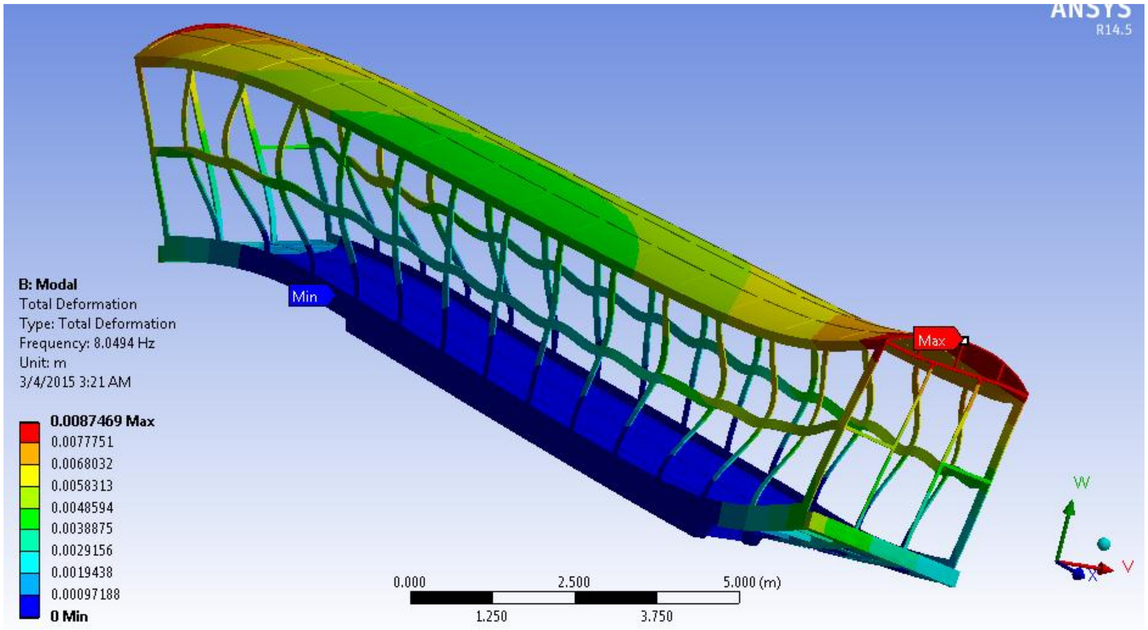


Fig.5.17. Second Torsion mode (10.625Hz)



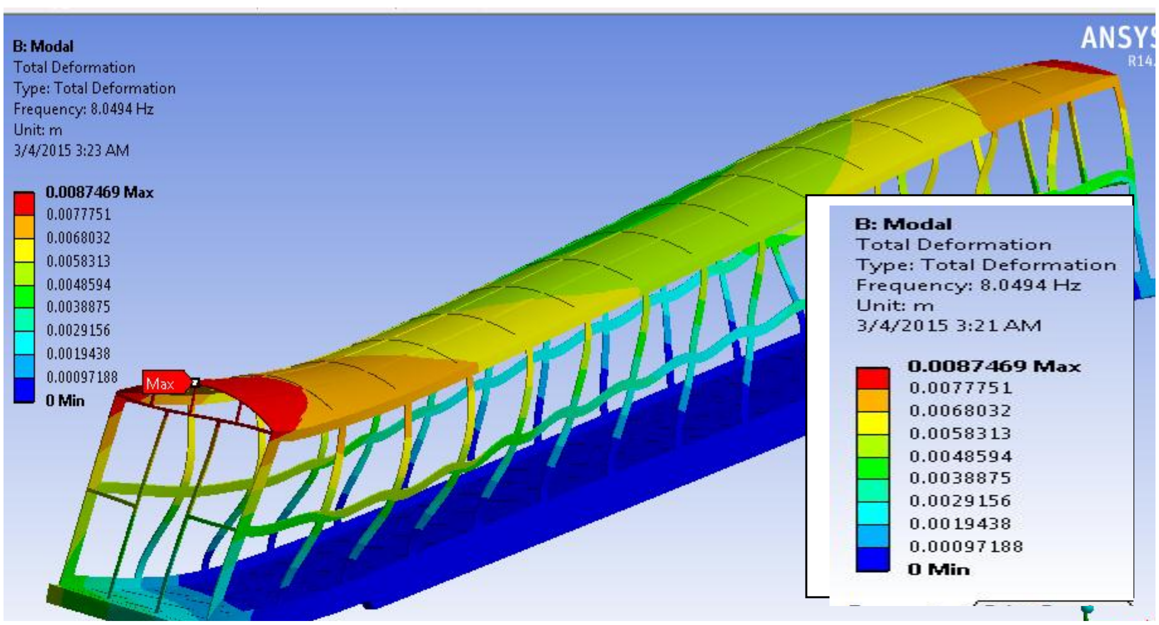


Fig 5.18.Second lateral bending mode (8.0494Hz)

