ADDIS ABABA UNIVERSITY

Addis Ababa Institute of technology (AAIT)

SCHOOL OF MECHANICAL & INDUSTRIAL ENGINEERING

Overload effect on the lifecycle of car body under frame steel structure for AALRT trains

Thesis submitted to the Addis Ababa Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Railway Mechanical Engineering

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Declaration of the Student and her advisors approval

I hereby declare that the work which is being presented in this thesis entitled **"**Overload effect on the lifecycle of car body steel structure for AALRT TRAINS**"** is original work of my own, has not been presented for a degree in any other university; and that all sources of material used for the thesis have been duly acknowledged.

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Acknowledgement

First of all I would like to thank God for all the extra energy He has given me in this work.

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Abstract

Ethiopian railways corporation invest a lot of money and construct AALRT and it's warmly welcomed by the people. Since it is been 1 and half year the trains start working, And even if the design life cycle of AALRT train car body structure should not be less than 30 years, train's body start to degrade from day to day. This will be a problem for AALRT in terms of quality of service, in terms of maintenance cost and damage of train body before design life cycle.

This paper aims to discuss the effect of un acceptable passenger over load effect on life cycle of AALRT train car body steel structure and show the effect of different loading conditions by modeling car body steel structure and making analysis using Catia and Ansys software .

The methodology of this paper starts by collected real overload condition data's, studied car body frame structure and materials used for AALRT trains, designed frame steel structure of AALRT train using Catia V5R19 software and analyzed by Ansys workbench 15.0 software using seven different loading conditions. The total fatigue life analyzed by using Palmgren-Miner Linear Damage Rule and the final fatigue life cycle result found. The calculated life cycle result converted to time.

The output of the analysis shows that some parts of under frame steel structures on Exit/Entrance area have fewer life cycles. The connection of the high floor and low floor area and near to turning table have less life cycle than design life, when the loading condition reach at maximum level . But the total life cycle is above from the design life.

Finally the total fatigue life cycle of four parts on Motor car had below the design life cycle. By adding additional reinforcement to those four parts, it is possible to increase the fatigue life. Even it can resist the over load at standing and seat area beyond designed load limit.

Key words: AALRT, over loading, Catia, Ansys workbench, Life cycle

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NOMENCLATURE

AALRT Addis Ababa light rail transit

ERC Ethiopian railway corporation

GRP glass reinforced plastic (fiber glass)

LRV light rail vehicle

Mc motor car

Tc trailer car structure

$W_{overall}$ weight of railway vehicle

$W_{motor\ bogie}$ weight of motor car bogie

$W_{trailer\ bogie}$ weight of trailer bogie

$W_{structure}$ weight of steel structure

Chapter One

Introduction

1.1 Background

The history of rail transport, including systems with man or horse power, and tracks or guides made of stone or wood, dates to as early as Greek times. The first trains were Single wagons pushed or pulled by people or animals, and were used to move goods, such as coal. Steam trains were the first type of trains. They use coal in firebox to boil water until it turns to steam. The steam is forced through powerful pistons to give the engine the power to drive the wheels. At first, steam engines moved mainly goods, but were soon used to carry passengers as well. Steam engines are still in use all over the world, although most have been replaced by diesel or electric trains. Diesel locomotives were first introduced in Australia in the 1930's.[14]

In the 1880s, electrified trains were introduced, and also the first tramways and rapid transit systems came into being. Starting during the 1940s, the non-electrified railways in most countries had their steam locomotives replaced by diesel-electric locomotives, with the process being almost complete by 2000. During the 1960s, electrified high-speed railway systems were introduced in Japan and later in some other countries.[15]

The railway transport system is one of the most crucial transport systems in the world with mass transport, very high speed, safety and durability. Now a day, there is a high demand of railway transportation systems in the world including in Ethiopia for a short and long distance transport of passengers and goods. Ethiopia has launched the construction of a 5,000 km railway network which aims to link the capital, Addis Ababa, to various regions of the country which is part of the country's five-year transformation plan (Corporation, 2011). The new railroad network is planned to have at least 8 main routes that extends to all compass points. [1]The Addis Ababa LRT is also the part of the plan.This project is Electrified light rail transit, total length of 34.25 km (North-South line 16.9 km and East-West line 17.35 km),two lines (i.e. North-South and East-West lines) use common track of about 2.7km., Standard Gauge (1.435 meters) and Double track for the whole route ,Capacity of 80,000 PPH (Passenger/hr). Special Features of the Project is Performs on steep gradient and sharp curves ,Urban Mass Transport for Addis Ababa city Enhances the image of Addis Ababa as the political capital of Africa and Reduces carbon dioxide emission (It's environmentally friendly) .[1] Light rail transit(LRT) is designed to accommodate a variety of environments, including streets, freeway medians, railroad rights-of-way (operating or abandoned), pedestrian malls, underground or aerial structures, and even in the beds of drained canals. It is this characteristic that most clearly distinguishes it from other rail modes. Because of this design flexibility, LRT generally is less costly to build and operate than other fixed-guide way modes[9]

Design lifecycle of Addis Ababa light rail transit(AALRT) vehicle(train) car body steel structure should not be less than 30 years[5]. The lifecycle of the steel structure depends on environment ,static strength, dynamic strength and fatigue strength . Fatigue failures often result from applied stress levels significantly below those necessary to cause static failure. Fatigue, or metal fatigue, is the failure of a component as a result of cyclic stress. The failure occurs in three phases: crack initiation, crack propagation, and catastrophic overload failure. The duration of each of these three phases depends on many factors including fundamental raw material characteristics, magnitude and orientation of applied stresses, processing history, etc[2]

1.2 Statement of the problem

Maximum design passenger overload capacity of AALRT train car body is: standing 8 persons/m^2 with 65 seated person19.02 ton (assume take 60 Kg average per passenger). But nowadays practically at peak hours the vehicle carrying up to 10 persons/m^2 standing and 89 seated persons. This passenger weight is greater than from the design passenger overload capacity and it is unacceptable over load effect. This thesis concentrated on the change of the lifecycle of the car body steel structure which depends only by overloaded passengers weight. At last the research comes up with what actions to be taken to maximize the life cycle of the structure and to minimize overload effect

1.3 Objective

1.3.1 General objective

To investigate change of the lifecycle of car body steel structure considering the current unacceptable overload passenger weight and compare the result to the design lifecycle. And also what action to be taken to maximize the life cycle and minimize overload effect.

1.3.2 Specific Objectives is as listed below

- analysis of the passenger load at a time
- identify the critical areas of the structure
- analysis of the stress, fatigue life depend on passenger load at a time
- gather the results and analysis the mean life cycle on Matlab

1.4 Scope and Limitation

Scope

The study is mainly focus on estimating the life cycle of car body steel structure specifically the under frame steel structure for AALRT trains depend on passenger over load i.e 89 seated with 10 persons/m^2 standing passenger (vertical passenger load) effect.

Limitations

This thesis project was intended to find only overload effect on the life cycle of car body structure for Addis Ababa light rail transit(AALRT) vehicle(train). But lifecycle of car body steel structure minimize not only by overload effect but also it depends on environment ,static strength and dynamic strength. In this project the other effects are not included.

1.5 Research methodology

- Data collection

Data will be collected from ERC

- What type of material is used to build the car body steel structure, it's Ultimate strength ,yield strength etc
- Full dimension of the car body steel structure with thickness.
- Number of passenger in different time per day from cctv camera inside the car saloon

- Modeling

The car body steel structure will be modeled similar to the real one on Catia V5 software and it's dimension will be the collected data .

- Method of analysis
- Analysis will be performed by Ansys software the passenger load is calculated by number of passenger at a time (average load take 60 Kg per passenger)
- The result is different at each time to investigate the desired value ,the Ansys value at each time is analyze by Matlab software.
- Observe and discus the simulation and Matlab results and give brief discussion
- Write conclusion, recommendation and future works

1.6 Organization of the Study

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.

Different literatures related to fatigue analysis of rail vehicle car body is discussed in chapter two; chapter three deals with brief introduction about Addis Ababa light rail transit . Chapter four deals with modeling and analysis of Addis Ababa light rail train steel structure . The fifth chapter is about the research result and discussion that deals with the presentation of the research finding and the last chapter deals with conclusion and recommendation which presents conclusion, contribution of the thesis and puts forward recommendations and future work.

Chapter Two

Literature review

2.1 fatigue analysis

Based on[8] the most common mode of fatigue failure consists simply of initiation and propagation of cracks to the point of static failure. A degradation of material properties during fatigue is not normally observed.

Superimposed on the general response of the material to cyclic loading, i.e. hardening or softening depending on the material, the load amplitude and the temperature, localized plastic deformation develops at stress concentration points. This repeated, localized plastic deformation leads to crack initiation. Provided the local stress concentration exceeds a certain threshold, a fatigue crack, once initiated, continues to grow a finite amount during each cycle

[7]indicated that There are three main factors, which affect the structure fatigue behavior: The S-N curve of structural components; the load time histories; and structural geometrical features. The car body structure of railway vehicle is subjected to a very large number of variable amplitude stress cycles during their operational life. Large structural stress and complex load conditions are the main causes which lead to vehicle structural components' fatigue crack initiation and crack growth.

According to[6] The fatigue life of a component is governed by the loading environment to which it is subject, the distribution of stresses and strains arising from that environment, and the response of the material from which it is manufactured. As a result, the major inputs to any fatigue analysis are component geometry, service loading, and cyclic material properties. These data are combined in the fatigue analysis process to estimate life

Geometry

In the context of fatigue analysis the term geometry is often used to describe how loads are transformed into stresses and strains at a particular point in a component. The geometry is the function between the externally applied load(s) and the local stress. The effect of geometry may be determined in either one of two ways. Firstly, by means of an elastic stress concentration factor, Kt and secondly, by means of finite element analysis.

material

Another major input to fatigue analysis is a definition of how a material behaves under cyclic loading conditions. Cyclic material properties are used to calculate elastic-plastic stress-strain response and the rate at which fatigue damage accrues due to each fatigue cycle. The material parameters required depend on the analysis methodology being used. Normally, these parameters are measured experimentally and may also be available in various handbooks and other publications. In situations where specific data are not readily available, approximate values may be deduced from static tensile properties such as ultimate tensile strength and ductility.

Fatigue Analysis

Fatigue analyses can be undertaken by using of one of three basic methodologies, i.e. the stress-life method, the strain-life method, and linear elastic fracture mechanics.

The stress-life approach considers nominal elastic stresses and how they are related to life particularly in situations where large numbers of cycles (greater than 105) are involved. Life is usually associated with catastrophic failure.

The strain-life methodology considers elastic-plastic local stresses and strains. It represents a more fundamental approach and is used to determine the number of cycles required to initiate an engineering crack.

Fatigue Results

Fatigue results are usually expressed in terms of the numbers of cycles, or repeats of particular loading sequences, required to reach a specified failure criterion at a location. Sometimes these values are associated with physical quantities such as hours, miles or fractions of a durability route. These results are, of course, sensitive to each of the major inputs: loading, geometry and material.

For the strength reliability, one of the important study themes is the strength or fatigue characteristic of each railway system component that is subject to repeated loads during use. The reason why it is necessary to consider the fatigue characteristic carefully is that fatigue is a microscopic fracture caused by the initiation and propagation of a crack due to a cyclic slip deformation of the size of a single grain, that fatigue occurs even under a stress smaller than the strength characteristic under a static load (e.g., tensile strength), and that it can suddenly lead to a fatal fracture without causing any macroscopic plastic deformation. Incidentally, fatigue characteristic is important not only to railways but also to many other machines and structures. In the 1860s, Wöhler of Germany conducted a systematic experiment to evaluate the fatigue of steam locomotive axles and studied the stress (S) -life (N) relationship, which is used even today as the most basic fatigue characteristic data. Since he established the foundation for the study of fatigue, the author feels a strong connection between fatigue and railway.[4]

2.2 Car body Structure

Railcar shells are typically designed to meet or exceed a 30-35 year life. They can go through several overhauls of the railcar systems during that time, with minimum consideration given to the railcar body structure. Near the end of the design life however, a closer look at the railcar body structure may be warranted. Conservative structural design usually places the railcar structure to the safe side of the specified life expectancy, yet the stress analyses and stress tests performed on railcar structures never show the entire structure to be stressed evenly. As a result, the cumulative damage due to repeated cyclical stress on the structure will accumulate differently throughout the vehicle. High stress areas may have less remaining life than areas conforming to the predicted stress loads. The critical areas are mostly located at a transition points between the relatively stiff end under frame structure of the car and the relatively flexible central under frame, mostly at the lower and upper door corners. This is also area of the expected highest vertical inflections. The car body twist and the vertical passenger loads are the loads responsible for such a stress concentration.[3]

The railway vehicles are mainly adopt carbon steel, stainless steel and aluminum alloy so far. There are many factors to affect vehicle operation cost, but in this point of view for the car body operating materials, according to domestic experience, the total cost for operation of stainless steel during service life shall be the minimum. Due to light weight, the stainless steel car body shall be long service lift, light weight, without painting and free of maintenance, and it has large development abroad.

The 70% Low-floor LRV for Addis Ababa, Ethiopia adopts frame bearing and adhesion exterior wall panel car body, and the general design of car body shall meet with requirement of basic function, as well as high quality and light weight. Meanwhile, the car body strength (incl. fatigue strength), rigidness shall bear dead load, vertical load and longitudinal load produced by traction and brake system. The car body strength shall meet with EN12663 standard.[19]

The vehicle body of the Addis Ababa light rail project in Ethiopia is mainly composed of two Mc modules and Tp modules, and the three modules are connected by hinges. Mc module body structure is composed of end wall steel structure, side wall steel structure, bottom frame steel structure, roof steel structure. Wherein the end wall comprises an end wall steel structure and two end wall steel structures. An end-wall steel structure includes the driver's room hood and front-end frame.[18]

2.3 Modeling and Analysis

[8]Every model used to estimate the fatigue life of a structural component under variable or random amplitudes from respective data of constant amplitude tests is confronted by the fact that damage mechanisms and with them the crack initiation or propagation conditions may be altered. Despite these inherent difficulties estimation procedures are often necessary either in a preliminary design stadium or because of the extreme cost of service behavior tests as already mentioned. The purely physical way to explain fatigue failure has not yet led and will not lead in the near future to a satisfactory all-encompassing model. So it is only understandable that it has been attempted to look upon damage as an irreversible process, governed by the number and magnitude of single, consecutive load cycles. Thus the idea of the damage accumulation was formed, under which we understand the summation of partial damage per cycle, so that damage can be quantified and calculated.

[20] says Railway vehicles are assessed for a large number of loads. Inertia loading, forces, pressures and moments are all used in combination to create a multitude of load cases. The Hyper Mesh load steps browser gives a clear and organized solution to generate load cases that uses various load types and factors. For each load case, boundary conditions are defined and sometimes symmetry constraints are used to reduce the number of modeled elements. This is commonly used through the car body length as the vehicle is usually assumed symmetrical along its width.

Due to the nature of railway structures symmetry boundary conditions are often created. This allows a reduction of the solving time by limiting the number of elements. If loading should only be applied on one side of the structure, the symmetrical side of the loading can be cancelled using linear superposition. It is achieved by running two load cases which are then superposed in order to remove the unwanted side of the loading at the post-processing stage of the analysis with Hyper View. Some structures rely on the appropriate contact condition between components. Contacts are Once the fatigue loading event is created with its own number of occurrences, it is interpreted and created as an FE fatigue load case in Hyper Mesh. Principal stresses are calculated and magnitude of stress with vector direction is displayed with Hyper View. Each stressed location is assessed against the allowable of the corresponding class of the design detail. Damage is calculated for each fatigue load case and Miner's summation is used to determine the cumulative fatigue damage.[20]

[11]indicate that Fatigue, by definition, is caused by changing the load on a component over time. Thus, unlike the static stress safety tools, which perform calculations for a single stress, fatigue damage occurs when the stress at a point changes over time. ANSYS can perform fatigue calculations for either constant amplitude loading or proportional non-constant amplitude loading. A scale factor can be applied to the base loading if desired. This option, located under the “Loading” section in the details view, is useful to see the effects of different finite element load magnitudes without having to re-run the stress analysis.

Chapter three

3.1 Brief Introduction about Addis Ababa Light Rail Train

Addis Ababa light rail project is comprised of east-west line and north – south line which belongs to the city traffic system of semi closed. The total length of planning line is 75Km and divided in to two phases. the first phase of the project implementation of the project is about 31.025Km length for line, there into about 16.998km for east –west line and about 16.689km for north-south line. Two lines in the down town area will run in the same rail and the rail length is about 2.662km[18]

The north end of the north south line of the first phase is considered as the starting point from the east of St.George Church to the south terminal end of Kality .subgrade section is about 10.057km long, elevated section is about 5.977km long(including the 2.662km share rail section); the underground length is about 0.665km.there are total of 22 stations including 8 overhead stations(including 5seat share rail station), 1 underground station, the rest is the ground station. And average station distance is 0.773km. kality depot is installed in north south line of the first phase project near the southern terminus[18]

The western end of the east west line of the first phase project is considered as the starting point, from south of Torhailoch hospital door ,through Mexico square, Meskel square ,Megenagna until the eastern end of Ayat. Subgrade section is about 12.891km long ,elevated section is about 3.91 km long(including the 2.662km share rail section),and the underground length is about 0.197km.there are total of 22 stations including 6 overhead stations(including 5seat share rail station), 1 underground station,1 semi underground station, the rest is the ground station. The largest space station 1.26km, the minimum distance between station is 0.435km; average station spacing is 0.798km. Ayat depot is installed near the east end of east west line project .[18]

Design principle[19]

Train is one of most important equipment in city traffic engineering and is the high –tech equipment and the key equipment of engineering cost and operating efficiency. It is advanced, reliability and practicality, meet the use environment ,traffic ,security, fast, comfortable, beautiful and energy requirements

When the engineering vehicle selection meets the operation condition and construction condition of this line ,at the same time ,combined with the actual local situation in Ethiopia ,Addis Ababa ,vehicle selection conforms to the following principles

1) the operation safety, reliability and comfort

2) using the new technology ,advanced and mature new technology, new material ,new tooling

3) to save energy and light weight design

4) The vehicle transport capacity meets the requirement s of the designed peak hour traffic of Ethiopia Addis Ababa light rail engineering.

5)low repair cost, convenient to repair and use

6)The service life is 30 years

7)The appearance

8)vehicle design meets the Ethiopia Addis Ababa area climate and natural conditions, suitable for the operation condition of Ethiopia Addis Ababa light rail vehicle engineering , and minimize the impact on surrounding environment as far as possible

9)the vehicle type selection of line is consistent, and it is convenient to share vehicles of each line, also be convenient for future operation and repair management.

The train weight and capacity

1)The maximum weight of the vehicle≤64t

2)The weight of the vehicle: ≤44t

3)The average axle load

- Motor car:≤10.5t
- Trailer car:≤11.5t

4) The train loading

Traction fixed state ,the standing passengers occupy 6persons/m^2 (AW2),for overcrowding state, standing passengers occupy 8 persons/m^2 (AW3) the average passenger weight is calculated as 60kg

3.2 Main parameters of lines[5]

- Track gauge: 1435mm
- Minimum radius of horizontal curve:
  - Mainlines between sections 50m
  - Yard line 30m
- Minimum radius of vertical curve: 1000m
- Maximum gradient: 5.5%
- Type of rails for main lines and depot: 50kg/m
  - Maximum superelevation: 120mm
  - Inclination at rail bottom: 1/40
  - Main lines and auxiliary lines adopt No.7 switches, the lines at yards adopt No.3 and No.7 switches.
- Axle load: ≤11（1+3%）t
- The vehicles adopt right-side running rules.
- Platform parameters
  - Platform height: 300mm
  - From platform edge to centerline of the line: 1420mm

Power supply

- Rated voltage: DC 750V
- Range of voltage variation: DC 500～900V
- Way of current collection: by catenary
- Height: Height of contact line for ground sections from top of rail is generally 4500 to 5400mm.

  Height of contact line for underground sections from top of rail is generally 4040mm.

Main technical indicators[5]

1. Speed

- Maximum operation speed: 70 km/h
- Average travelling speed: ≥20km/h (average dwelling time of 30 seconds at each station)
- Operation speed during car wash: 3~4 km/h

2 Average acceleration

Under rated load and rated voltage on straight and dry track, with half-worn wheels, average acceleration is as below:

- Vehicle speed from 0km/h to 40 km/h ≥1m/s2
- Vehicle speed from 0km/h to 70 km/h ≥0.5m/s2

3. Average braking deceleration

Under rated load on straight and dry track, with half-worn wheels, average deceleration from maximum vehicle operation speed of 70 km/h until stop is as below:

- Maximum service brake deceleration: ≥1.1m/s2
- Emergency brake deceleration: ≥2.0m/s

Fault operation and rescue capability[5]

Within range of permissible adhesion, under seating capacity and working conditions, with loss of 1/4 power, vehicles should be able to complete a round trip as normal and return to depot. With loss of 1/2 of traction power, empty vehicle should be able to continue the operation until it reaches deport in case of failure. One empty vehicle should be able to bring another empty vehicle, stopping on a maximum slope (uphill) with failure, to depot.

Noise[5]

1） External noise

Equivalent noise level outside the vehicle, measured where it is 7.5m from centerline of track and 1.5m from top of rail, when vehicle is running at 52.5km/h in open area above the ground along long seamless rails on gravel ballast through free sound field within horizontal and straight sections: ≤80dB(A) Equivalent noise level outside the vehicle, measured where it is 7.5m from centerline of track and 1.5m from top of rail, when vehicle is parked on horizontal and straight line with gravel ballast in free sound field while auxiliary equipment is working normal: ≤69dB(A)

2） Internal noise

Noise level at the center inside of a vehicle, measured where it is 1.5m above floor, with the vehicle operating at a speed of 52.5km/h on straight tracks: ≤75dB

3.3 Brief introduction of car body steel structure

The main structure of car body steel structure for 70% Low-floor LRV for Addis Ababa, Ethiopia is stainless steel and aluminum alloy, with painting on the surface. The carbody is mainly composed of two Mc modules and one T module, hinge joint shall be provided among these three modules. The car body steel structure of Mc module is composed of end wall steel structure, side wall steel structure, under frame steel structure, roof steel structure and cab structure. The cab structure is composed of head shield system and front end frame. The T module carbody steel structure is composed of under frame structure, side wall steel structure, roof steel structure, end wall steel structure and other components. See Table for the component quantity of Mc module and T module. The car body steel structure shall meet with requirement of standstill strength and fatigue strength for P-IV type vehicles specified in EN 12663. The welding shall meet with requirement specified in EN 15085. The carbody steel structure shall guarantee the vehicle operation at least 30 years, and without permanent deformation or breakage caused by fatigue for normal or abnormal stress.[18]

The car body structure of 70% Low-floor LRV for Addis Ababa, Ethiopia adopt frame bearing adhesion external wall panel structure for the first time in domestic railway vehicles. The external wall panel is of composite aluminum –plastic panel, adhesion type will be provided between wall panel and frame. The adhesive during adhesion phase adopts modified saline adhesive or polyurethane adhesive with well-known internationally. This kind of adhesive has strong compressibility, fatigue durability, ageing resistance and larger adhesive layer scope, and it will buffer the vibration during vehicle operation for adhesion effect. The theoretical thickness of adhesive layer is 4mm, and the thickness of aluminum-plastic panel is 6mm. The external wall panel of side wall shall provide adhesion after vehicle general assembly, it shall cover roof side beam on the top, and cover under frame side beam on the bottom. This structure will assure airtightness of the whole vehicle better. It will introduce the replacement of external wall panel, as below:[19]

The single side wall of T module is composed of 5 pieces of external wall panels, and single side wall of MC module is composed of 14 pieces of external wall panels, 10mm adhesive line will be reserved between all wall panels.

Car body steel structure and load mode[18]

- The car body structure adopts straight type, with frame load and adhesion structure of external wall panel for side wall, and it is mainly composed of roof, side wall, under frame, end wall, etc. The design strength shall meet with EN12663-PⅣ, and the compressed load is 40 tons.
- The car body steel structure has enough strength to bear all loads during operation.
- Under the premise that assure enough strength and rigidness, the carbody shall realize light weight.
- The roof shall bear all loads for supporting, including equipment and service personnel’s.
- The vibration frequency of car body structure shall assure that no resonance produced with vibration frequency of bogies.

Car body main parameters

- MC car： 11340mm
- T car： 3600mm
- Max. width of car body： 2650mm
- Car body height (to rail top)： 3025mm

Material and performance

The car body steel structure is mainly adopt SUS301L stainless steel and 6005A-T6 aluminum profile, which are specially used for railway vehicles. The main body of under frame adopts carbon steel panel S500MC and weathering resistant steel 09CuPCrNi-A with high strength, and the roof hinge joint seat adopts B-level steel.

Table 3.1: Chemical component of SUS301L and SUS304 stainless steel

Material	C	Si	Mn	P	S	Ni	Cr	Others
SUS301L	<0.03	<1.00	<2.00	<0.045	<0.030	6.00~ 8.00	16.00~ 18.00	N<0.20
SUS304	<0.08	<1.00	<2.00	<0.045	<0.030	8.00~ 10.50	18.00~ 20.00	

Table 3.2 Mechanical properties of SUS301L and SUS304 stainless steel

Material type and strength level	Calendering (delivery state)	Yield strength (N/mm^2)	Tension strength (N/mm^2)	Percentage elongation (%)
SUS301L-DLT	1/4H	>345	>689	>40
SUS304		>205	>520	>40

Table 3.3 Chemical component of high weathering resistant structure steel

Material type	Uniform code	Chemical component %							
		C	Si	Mn	P	S	Cu	Cr	Ni
Q345GNHL	L53452	≤0.12	0.25 ~0.75	0.20 ~0.50	0.07 ~0.15	≤0.035	0.25 ~0.55	0.30 ~1.25	≤0.65

Table 3.4 Mechanical property and process performance of high weathering resistant structure steel

Material	Delivery state	Thickness mm	Yield Point σ_N MPa Not less than	Tension strength σ_b MPa Not less than	Extension rate δ% Not less than	180° bending test
Q345GNHL	Hot rolling	≤6	345	480	22	d=a
		>6				d=2a
Note: d is flexural center diameter, a is steel thickness						

Table 3.5: Chemical component of cast steel

Chemical component	C(%)≤	Mn(%)≤	P(%)≤	S(%)≤	Si(%)≤
B-level steel	0.32	0.90	0.04	0.04	1.50

Table3.6: Mechanical property and process performance of cast steel

Mark	Delivery state	Yield Point σ_N MPa Not less than	Tension strength σ_b MPa Not less than	Extension rate δ% Not less than	Percentage reduction of area (%)
B-level	Cast steel	260	485	24	36

Table3. 7: Chemical component of 6005A aluminum alloy

Mark of alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Mn+Cr	Others		Al
										Each	Total	
6005A	0.5-0.9	0.35	0.3	0.5	0.4-0.7	0.3	0.2	0.1	0.12-0.5	0.05	0.15	Residual

Table 3.8 Mechanical performance of 6005A aluminum alloy

Mark of alloy	Supply state	Sample state	（mm）Wall thickness	Tension strength σ(MPa)	Regulated non-proportional extension stress $\sigma P_{0.2}$(MPa) Not less than	Extension rate δ（%）	Brinell hardness HB2.5 /662.5
6005A	T6	T6	e≤5	270	225	8	
			5＜e≤10	260	215	8	
			10＜e≤25	250	210	8	

3.4 Technical description of all components for car body steel structure[18]

The carbody steel structure is mainly composed of end wall ,side wall, under frame and roof structures.

End wall structure

The end wall steel structure of Mc module and T module are the same. the selected material are stainless steel. The end wall steel structure is spot welding by vertical shaft, cross beam and wall panels The air duct passing flange shall be provided on the top of the end wall steel structure.

Side wall steel structure

In order to assure the flatness of side wall panel of car body, and reduce the car body weight ,the side wall adopts skeleton bearing adhesion panel structure. the side wall structure is composed of side wall skeleton and external wall panel. the side wall skeleton is composed of vertical post and cross beam, which are rectangle structure mostly ,the window and door shall provide angle iron for Strengthen the side wall skeleton beam and post shall be welded by cold rolled section steel, whose main material is SUS301L-DLT with high strength, this kind of structure shall improve tension rigidness. the door corner and window corner shall be stress concentration area, and the window corner shall be strengthened with high strength panels

The external wall panel adopts complex aluminum –plastic panel, the adhesion shall be provided between wall panel and skeleton. The adhesive during adhesion phase adopts modified silane adhesive or polyurethane adhesive with well-known internationally .this kind of adhesive has compressibility, fatigue durability, ageing resistance and larger adhesive layer scope and it will buffer the vibration during vehicle operation for adhesion effect. The theoretical thickness of aluminum-plastic panel is 6mm. The external wall panel of side wall shall provide adhesion after general assembly, it shall cover roof side beam on the top, and cover under frame side beam on the bottom. this structure will assure air tightness of the whole vehicle better.

Under frame steel structure

Mc module under frame is composed of high floor area under frame and low floor area under frame. The high floor area under frame is including floor beam, draft sill assembly ,side beam, longitudinal beam, energy absorption structure, stairway structure and bolster. the low floor under frame is including cross beam, side beam ,end beam and lower hinge joint seat. T module under frame is composed of bolster, side beam, end beam, floor beam and lower hinge joint seat. The main material of under frame steel structure is SUS301-DLT stainless steel with high strength ,but at the stress position ,especially at interface area with bogie shall use SUS301-DLT stainless steel with high strength. The bolster is spelled and welded with

Thick panels, the lower plane shall be machined after welding operation ,and strengthening rlb shall be provided at interface with bogie .there are so many interfaces between under frame and bogie , in order to assure entire flatness and roughness of interface after the entire under frame is welded and assembled, the interfaces with bogie and hinge joint shall be machined mechanically.

On the top of the bogie area and on the bottom of under frame steel structure shall paint Henkel Damping slurry with good quality performance, in order to improve corrosion prevention of strengthened carbon and steel material, and reduce spread of wheel and rail noise

Fig 3.1 Under frame structure on the train Mc low floor area

Roof steel structure

The roof steel structure is composed of steel module and aluminum module both ends of steel structure shall provide steel module ,to meet with requirement of strength for hinge joint installing seat on the cast steel .The bolt shall be provided between aluminum modules for connection. The steel module is welded by end beam ,longitudinal beam and roof ,and it uses SUS301-DLT stainless steel with high strength .the end beam shall select large sectional rectangle cold rolled section steel, which has higher corrosion resistance .The aluminum module is assembled and welded by five pieces of five pieces of aluminum profiles. the welding structure of aluminum profile shall be high strength and rigidness ,to meet with requirement of many equipment on the roof for the low floor vehicle

Cab structure

Cab frame

The cab steel structure shall be connected to car body steel structure with welding connection.

The cab hood, fairing and rear barrier strip of side door shall be GRP, local part is including foam reinforcing material, with painting on the surface. It will be connected on cab and carbody steel structure by means of M8 bolts. The cab hood and side rear barrier strip and steel structure use sealing adhesive to provide sealing and auxiliary fixing.

Interior layout

Mc1 car and Mc2 car are the motor module with bogie and cab, and the interior is composed of compartment and cab. The interior module of Mc1 car and Mc2 car will provide difference only at handicapped area, other areas are the same. Tp car is a trailer module with pantograph and trailer bogie installed.

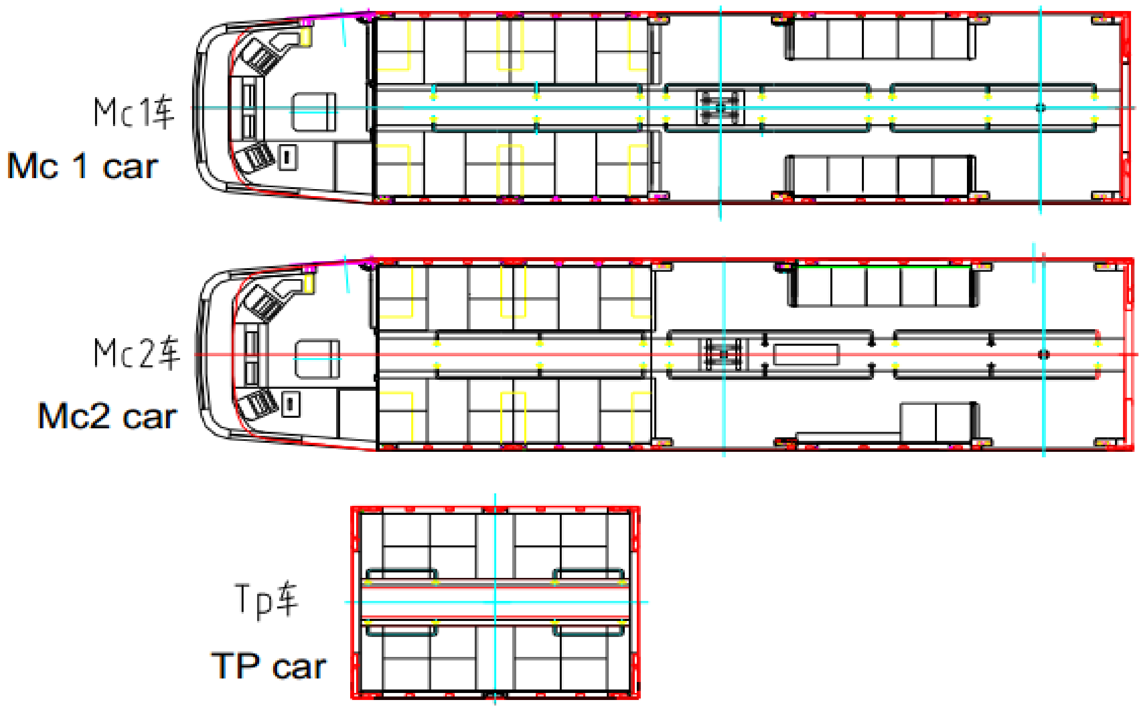


Fig 3.2 Interior Layout

The interior decoration is mainly including side ceiling, central ceiling, side wall panel, vertical panel, end wall, flooring, cab partition, partition door, compartment seat, wind screen and handle, handicapped area layout, fire extinguisher, etc. The design fireproof performance is conforming to DIN5510 fireproof standard. The material selected has ability of firm, long service life, convenient to clean or service, graffito prevention. The sectional view is shown a s follows:

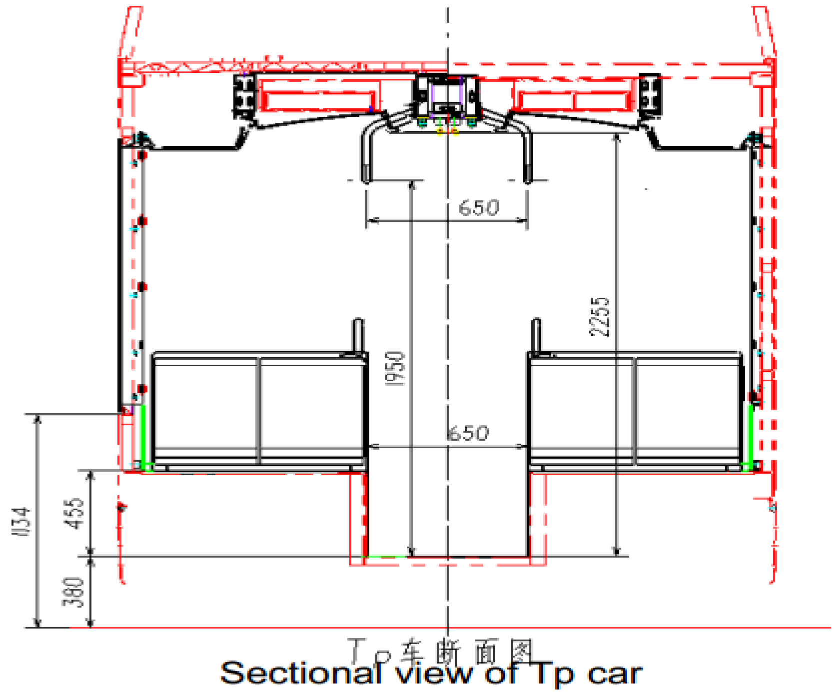


Fig 3.3 sectional view of TP car

Fig 3.4 sectional view of low floor and sectional view of high-floor area in MC car

Chapter Four

4 Modeling and analysis of the structure

4.1data Collection and Analysis

4.1.1Basic technical conditions and overloading assumptions of the train.

4.1.1.1Main dimension of vehicles

1. body length 29650mm
2. the height from vehicle top to rail top to (not including pantograph) 3610
3. maximum width 2650
4. The height from vehicle floor to the rail top(low floor area)380mm
5. The height from vehicle floor to the rail top(high floor area)835mm
6. The wheel base on powered bogie 1900mm
7. The wheel base on non powered bogie 1800mm

4.1.1.2Car body main parameters

- Mc body length 11400 mm
- Tp Body length 3600 mm
- The maximum width of the vehicle body is 2650 mm
- Body height (from the rail) 3025 mm

4.2 AALRT train overloading capacity assumptions.

- Data collected from the Addis Ababa light rail transit train masters and technicians at peak hour the Addis Ababa light rail train is overloaded. number of passengers at this hour is above the recommended passenger overload 8persons/m^2 it will be maximize up to 10 persons/m^2 standing .and also 89 seated persons on the train. So this research takes this unacceptable loading on Addis Ababa light rail train and indicating the possible overloading area and conditions inside the train.
- Selected line for this research is Torhayloch to Ayat line (line 1)
- Data is collected from single car
- One car is work eighteen times per day Ayat to Torhayloch and Torhayloch to Ayat.
- Monthly maintenance take one day

- Quarterly maintenance (on three month) take one day
- Annually maintenance takes five days
- One Addis Ababa light rail train is work 344 days per year on normal operating condition. But on the light problem and some accident like car accident on the rail, electric line, signal equipment's on the train the train transportation will be stop. and the working day of one train per year will be minimize .
- Model of the train for this research is similar to the real one

4.2.1 Train Loading assumption

- Number of passenger is registered to the closest number of passenger per meter square the real number of passenger is above or below to take.
- Load of bogies and the steel structure mass are subtracted from the dead weight of the Addis Ababa light rail vehicle.
- Applied load on this research as pressure

4.3 Average passenger load condition

Passenger loading capacity and acceptable load of a locomotive from technical specification is summarized in the following table

Table 4.1design weight of AALRT trains

Loads	Car body weight	Passenger weight	Total weight
Empty vehicle (t)	44	0	44
Searing capacity (t)	44	15.24	59.24
Overload capacity (t)	44	19.02	63.02
Axle load	≤11（1+3%）t		

Passenger loading capacity and unacceptable load of a locomotive on the operating condition is summarized in the following table

Table4.2 seating and standing passenger loading value of a train

condition	**Number of passengers**	**Seated**	**Standing**	**Total**
1	Seats	65	0	65
2	Seating capacity(standing 2persons/m^2)	65	63	128
3	Seating capacity (standing: 4 persons/m^2)	65	126	191
4	Seating capacity (standing:6 persons/m2)	89	189	278
5	Recommended Overload capacity (standing: 8 persons/m2)	89	252	341
6	Unacceptable overloading capacity(standing: 10 persons/m2)	89	319	408

Train weight

Weight of train i.e car body weight and passenger weight at each condition is summarized on the table below.