The first6Mode shapes and frequency of the rail vehicle

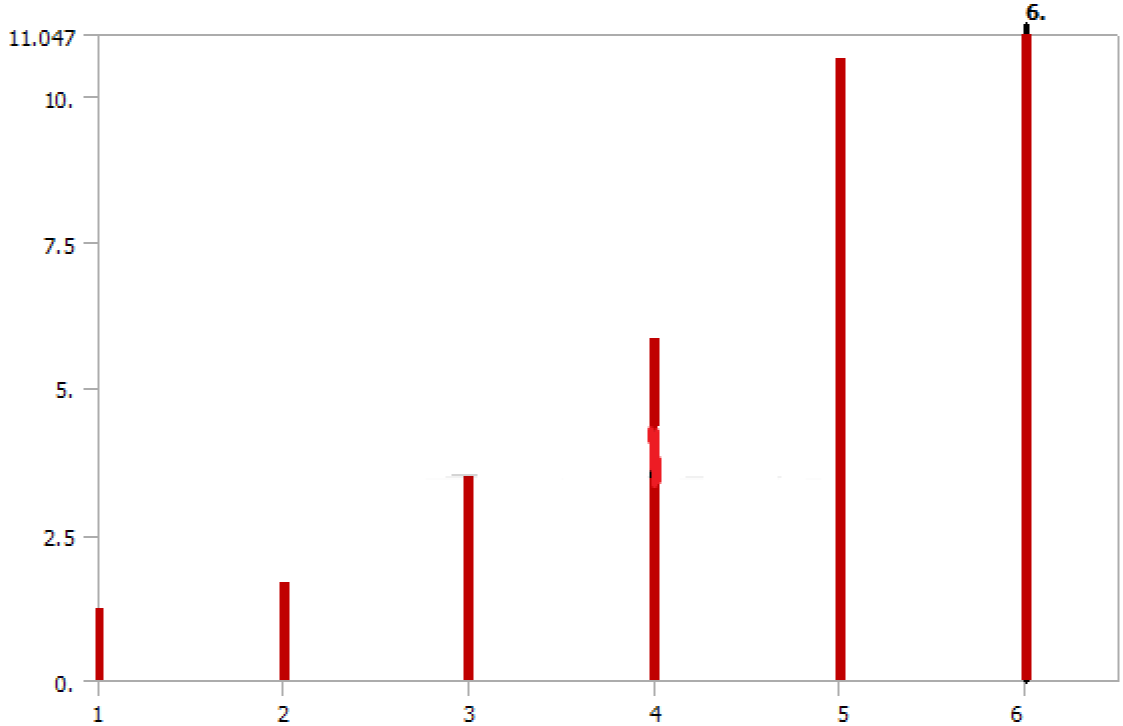


Fig 5.19.Response of passenger rail vehicle towards compressive & vertical load

CHAPTER SIX

6. Conclusion and Recommendation

This research focuses on the study of rail car body by doing the structural analysis using finite element method.

6.1 CONCLUSION

The conclusions that are drawn from this research are:

- The center sill, particularly, part of the under frame where there is change in cross-section is affected most by static loads. The center sill section's yield stress is 460Mpa(St 36) whereas the load at that particular cros-section is124.57Mpa.
- The structural flexibility of the carbody must be taken into account when predicting vertical vibration comfort.
- The maximum deformation is 4.289mmthe rail vehicle structure occurs at the midway of span is within the allowed range of 1/700-1/1000 for structural beams and members. Hence; mathematically, the design is valid.

Passengers boarding this rail vehicle car are exposed to a vibration frequency ranging from 1.264-11.04Hz. This result is the natural frequency of the vehicle itself and is inevitable. Especially, the vertical bending mode having frequency of 5.8482Hz is the primary concern as it is within the sensitivity range of human beings in vertical ride comfort.

Rigid vibration modes of the first lateral bending (1.2644Hz) and first torsion (1.6898Hz) are also in the sensitive frequency range. However, this is considered little concern compared to the vertical bending mode.

6.2. RECOMMENDATIONS

The rail vehicle body shall be designed as stiff as possible to resist the incoming compressive, vertical, quasi static, vibration stress and as the same time provide comfort to the passenger on board. The appropriate material must be selected for rail vehicle body to reduce the weight and increase the strength of rail vehicle body and improve the comfort of the passenger. However, this passenger rail vehicle structure is made out of steel of different profile that is believed to be available on the market with low cost. Even thought, it increases the dead load, operational cost, and efficiency of passenger rail vehicle. It is recommended to use more strong and lightweight structures which area esthetically, structurally, and operationally viable.

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

- Make the car body as short as possible. However, this conflicts with the desire to maximize the number of passengers in relation to the number of bogies.
- The sheet metal which is covered on the structure should be included in the finite element analysis in order to find a more refined result.
- Use stiffer carbody materials or design resulting in high car body stiffness. This is, however contradictory with the requirement of lightweight car bodies.

6.3. FUTURE WORK

- Crashworthiness analysis of passenger rail vehicle carbody structure
- Dynamic analysis of passenger rail vehicle car.
- Optimization of passenger rail vehicle structural members.
- Fatigue analysis of passenger rail vehicle carbody

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