Table 4.3 Total weight of a locomotive

Condition	Loads	Car body weight	Passenger weight(ton)	Total weight(ton)
0	Empty train	44	0	44
1	Seats	44	3.9	47.9
2	Seating capacity(standing 2persons/m^2)	44	7.68	51.68
3	Seating capacity (standing: 4 persons/m^2)	44	11.46	55.46
4	Seating capacity (standing:6 persons/m2)	44	16.68	60.68
5	Recommended Overload capacity (standing: 8 persons/m2)	44	20.460	64.46
6	Unacceptable overloading capacity(standing : 10 persons/m2)	44	24.48	68.48

Note: Take 60 kg as average weight of each passenger.

Applied load on under frame steel structure

Applied load on car body steel structure is summarized below

1.from car body weight 44 ton I will subtract the weight of the car body steel structure, weight of bogies and finally I will get weight of internal wall, ceiling ,air condition materials outer wall etc. there fore

$W_{overall}$ =44 ton

$W_{motor\ bogie}$ =6ton

$W_{trailer\ bogie}$ =4ton

$W_{structure}$ =11.75 ton

$W_{applied} = W_{overall} -(W_{motor\ bogie} + W_{trailer\ bogie} + W_{structure})$

$W_{applied}$ =44ton-(6ton+6ton+4ton+11.75)

$W_{applied}$ =<u>16.25 ton</u>

weight of a train at each condition is summarized on the table below.

Table 4.4 weight of train at each condition

Condition	Loads	Another parts on train weight(ton)	Passenger weight(ton)	Total weight(ton)
0	Empty train	16.25	0	16.25
1	Seats	16.25	3.9	20.15
2	Seating capacity(standing 2persons/m^2)	16.25	7.68	23.93
3	Seating capacity (standing: 4 persons/m^2)	16.25	11.46	27.71
4	Seating capacity (standing:6 persons/m2)	16.25	16.68	32.93
5	Recommended Overload capacity (standing: 8 persons/m2)	16.25	20.460	36.71
6	Unacceptable overloading capacity(standing: 10 persons/m2)	16.25	24.48	40.73

From the time table on Appendix A one rail car (car116) have the following loading condition per day on the east-west rail line

Table 4.5 load frequency at each condition per day

Loading condition	Frequency	percentage
Condition0	1	5.6
Condition1	3	16.7
Condition2	2	11.1
Condition3	2	11.1
Condition4	4	22.2
Condition5	4	22.2
Condition6	2	11.1

4.4 Palmgren-Miner Linear Damage Rule

Total life cycle is calculated by using Palmgren-Miner Linear Damage Rule:[21]
The damage caused by one cycle is defined as

D = 1/Nf
where Nf is the number of repetitions of this same cycle that equals life to failure.
The damage produced by n such cycles is then nD = n/Nf.
Cumulative Damage Theories
The damaging effect of n1 cycles at Sa1 stress amplitude is assumed to be n1D1= n1/Nf1, while the damaging effect of n2 cycles at Sa2stress amplitude is assumed to be

n2D2 = n2/Nf2.
Similarly, the cycle ratio or damage caused by ni cycles at Sai stress amplitude is

niDi= ni/Nfi.
Failure is predicted when the sum of all ratios becomes 1 or 100%.

- The following relation expresses the **linear damage rule**, proposed by Palmgren and later again by Miner

$$\sum \frac{ni}{Nfi} = \frac{n1}{Nf1} + \frac{n2}{Nf2} + \frac{n3}{Nf3} + \ldots\ldots = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq(a)}$$

4.5 Modeling of car body steel structure

To define the car body steel structure, a structural model is developed by using CATIAV5-R19 modeling and analysis ware. This model is import the mode with a file format such as IGES, to ANSYS-15 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 drawing includes under frame sub-assembly, side wall sub-assembly ,end wall sub-assembly roof sub-assembly for motor car and trailer car and also cab sub assembly for motor car and final car body is composed of one trailer car assembly and two motor car assemblies.

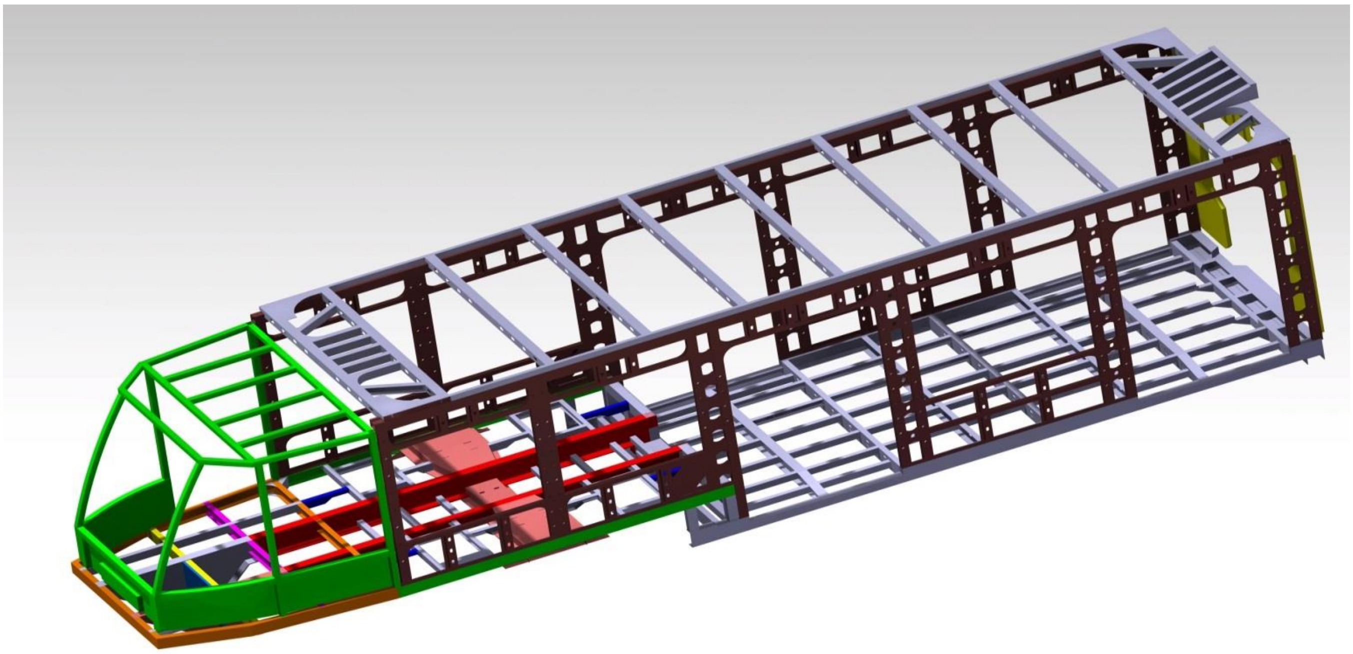


Fig .4.1Motor car structure assembly

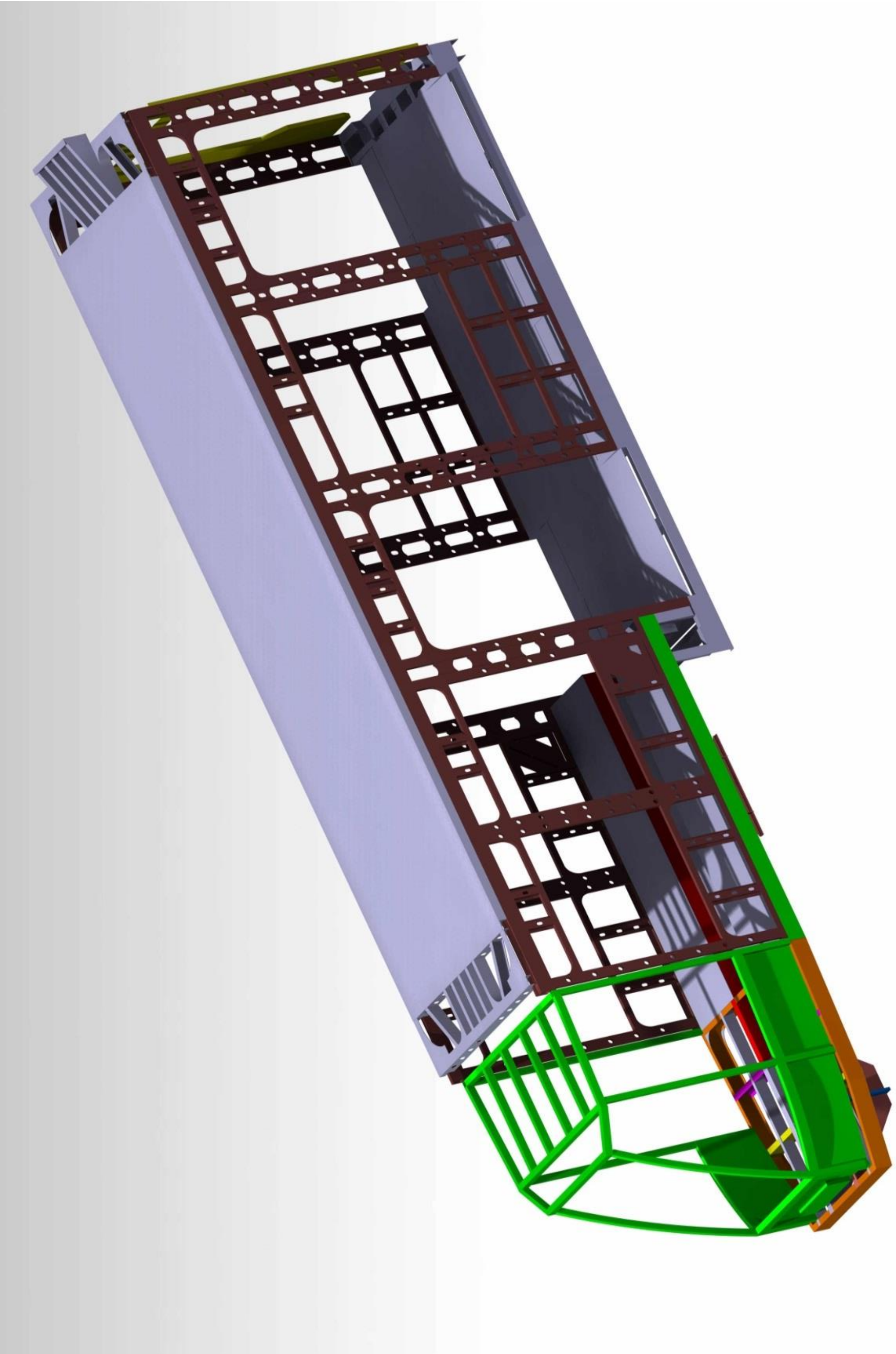


Fig. 4.2 Motor car with roof assembly

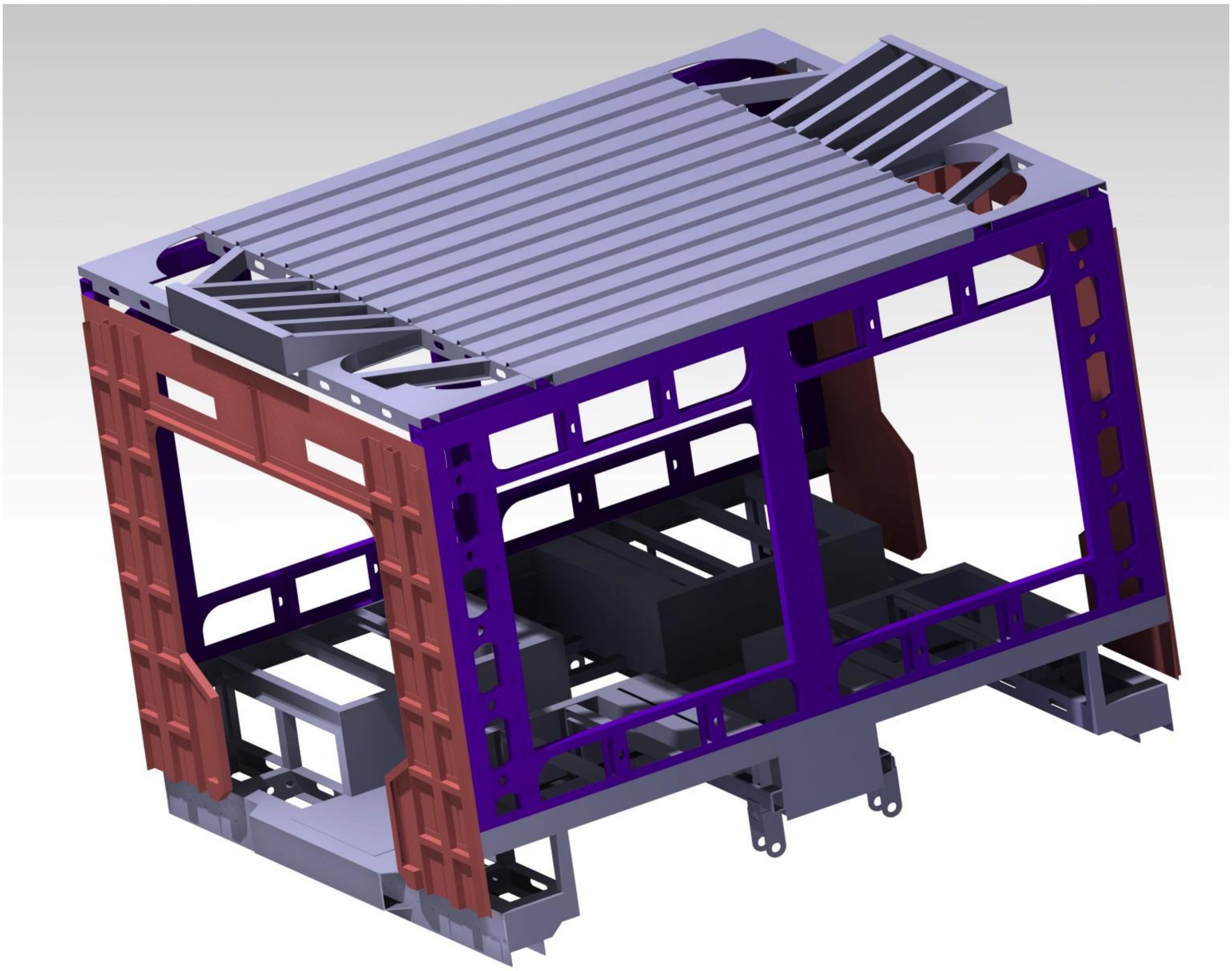


Fig .4.3 Trailer car assembly

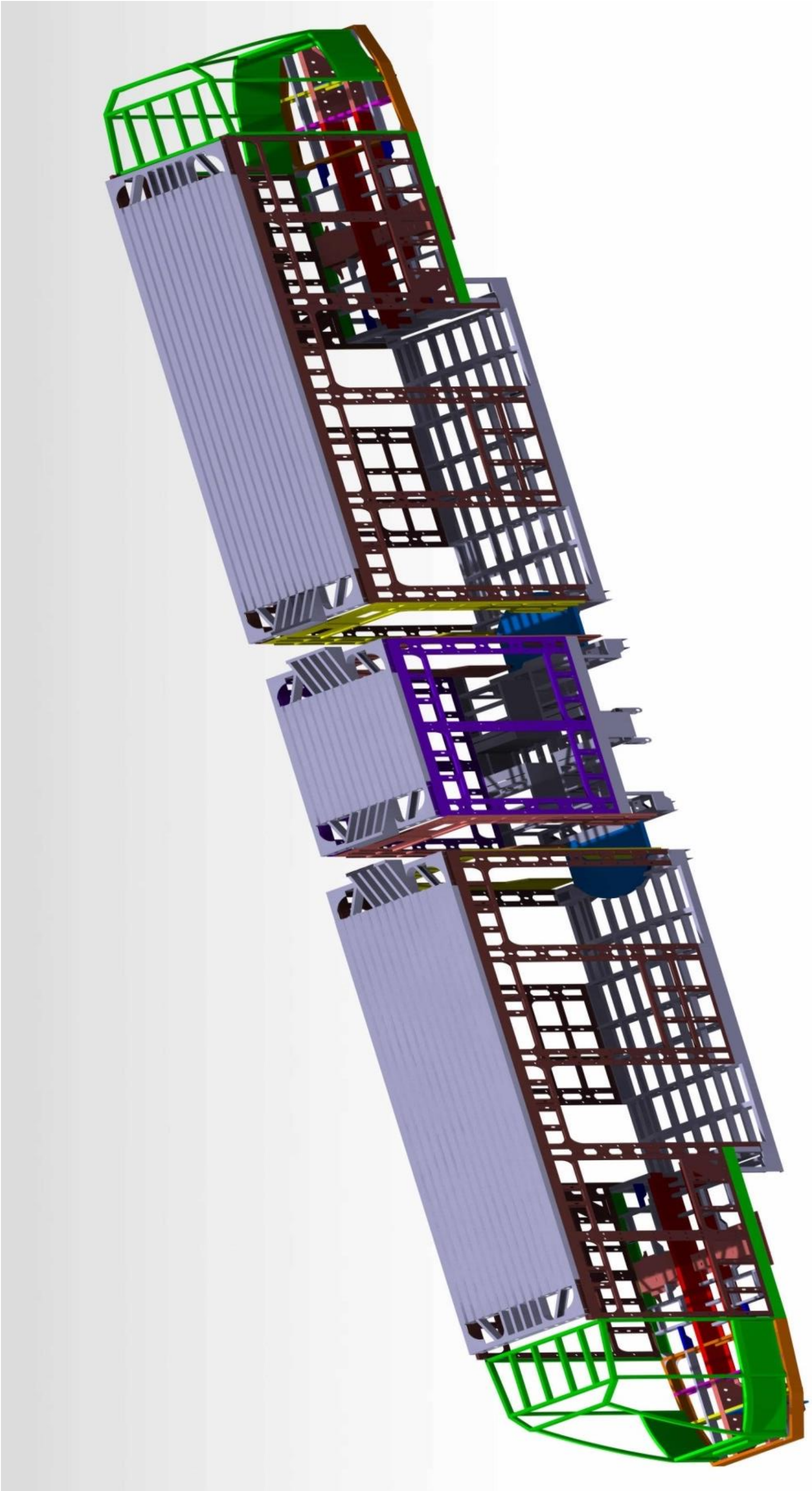


Fig. 4.4Model of Car body steel structure assembly

4.6 Material property of under frame structure

AALRT train under frame steel structure constructed from SUS301-DLT stainless steel. For structural analysis of the structure certain physical properties of from SUS301-DLT stainless steel are given below

Table 4.6 Mechanical properties of the structure

Property	Value
Density	7880 kg/m^3
Modulus of elasticity	193 MPa
Poisons ratio	0.265
Tensile strength	689 MPa
Yield strength	345 MPa
Percentage elongation (%)	40

4.7 Passenger Load position

On motor car assembly

Position 1 –between high floor car area chairs

Position 2 – chairs area at high floor car area

Position 3 – on doors area

Position 4 – low floor area chairs

Position 5 –between low floor chairs

On trailer car

Position 6 – between trailer chairs

Position 7 – on trailer chairs

Another parts load is distributed all over the structure

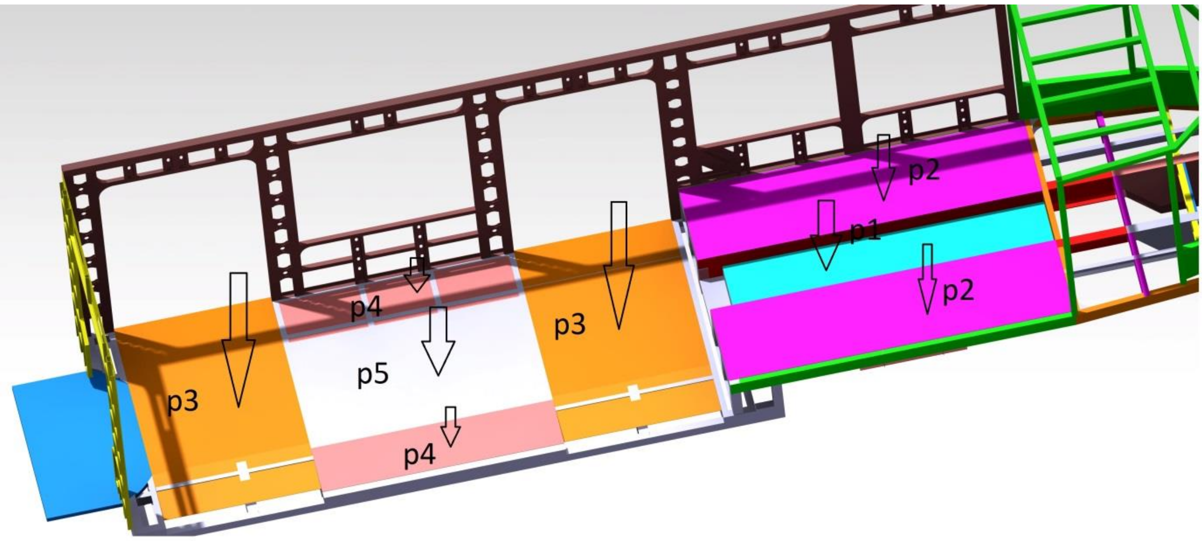


Fig4.5 Load position on motor car

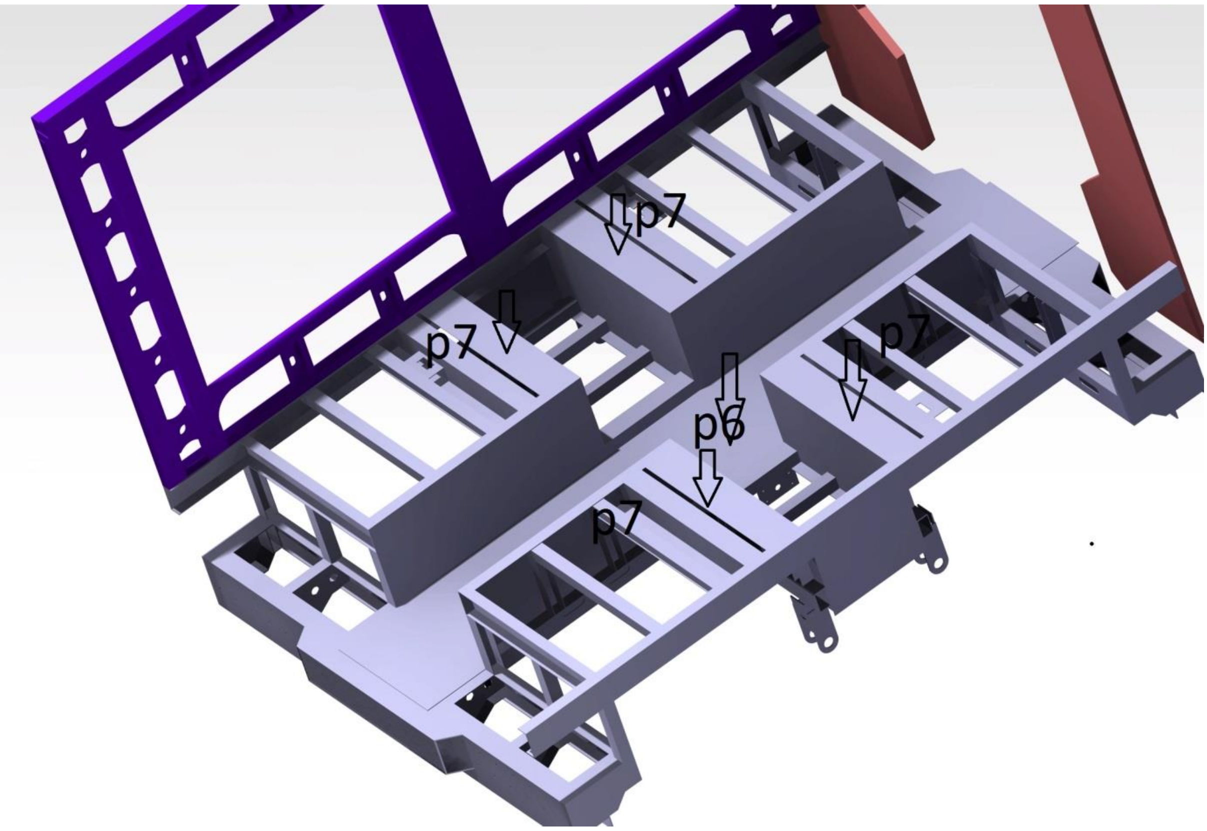


Fig4.6 Load position on trailer car

Area of position 1=3.244×0.65 =2.1086 m^2

Area of position 2=0.94×3.484 = 3.275 m^2

Area of position 3=1.59×2.53=4.0227 m^2

Area of position 4=0.575×2.44 =1.403 m^2

Area of position 5=1.38×2.44 =3.3672 m^2

Area of position 6=3.6×0.65 =2.34m^2

Area of position 7=2.84×0.996 =2.829 m^2

Overall area = 72.08 m^2

Acceleration due to gravity =9.81 m/s^2

Applied force =mass × gravity

Pressure = force ÷ applied area

Therefore pressure load on different loading condition and position on under frame steel structure are given below

Table 4.7 :Applied pressure at different condition and position

condition	Another parts load(Pa) Mc	Another parts load(Pa)Tc	Position1 (Pa)	Position 2 (Pa)	Position 3 (Pa)	Position4 (Pa)	Position5 (Pa)	Position 6 (Pa)	Position7 (Pa)
0	1610.915	1847.766	0	0	0	0	0	0	0
1	1610.915	1847.766	0	1437.8	0	2097.65	0	0	1664.475
2	1610.915	1847.766	558.3	1437.8	1463.2	2097.65	1398.43	754.61	1664.475
3	1610.915	1847.766	1674.85	1437.8	2780.1	2097.65	2796.86	1509.23	1664.475
4	1610.915	1847.766	2791.42	2156.7	4096.95	2517.18	4195.3	2263.85	2080.6
5	1610.915	1847.766	3908	2156.7	5560.14	2517.18	5244.12	3018.46	2080.6
6	1610.915	1847.766	5582.85	2156.7	6584.4	2517.18	7167	4276.15	2080.6

For simplifying the analysis on Ansys workbench I use one motor car and one trailer car under frame steel structure attached by turn table.

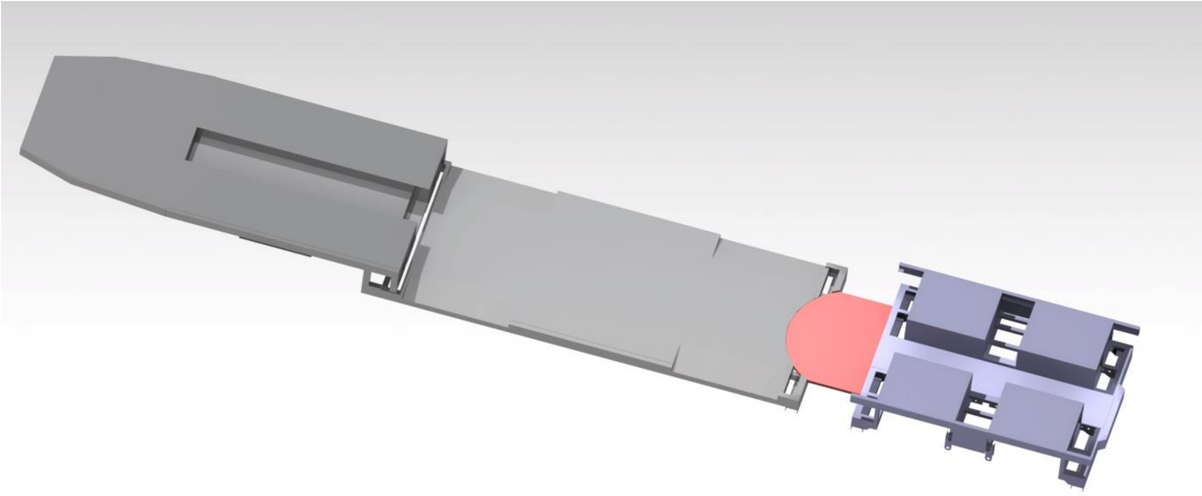


Fig 4.7 One Mc and Tc Under frame steel structure with turn table model

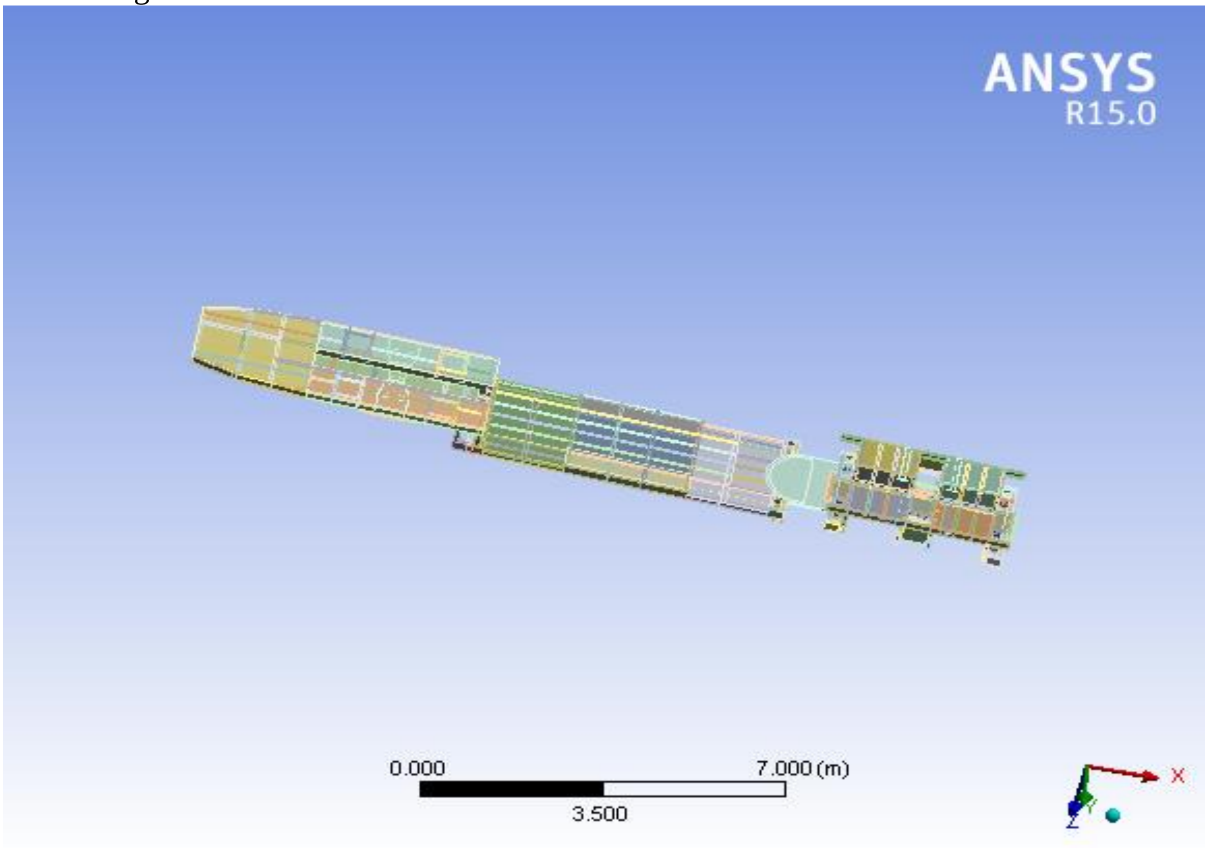


Fig4.8 Imported structure to Ansys workbench

4.8 Meshing

Meshing is discretizing the solid object to finest parts to perform the analysis for getting the more accurate value at each element of the meshed object

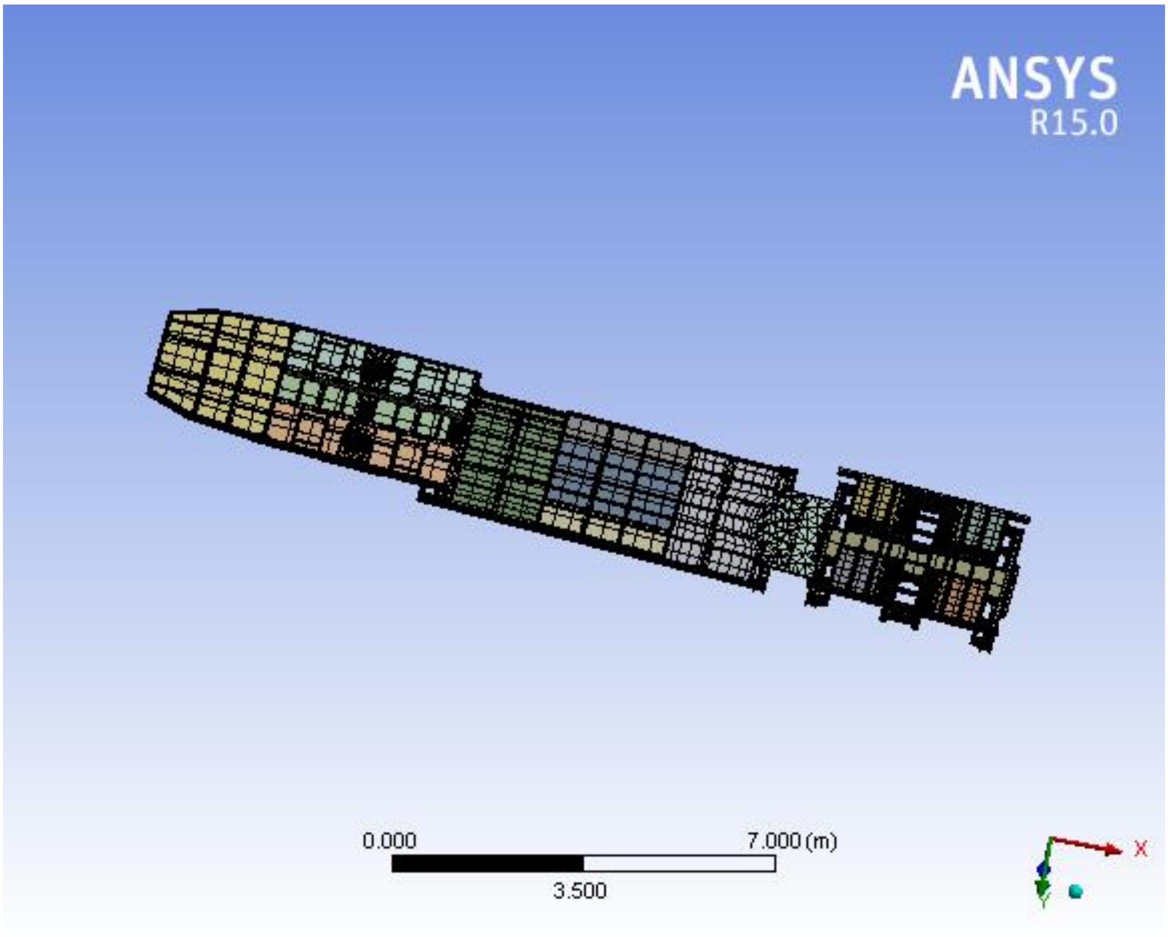


Fig 4.9 Meshed under frame structure

4.9 Loading and boundary condition

Boundary condition for all cases

- Initial temperature is 25^0C
- Material properties of structure is SUS301-DLT stainless steel
- Applied load (pressure) is on the above table

4.10 Loading at each condition

For this analysis we have seven conditions

Condition0

At this condition applied pressure was the dead weight of the hole structure except the under frame steel structure and bogies.

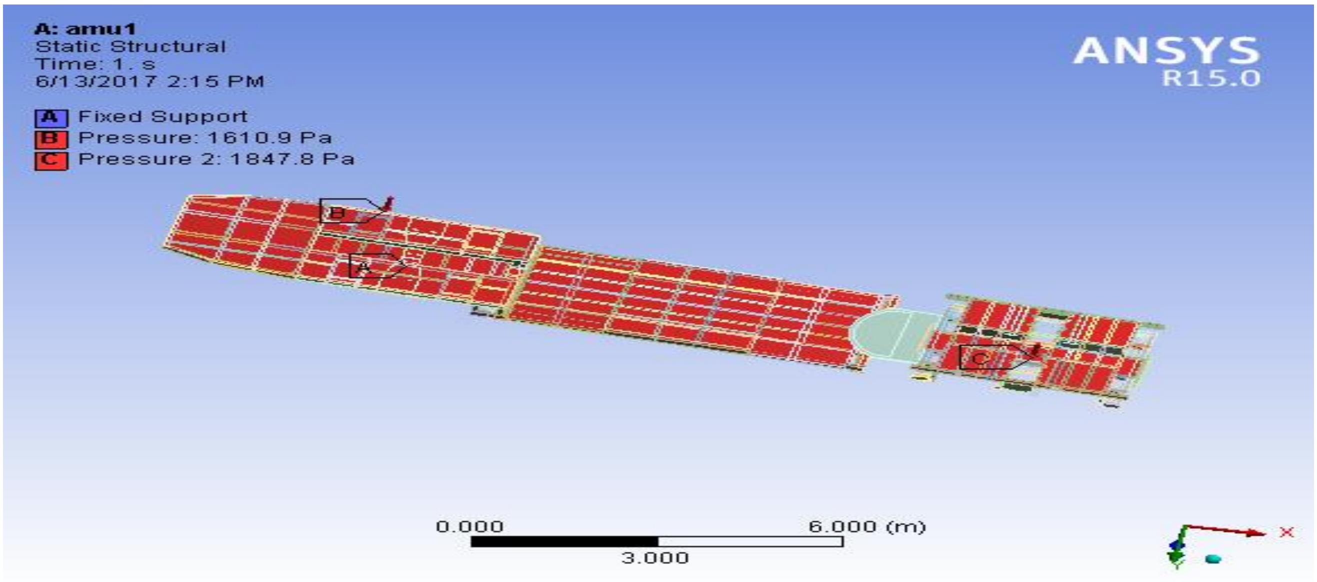


Fig.4.10 Fixed support and applied pressure position at condition0

Condition1

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies and 65 persons seated on the chairs.

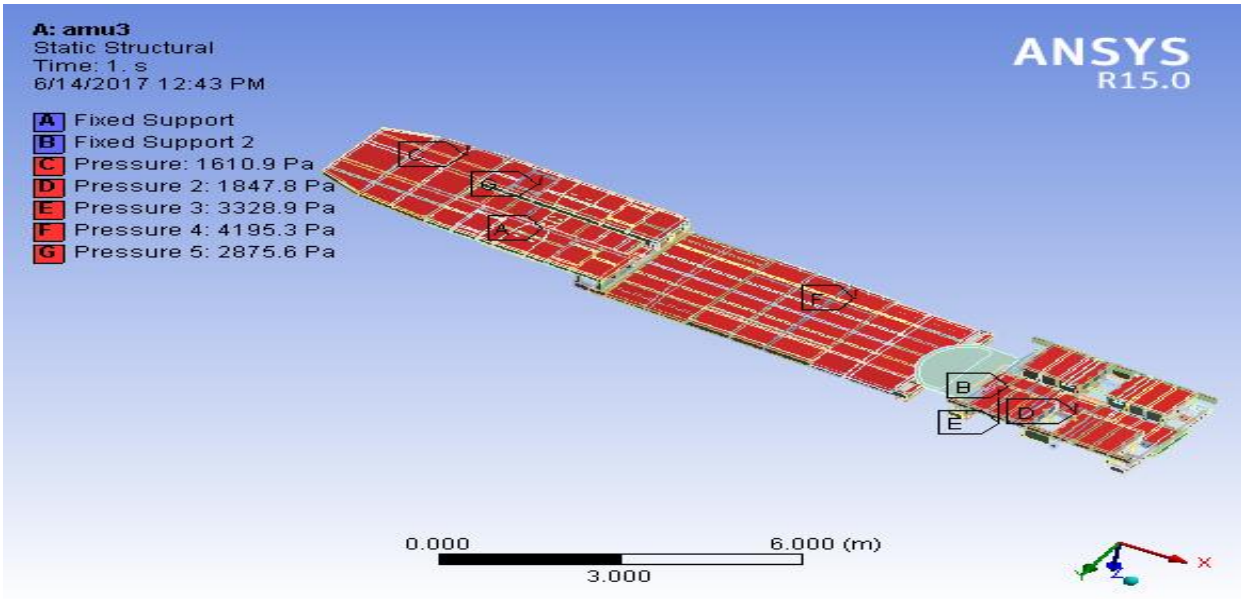


Fig4.11. Fixed support and applied pressure position at condition1

Condition2

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies , 65 persons seated on the chairs and 63 persons stood.

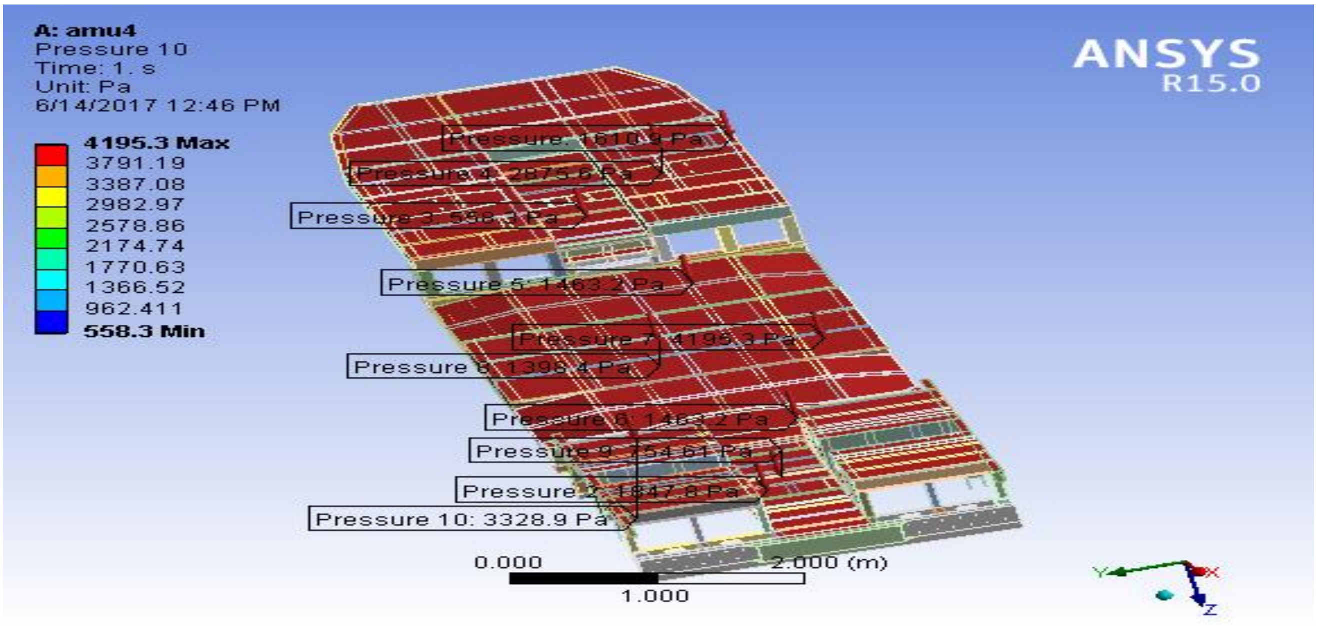


Fig.4.12 Fixed support and applied pressure position at condition2

Condition3

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies , 65 persons seated on the chairs and 126 persons stood.

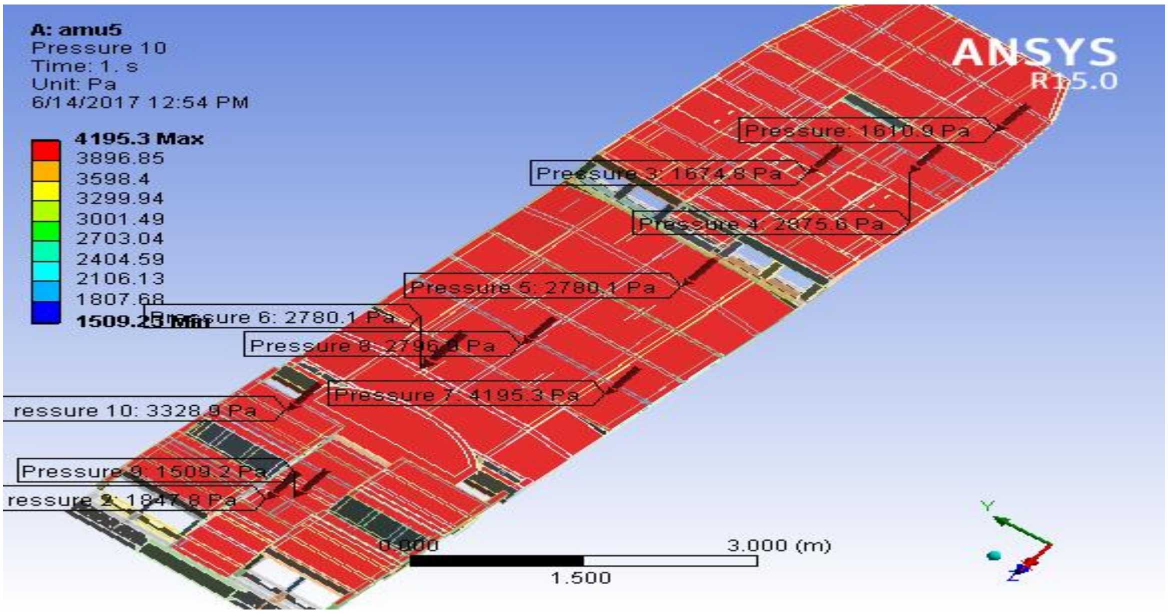


Fig.4.13 Fixed support and applied pressure position at condition3

Condition4

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies , 89 persons seated on the chairs and 189 persons stood.

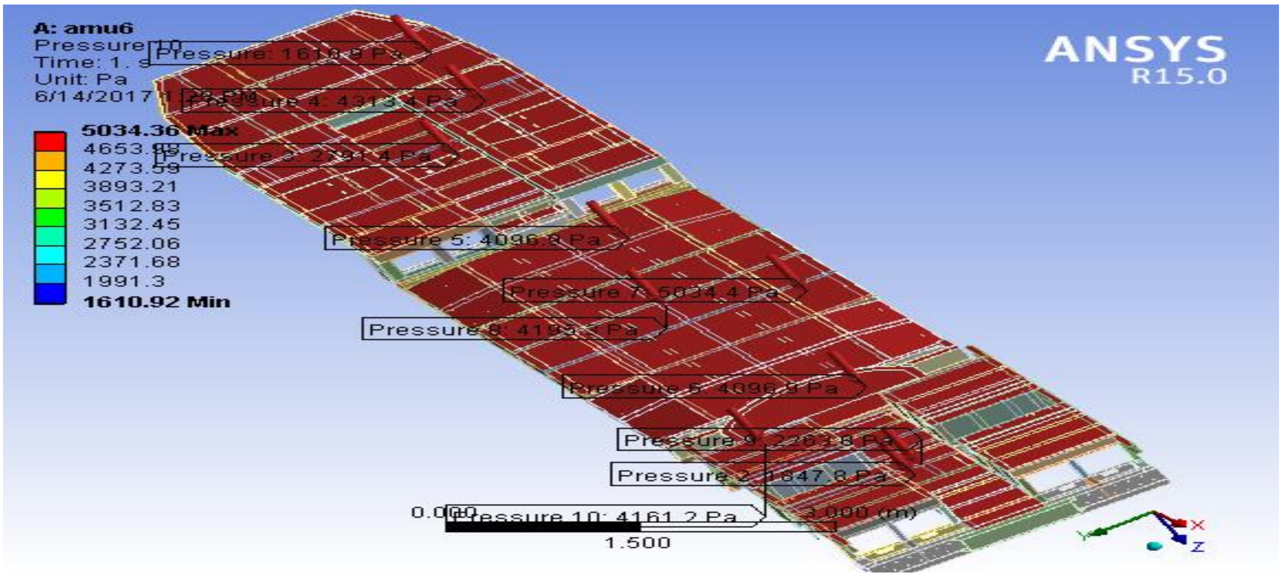


Fig. 4.14Fixed support and applied pressure position at condition4

Condition5

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies , 89 persons seated on the chairs and 252 persons stood.

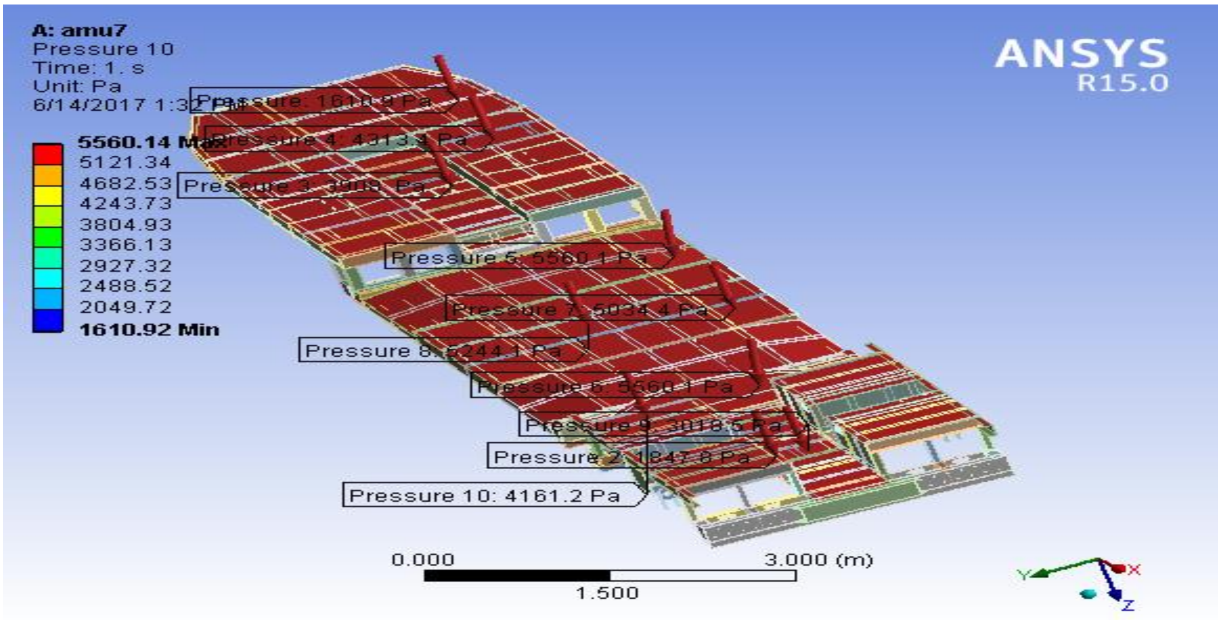


Fig.4.15 Fixed support and applied pressure position at condition5

Condition6

At this condition applied pressure were the dead weight of the hole structure except the under frame steel structure and bogies , 89 persons seated on the chairs and 319 persons stood.

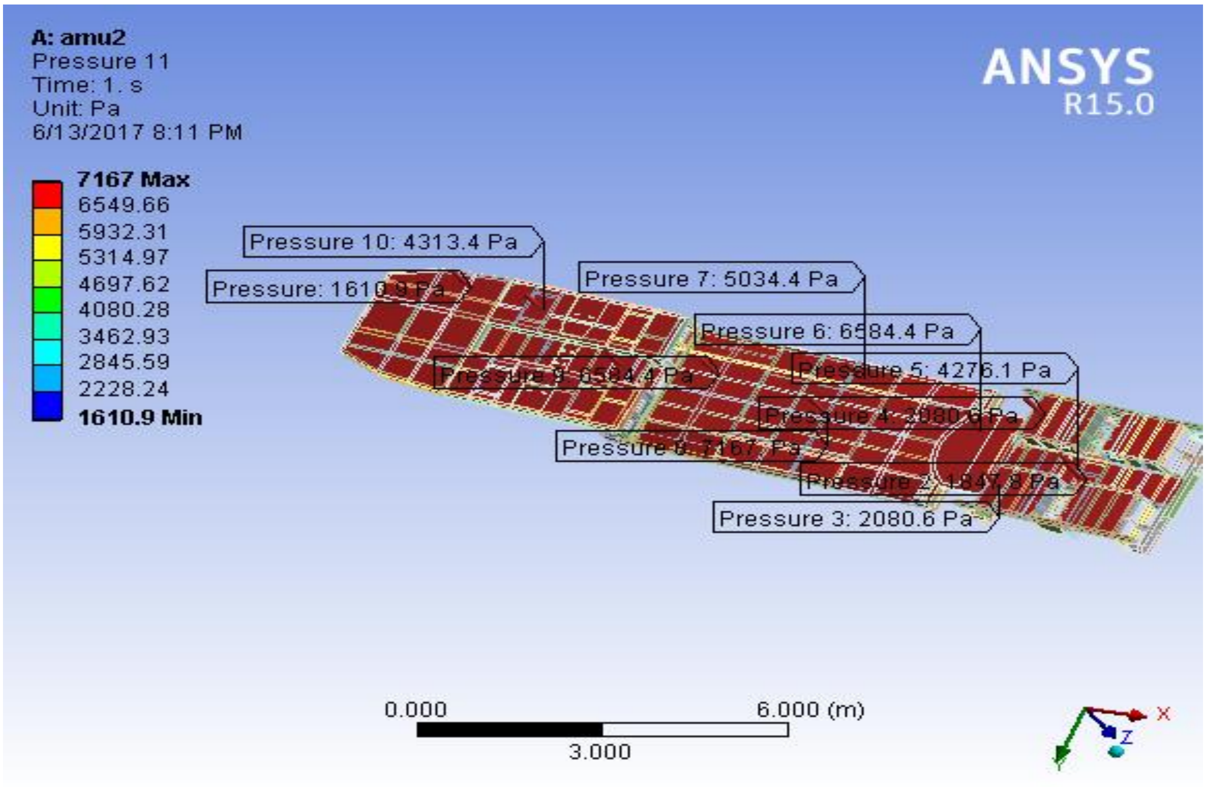


Fig.4.16 Fixed support and applied pressure position at condition6

Chapter five

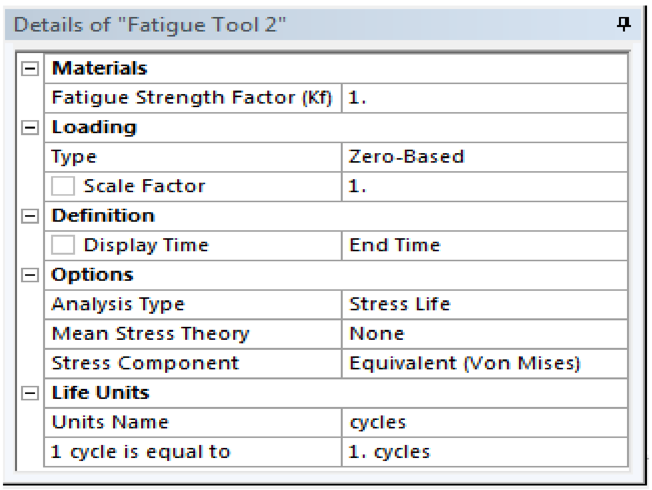
5.Result and Discussion

5.1Result

The minimum design life cycle requirement of AALRT 30 years. AALRT car body under frame steel structure meet the design requirement due to static strength but on fatigue strength some parts cannot meet the design requirement,because fatigue failures often result from applied stress levels significantly below those necessary to cause static failure .for this project analysis of fatigue life was done by using only vertical load effect i.e passenger load and weight of the vehicle except bogies and under frame steel structure . Time table of car116 AALRT train is used for counting the life cycle of this train. Car 116 starts traveling at 06:04 at the morning from Ayat station and it works up to 21:48 Torhayloch station. From Torhayloch station up to Ayat depot this train goes at condition0 .finally car116 train travel 18 times/day (Appendix A) and one train works 344 days/year .For this thesis assumes that the run " Ayat to Torhayloch" or" Torhayloch to Ayat"(approximately 50 minutes) is a duty cycle. because at those final stations the passenger load reach at zero. From the above data the fatigue life cycle for thirty years is equal to 185,760 fatigue life cycle

5.2Fatigue life result

Fatigue life analysis is done by using stress life (Available in ANSYS Fatigue Module) fatigue life type and loading type is Zero based. After applying necessary load at each condition the following result are gain. for all condition fatigue tool is adjusted as the following figure


Details of "Fatigue Tool 2"

Materials	
Fatigue Strength Factor (Kf)	1.
Loading	
Type	Zero-Based
Scale Factor	1.
Definition	
Display Time	End Time
Options	
Analysis Type	Stress Life
Mean Stress Theory	None
Stress Component	Equivalent (Von Mises)
Life Units	
Units Name	cycles
1 cycle is equal to	1. cycles

Fig 5.1 fatigue analysis adjustment

5.2.1fatigue life cycle result at Condition0

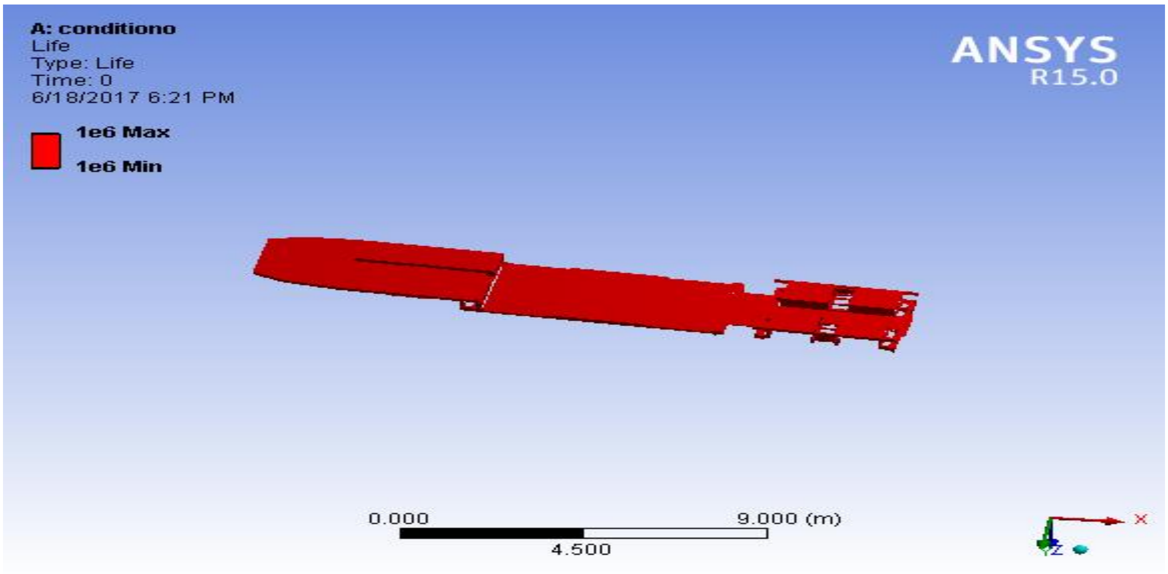


Fig 5.2 fatigue life result at condition0

At this condition the train have only its own weight there is no passenger load at this condition. Fatigue life cycle of this condition meet the design life cycle requirement.

5.2.2fatigue life result at Condition1

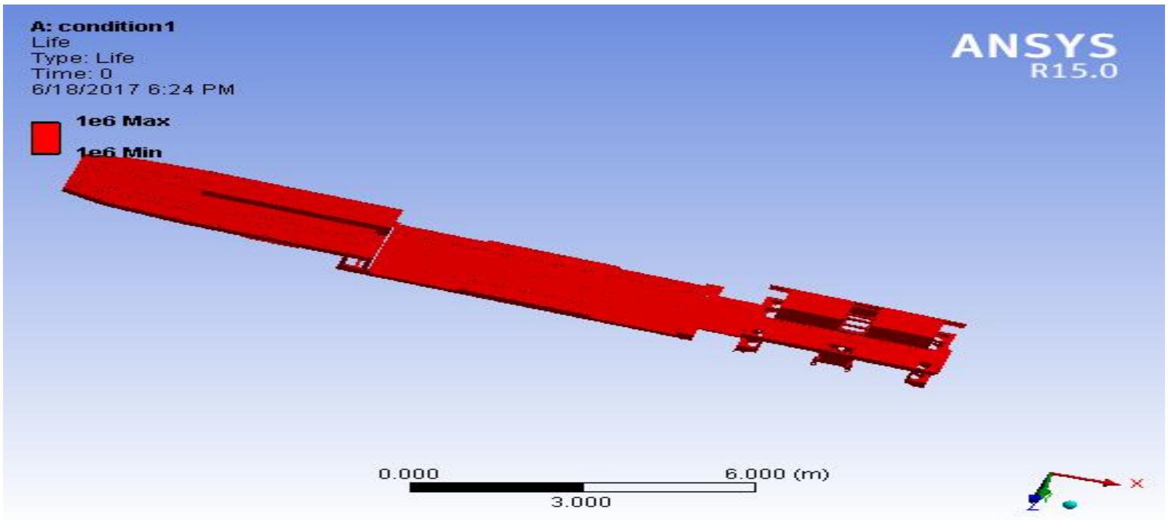


Fig 5.2 fatigue life result at condition1

At this condition the train have it's own weight and 65 seated persons. At this condition also fatigue life of this condition meet the design life cycle requirement

5.2.3 fatigue life result at Condition2

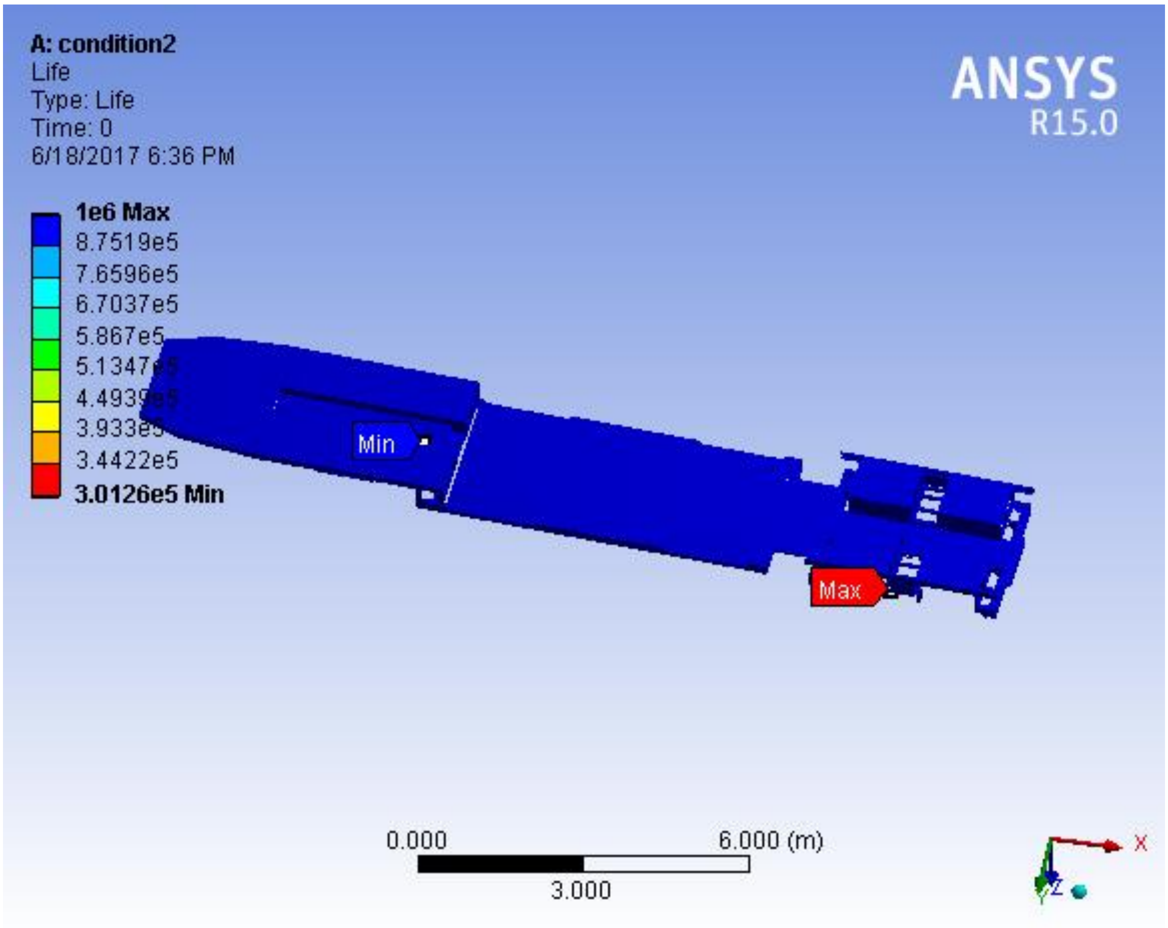


Fig 5.3 fatigue life result at condition2

At this condition the train have it's own weight ,65 seated persons and 63 standing persons (two persons/m^2).At this condition part 256 have minimum value 301,260 cycle. This value also meet the design life cycle.

5.2.4 fatigue life result at Condition3

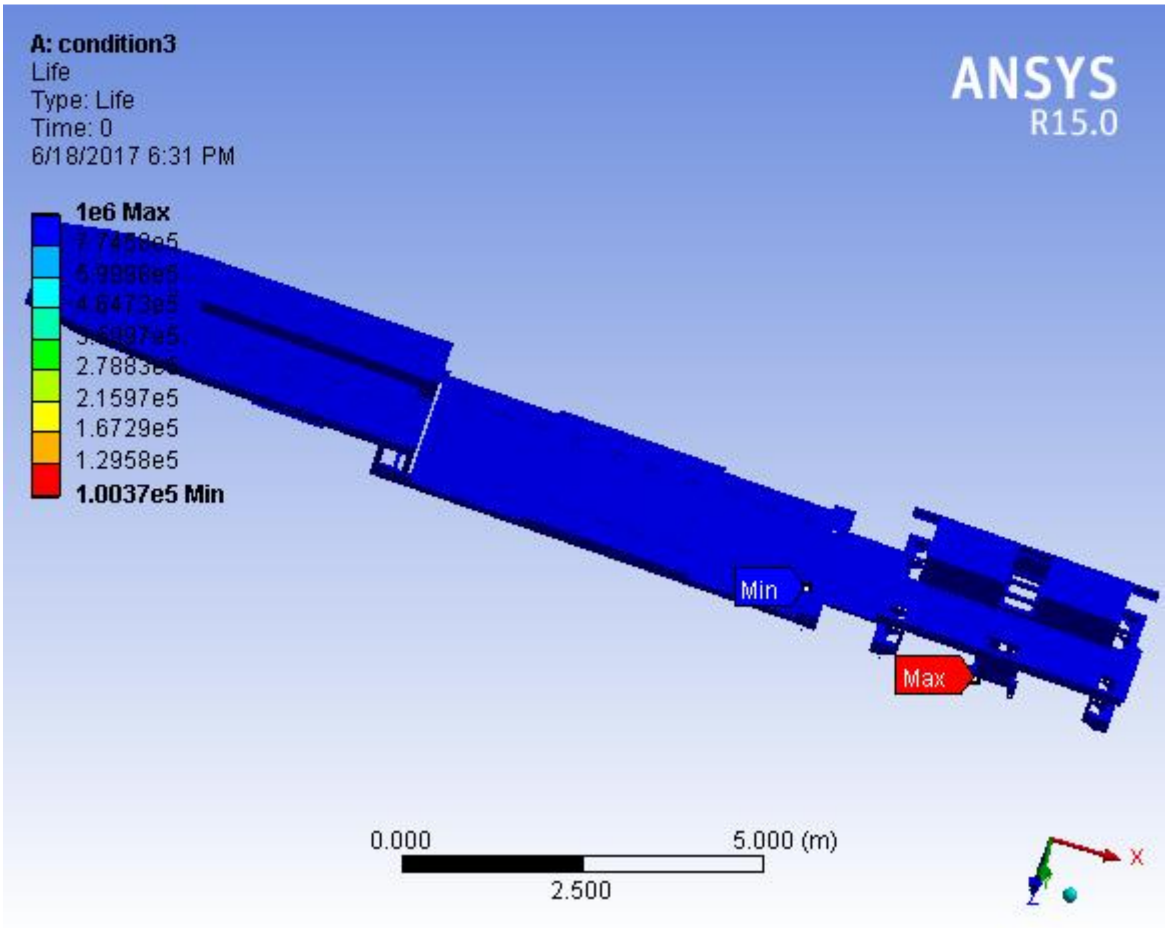


Fig 5.4 fatigue life result at condition3

At this condition the train have it's own weight ,65 seated persons and 126 standing persons (four persons/m^2).At this condition part 174 have minimum value 100370 cycle. This value is minimum from the design life cycle. This train travel only on this condition part174 works for sixteen years with two months and twelve days without failure .and also part 256 and part 146 have eighteen years with one hundred twenty four days and twenty two years with seventy four days respectively.

5.2.5 fatigue life result at Condition4

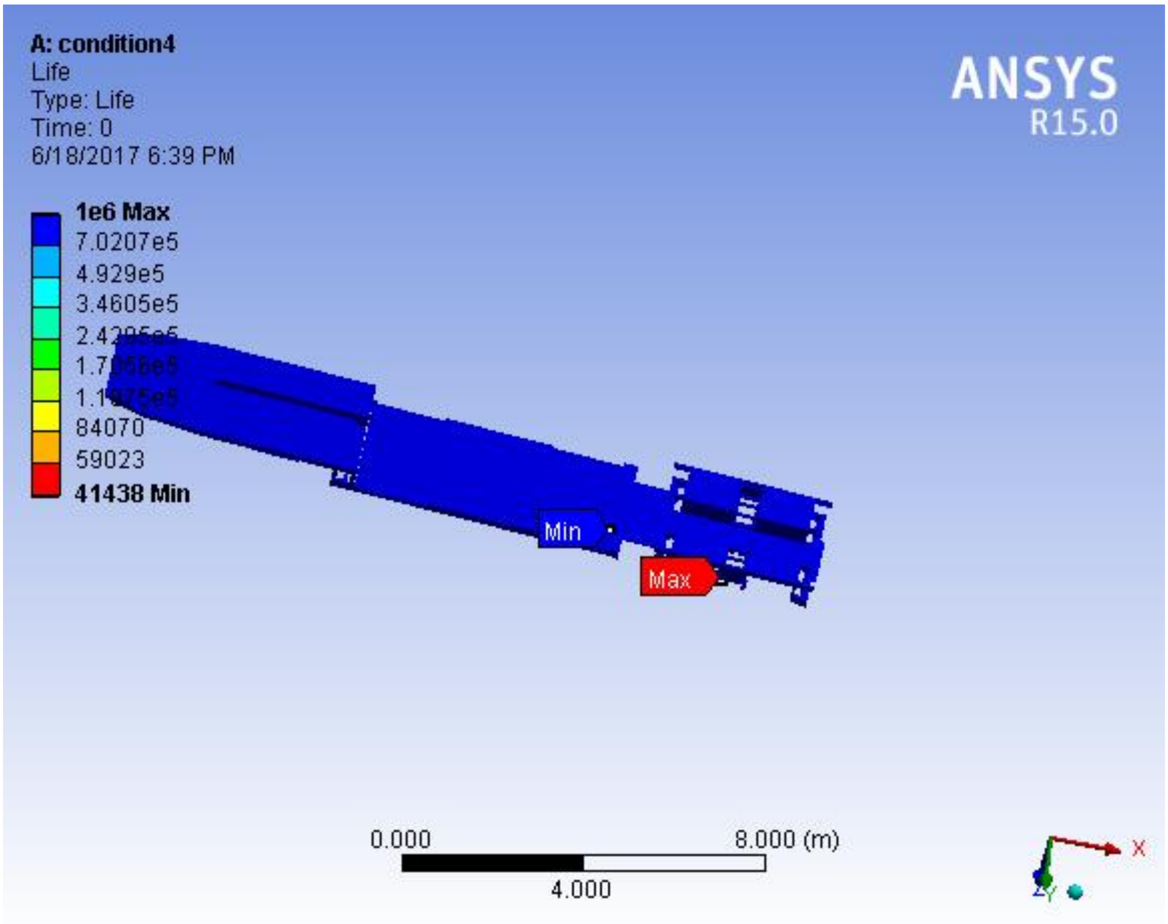


Fig 5.5 fatigue life result at condition4

At this condition the train have it's own weight ,89 seated persons and 189 standing persons (six persons/m^2).At this condition part 174 have minimum value 41438 cycle. This value is minimum from the design life cycle. This train travel only on this condition part174 works for six years with two hundred thirty eight days without failure .and also part 256 have seven years with one hundred sixty seven days , part 146 have nine years with one hundred six days and part140 have seventeen years with two hundred forty nine days.

5.2.6 Fatigue life result at Condition5

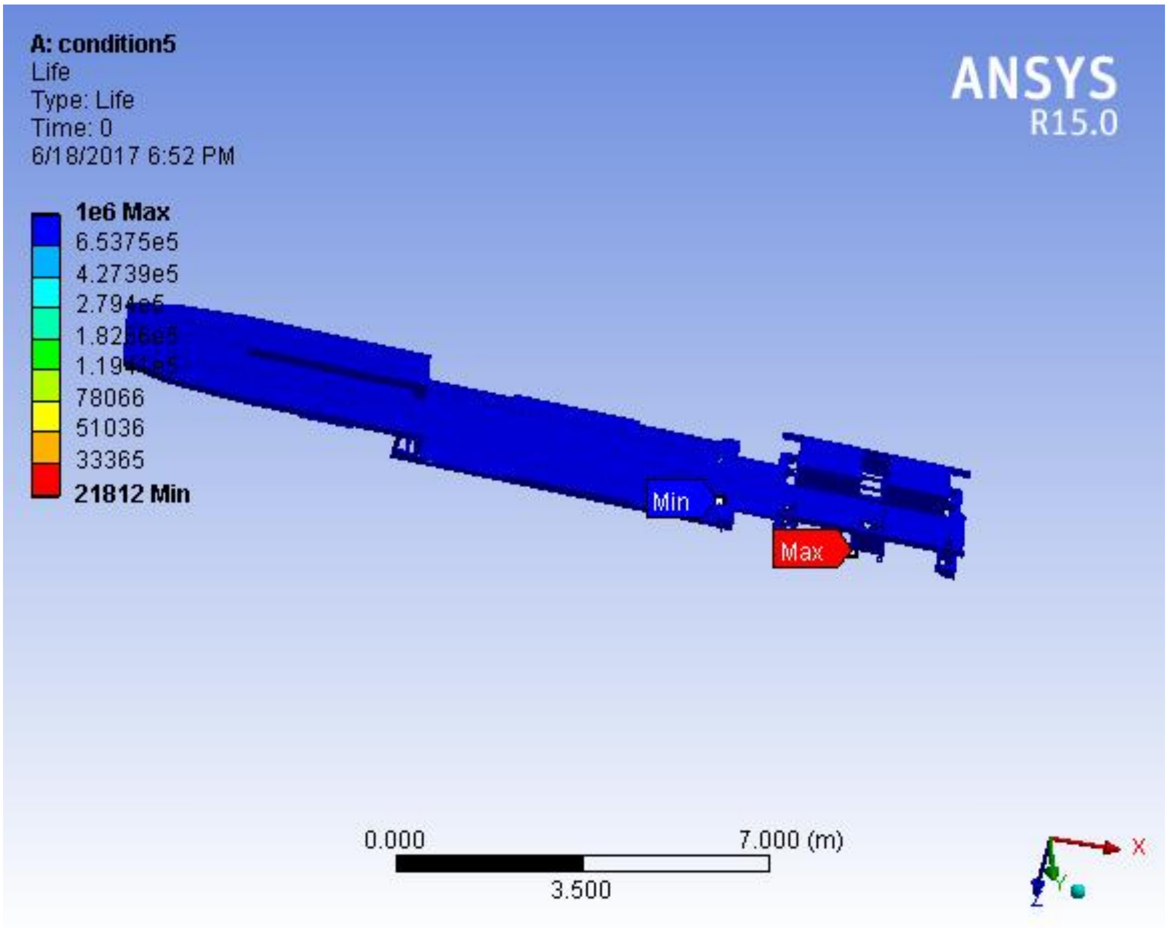


Fig 5.6 fatigue life result at condition5

At this condition the train have it's own weight ,89 seated persons and 252 standing persons (eight persons/m^2).At this condition part 174 have minimum value 21812 cycle. This value is minimum from the design life cycle. This train travel only on this condition part174 works for three years with one hundred eighty days without failure .and also part 256 have four years with one hundred twenty four days , part 146 have five years with twenty three days , part140 have nine years with two hundred eight days, part 205 have twenty two years with one hundred ninety six days and part 153 have twenty seven years with three hundred fourteen days.

5.2.7 Fatigue life result at Condition6

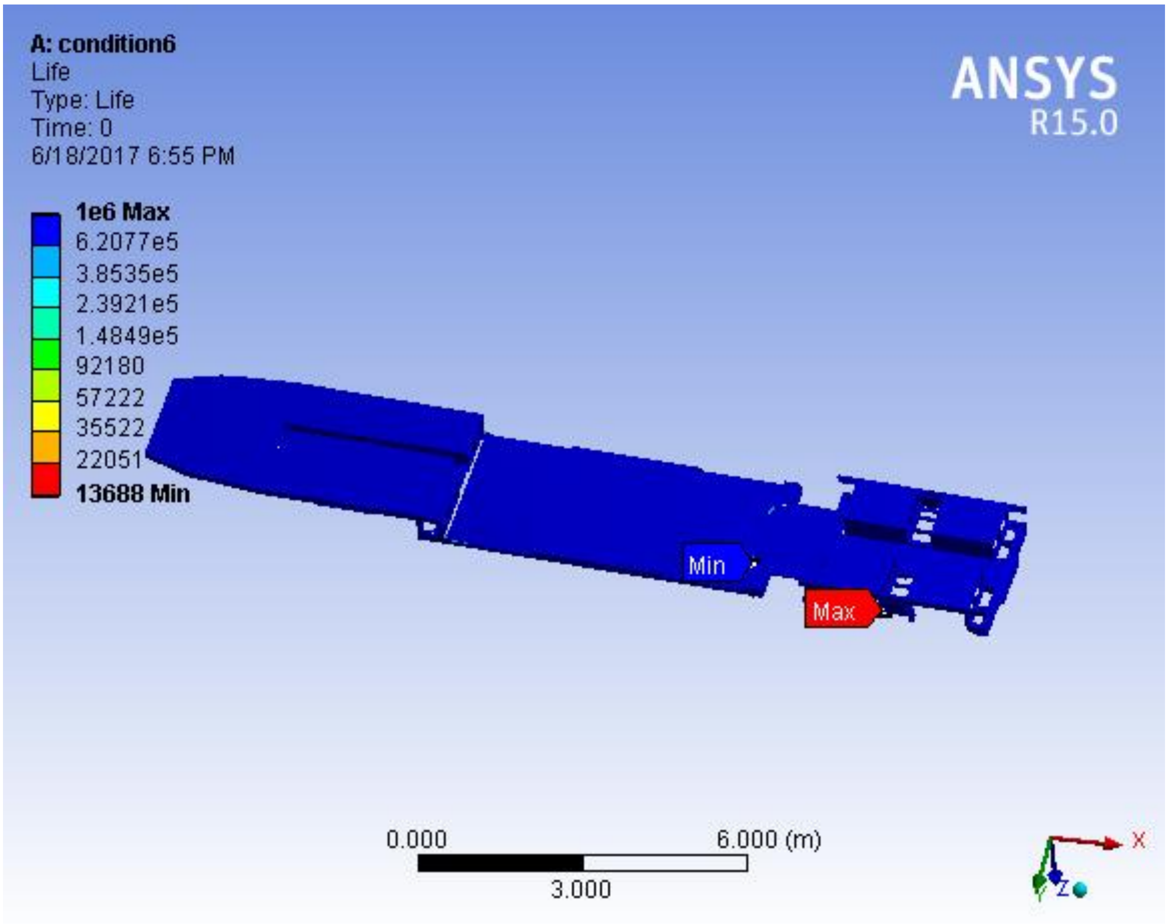


Fig 5.7 fatigue life result at condition6

At this condition the train have it's own weight ,89 seated persons and 319 standing persons (ten persons/m^2).At this condition part 174 have minimum value 13688 cycle. This value is minimum from the design life cycle. This train travel only on this condition part174 works for two years with seventy three days without failure .and also part 256 have two years with two hundred sixty four days , part 146 have three years with thirty four days , part140 have five years with two hundred seventy days, part 205 have thirteen years with two hundred seven days, part 153 have seventeen years with sixty six days and part157 have eighteen years with two hundred ninety five days.

Parts of the under frame steel structure less than from the design fatigue life cycle are showed on the figure below

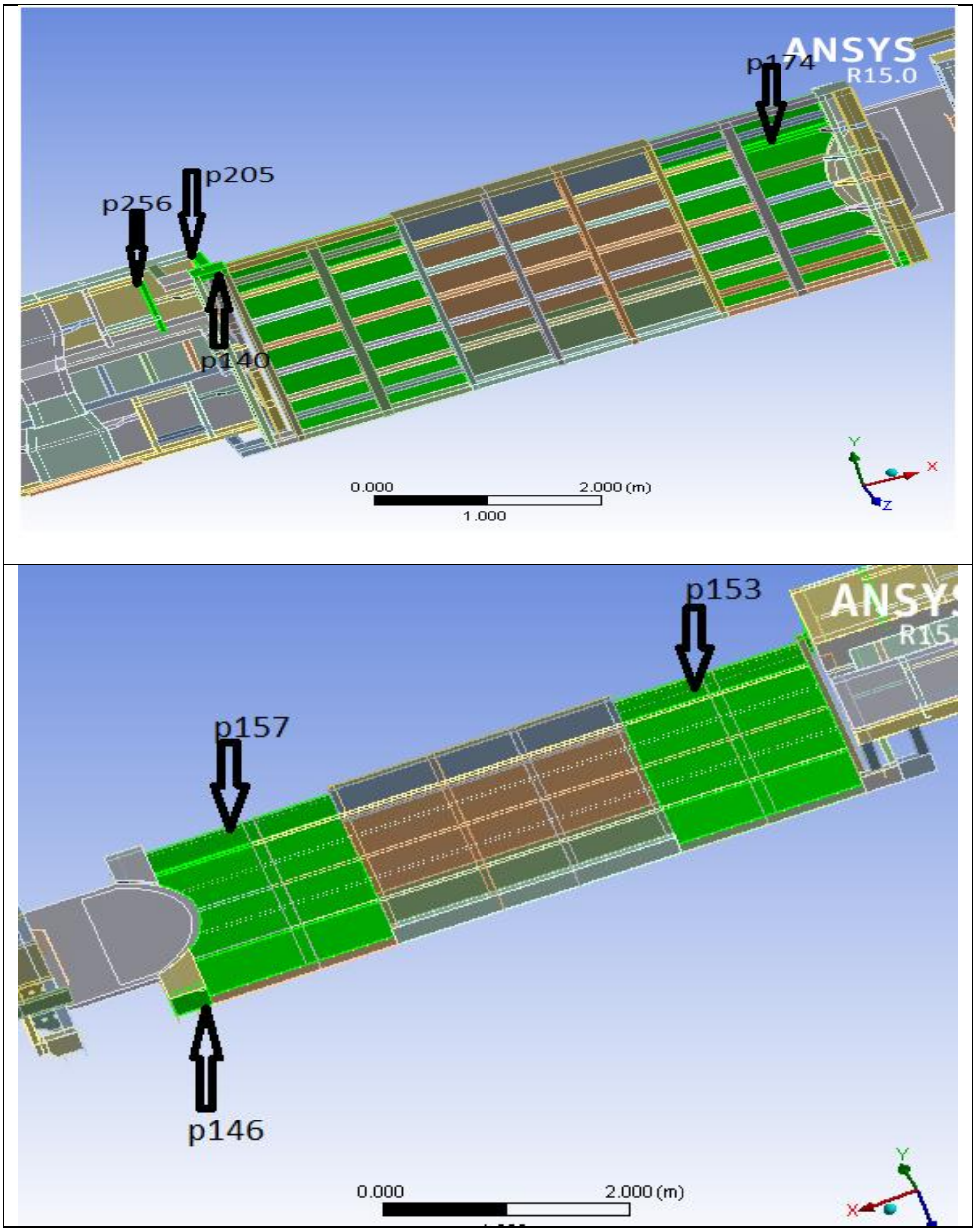


Fig 5.8parts at risk location

From the above results at part 174 minimum life cycle is registered (appendix B.6)

- To estimate total life cycle of part 174 by using Palmgren-Miner Linear Damage Rule

$$\frac{ni}{Nfi} = \frac{n1}{Nf1} + \frac{n2}{Nf2} + \frac{n3}{Nf3} + \ldots = 1$$

$$D=\frac{cond0n}{Nfcond0}+\frac{cond1n}{Nfcond1}+\frac{cond2n}{Nfcond2}+\frac{cond3n}{Nfcond3}+\frac{cond4n}{Nfcond4}+\frac{cond5n}{Nfcond5}+\frac{cond6n}{Nfcond6}=1$$

$$D=\frac{0.056n}{1e006}+\frac{0.167n}{1e006}+\frac{0.111n}{314620}+\frac{0.111n}{100370}+\frac{0.222n}{41438}+\frac{0.222n}{21812}+\frac{0.111n}{13688}=1$$

D = 2.5326e-005 n

n =1/ 2.5326e-005 = 3.9485e+004

total life of part 174 will be 39485 cycle.

Finally life cycle of part 134 at the total operating condition six years with one hundred thirty days.

The other parts there fatigue life is below the requirement at condition6 there total fatigue life will be on the following table

Table 5.1 Total life cycle of risked parts.

parts	Life (cycle)
Part256	47491
Part157	335420
Part140	104540
Part205	244240
Part153	316880
Part146	55637

From the above table part 157,part205 and part 153 can reach the design requirement. but part 256,part 140 and part 146 have below the design requirement fatigue life cycle.

Four parts on the under frame structure have minimum fatigue life cycle. To maximize their fatigue life adding piece metal as reinforcement is one option.

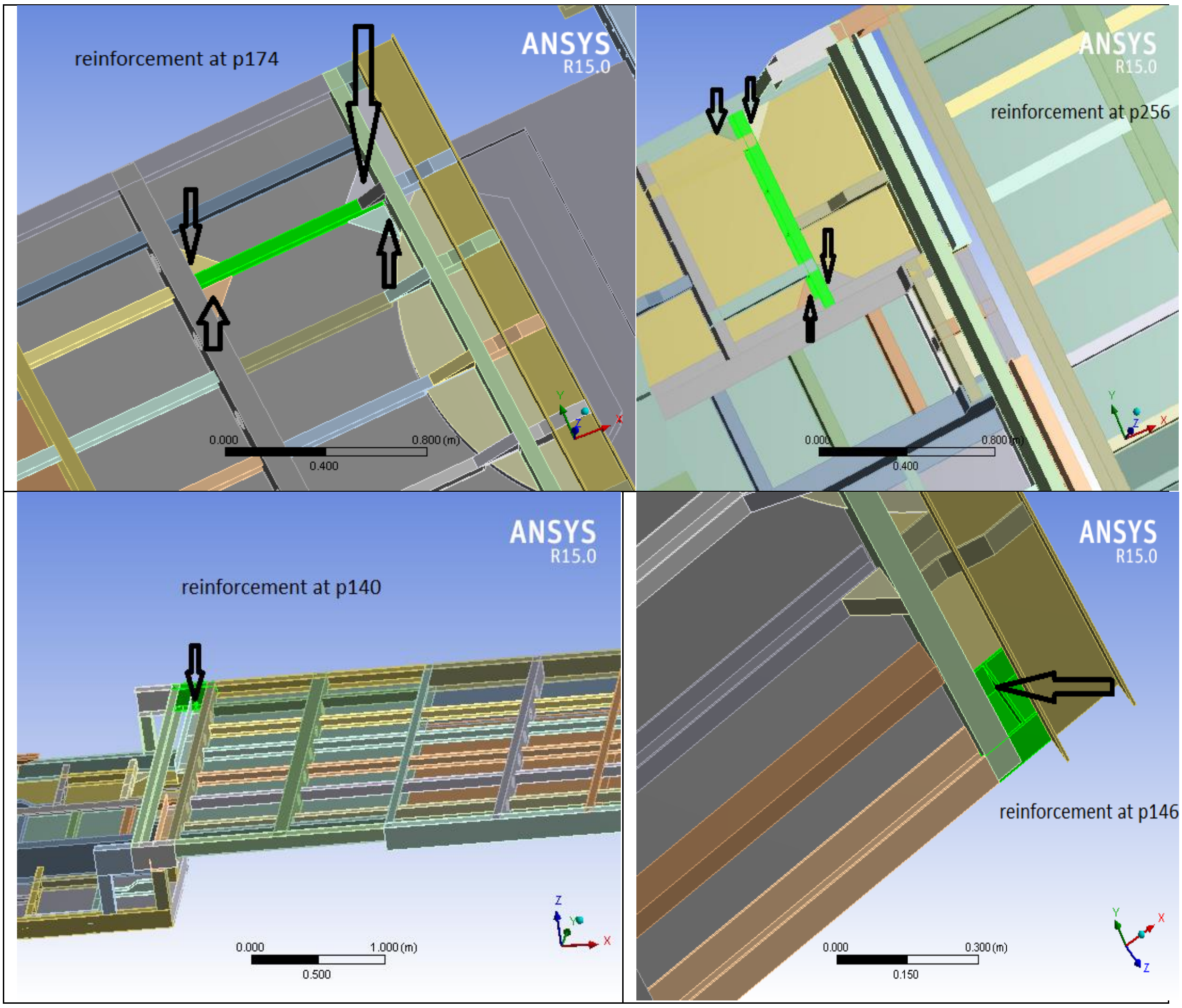


Fig5.9 Position of reinforcement

Therefore by adding the reinforcement the following results are gain.[appendix B.7]

Table 5.2 fatigue life values after reinforcement

parts	Life(cycle)
Part174	$1e^{006}$
Part256	$1e^{006}$
Part140	547650
Part146	274650

The above results are gain at condition6 i.e 10 persons/m^2 standing and 89 seated persons. Those fatigue values are above from the required minimum fatigue life 185,760 cycle. Therefore the under frame steel structure will meet the fatigue life cycle requirement.

5.3 Modal analysis result

Modal analysis is a numerical technique to calculate the vibration characteristics of structure, the structure vibration characteristics including natural frequency and vibration mode. Modal analysis is the basic of dynamics analysis, also is the foundation of other dynamics analysis, such as the response spectrum analysis, random vibration analysis and the harmonic response analysis. Modal analysis can make structure design to avoid the resonance, help to solve the control parameter in other dynamic analysis.[23]

During operation the car body is continuously excited due to the dynamic interaction between track, wheels, bogie and car body. To avoid resonances, a common practical design rule is to keep the first natural frequency of the car body as high as possible, typically above 12 Hz.[22]

Results for the Modal analysis of AALRT car body under frame steel structure are listed below. The six lowest mode shapes and un damped frequencies of the studied body under frame steel structure is shown in the table below.

Table 5.3 Modal frequency and displacement of rail vehicle car body

No	Mode shape	Frequency (Hz)	Max .deformation(m)
1	Vertical bending 1	20.337	0.57591
2	Torsion on lateral axis 1	21.853	0.38696
3	Longitudinal bending	24.091	0.45532
4	Vertical bending 2	25.205	0.77091
5	Torsion on lateral axis 2	26.039	0.082755
6	Torsion on vertical axis	31.752	0.049652

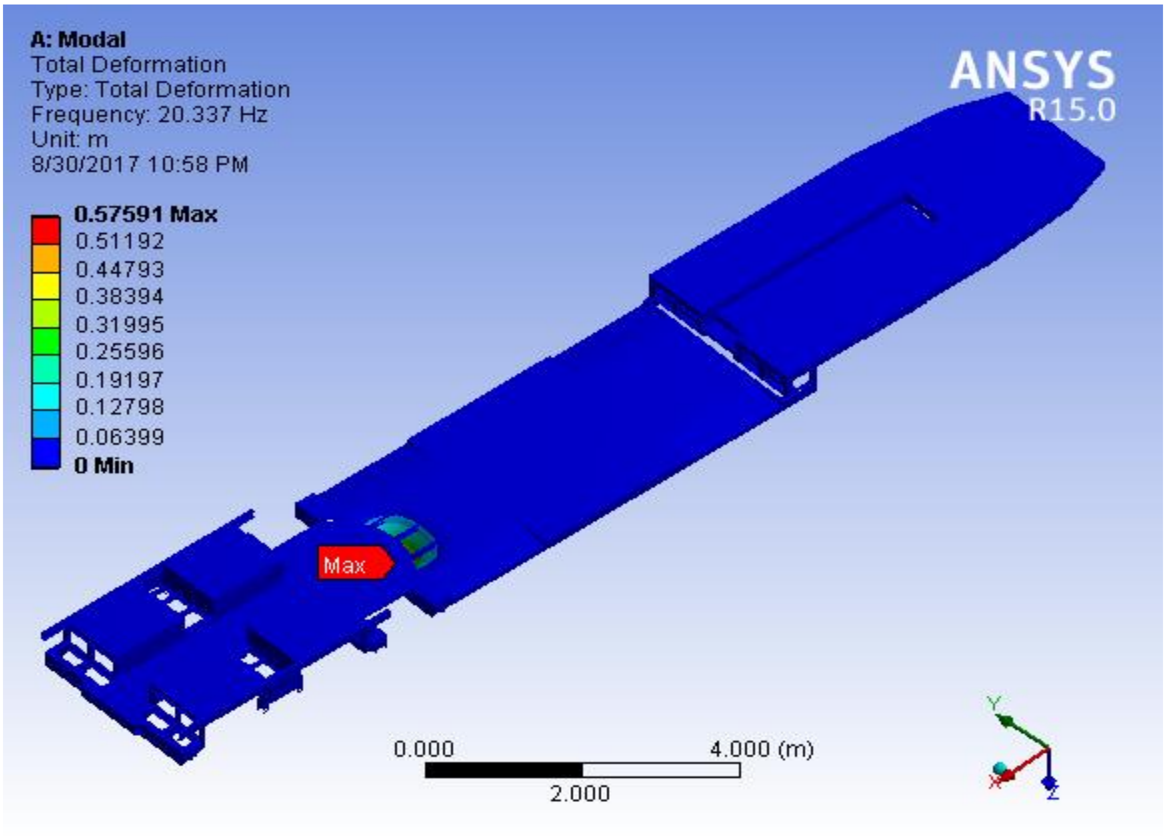


Fig 5.10 vertical bending 1 mode shape

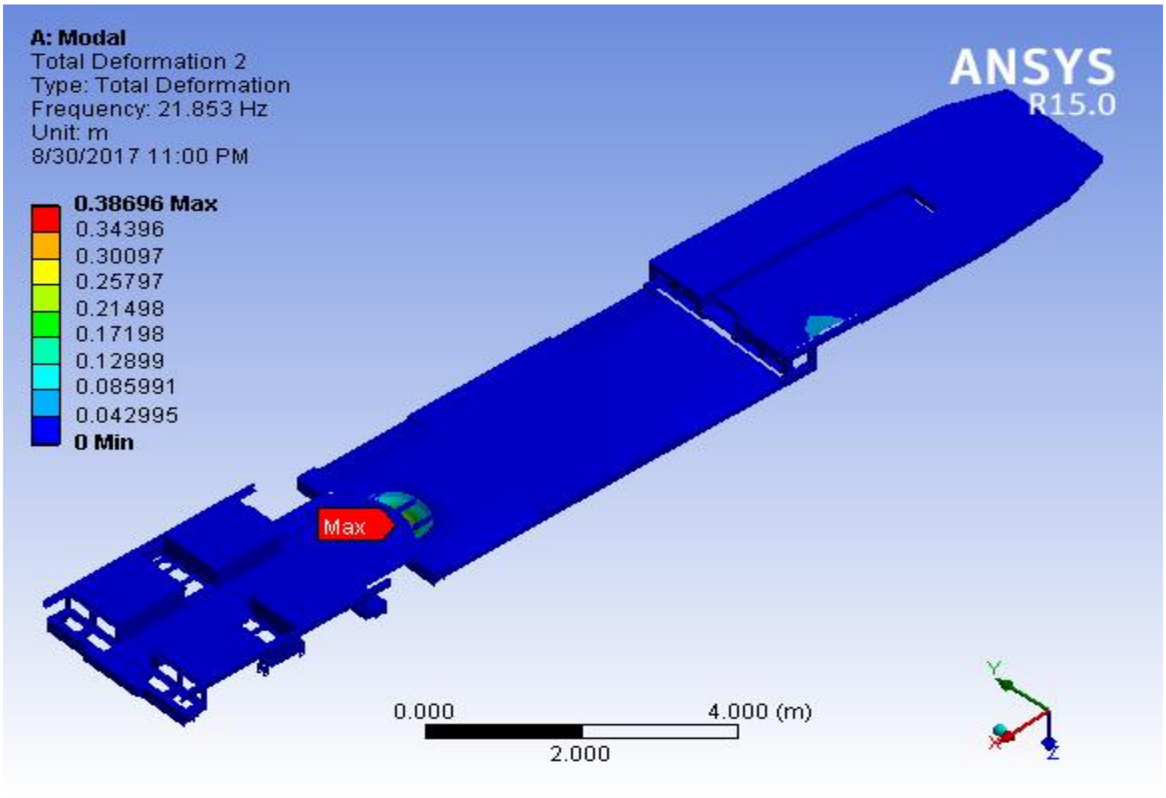


Fig 5.11 Torsion on lateral axis 1 mode shape

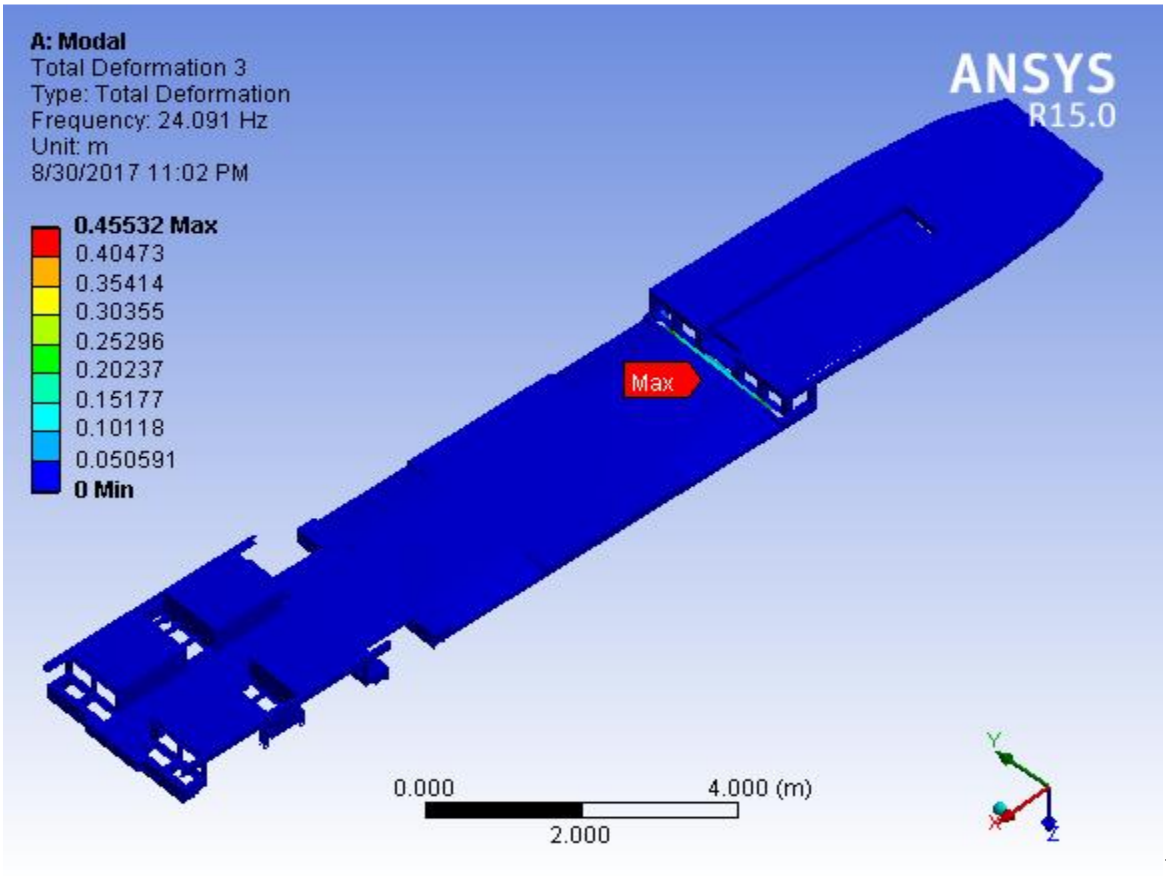


Fig 5.12 Longitudinal bending mode shape

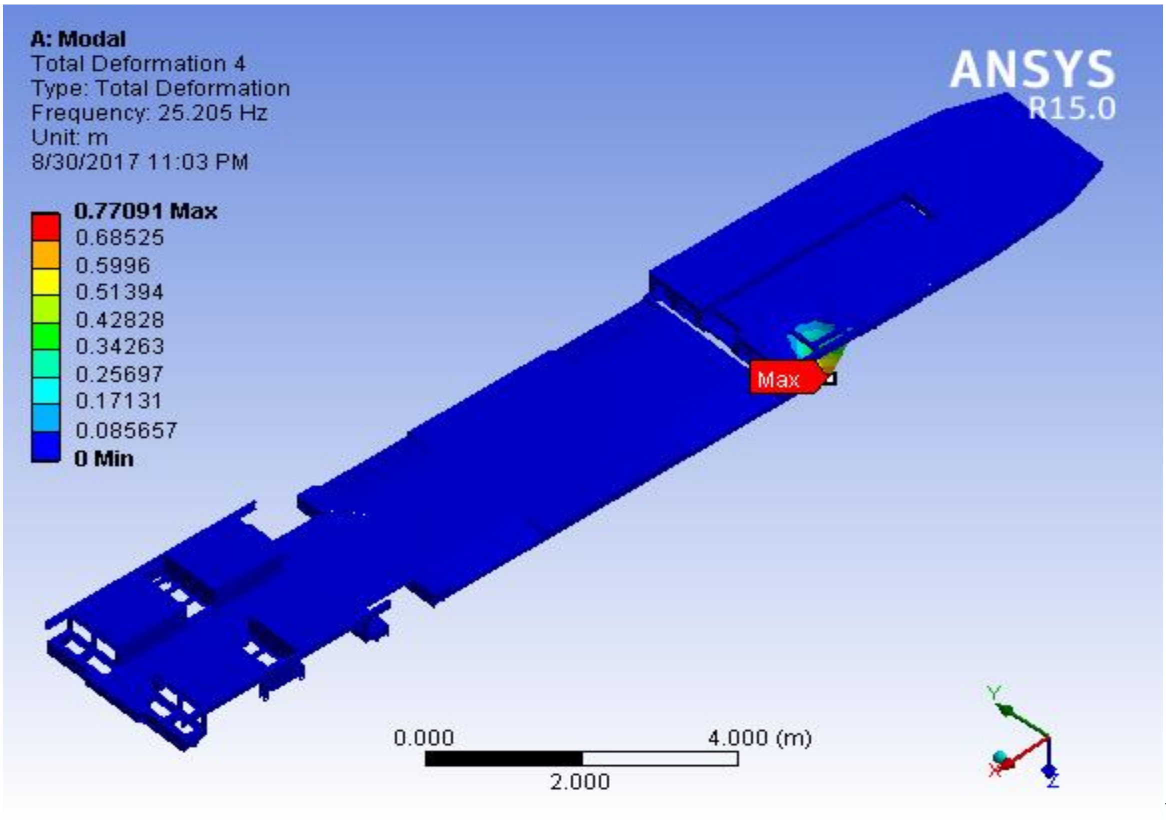


Fig 5.13 Vertical bending 2 mode shape

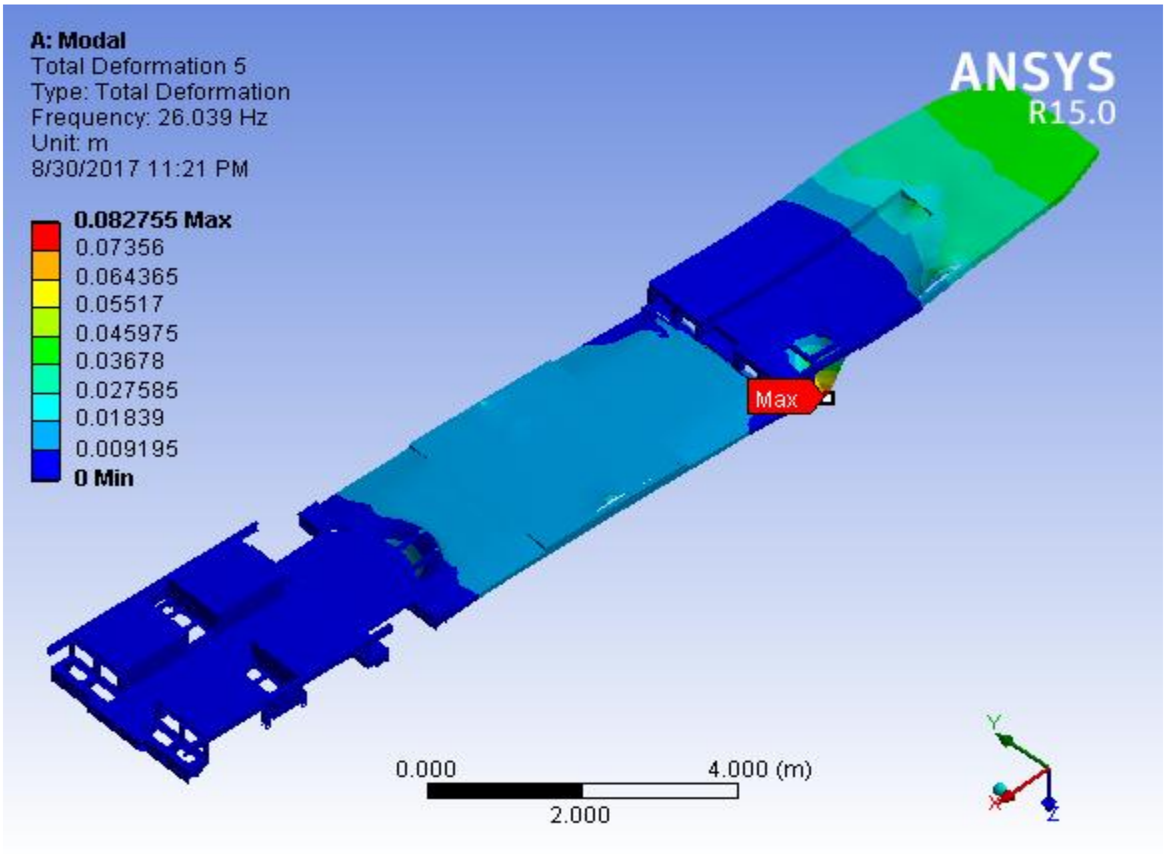


Fig 5.14 Torsion on lateral axis 2 mode shape

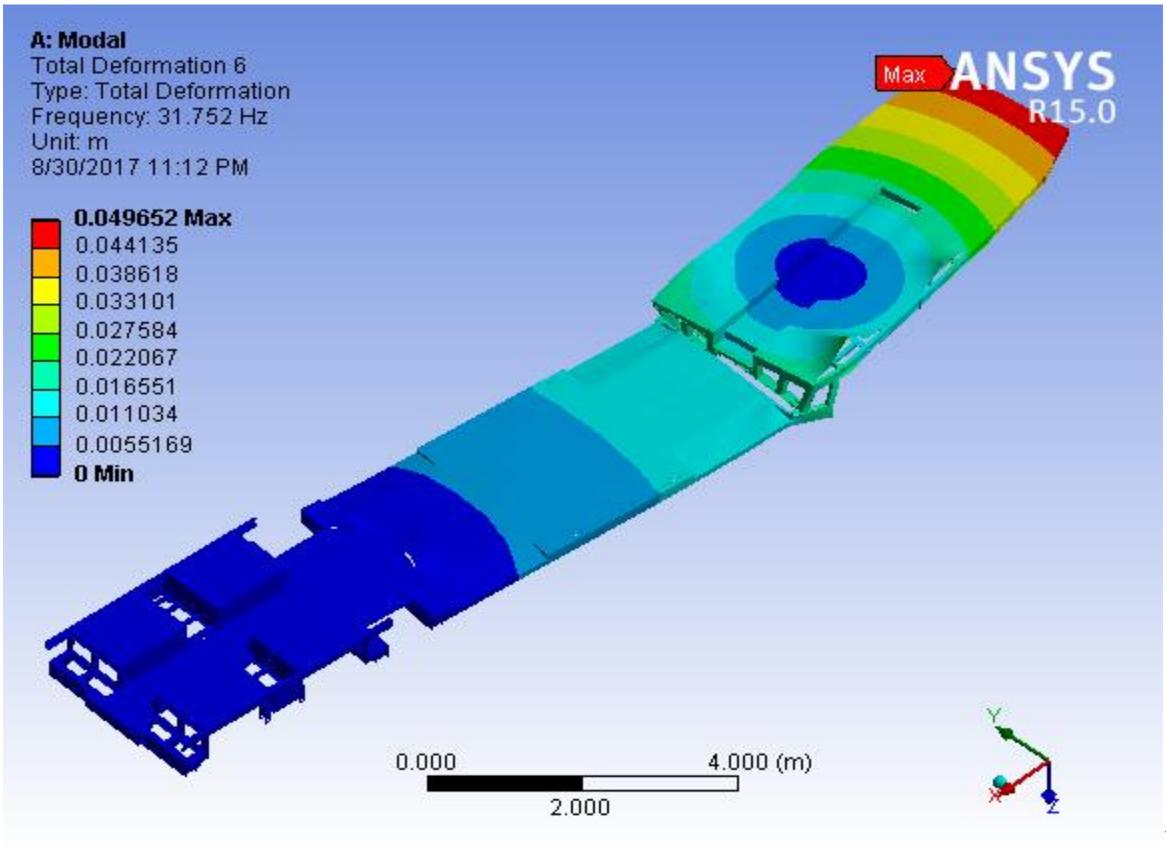


Fig 5.15 Torsion on vertical axis mode shape

Chapter six

Conclusion and Recommendation

6.1 Conclusion

From the analysis and the results; the unacceptable loading which is 10 persons /m^2 standing and 89 seated persons decreases the train under frame life cycle at around the door area and the areas which is the contact of high floor and low floor. The minimum value of the fatigue life at this area is 39,485 cycles.

In some cases like parts 153,157 and 205 the under frame steel structure life cycles are below the required life at condition 6(10 persons/m^2 standing & 89 seated persons) but the total average life cycles of those parts meet the desired (required) life cycles.

From the results the minimum fatigue life cycles are occurred on part 174 which is 39485 cycles but from those parts ; part 140,146,174 and 256 life cycle are below the required life cycle. But using reinforcement; life cycle of this parts are increased and can meet the desired life cycles.

Finally the under frame steel structures life cycle are safe except the above four parts and also it is possible to use reinforcement to increase the unsafe parts life cycle to meet the designed life cycles. And also due to modal analysis the under frame structure can meet the desired minimum requirement

6.2 Recommendation

Depend on the analysis result to maximize the life cycle of the under frame steel structure at high floor and low floor contact and Exit/Entrance areas it is recommended adding piece metals as reinforcement .

AALRT coordinators should reduce unacceptable passenger overload by operating double car at a time and by minimizing the time interval between trains during peak hours.

6.3 Future work

- Analyzing passenger over load effect on the life cycle of AALRT train car body steel structure by using dynamic strength
- Analyzing passenger over load effect on the life cycle of AALRT train car body steel structure at curved rail

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Appendix A
Time table of car116 rail train and it's Average loading condition

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	06:04	1	Torhailoch	07:01	2
2	Meri	06:06	1	Coca cola	07:03	2
3	c.m.c.	06:08	1	St. Lideta		
4	St .michael	06:10	1	Tegbared	07:07	3
5	Civil service collage	06:12	1	Mexico	07:09	3
6	Management institute	06:14	1	Leghar	07:11	4
7	Gurd shola 1	06:17	1	Stadium	07:13	5
8	Gurd shola 2	06:20	1	St.Estifanos	07:15	5
9	Megenagna	06:22	1	Bambis	07:17	5
10	Lemhotel	06:23	1	St. Urael	07:19	5
11	Hayahulet 1	06:25	1	Hayahulet 2	07:21	5
12	Hayahulet 2	06:28	1	Hayahulet 1	07:24	5
13	St. Urael	06:30	1	Lemhotel	07:26	5
14	Bambis	06:32	1	Megenagna	07:27	4
15	St.Estifanos	06:34	1	Gurd shola 2	07:29	4
16	Stadium	06:36	1	Gurd shola 1	07:31	3
17	Leghar	06:38	1	Management institute	07:33	3
18	Mexico	06:40	1	Civil service collage	07:36	3
19	Tegbared	06:42	1	St .michael	07:38	3
20	St. Lideta			c.m.c.	07:40	2
21	Coca cola	06:46	1	Meri	07:42	1
22	Torhailoch	06:48	0	Ayat	07:44	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	07:54	2	torhailoch	08:51	2
2	Meri	07:56	3	Coca cola	08:53	2
3	c.m.c.	07:58	4	St. Lideta		
4	St .michael	08:00	5	Tegbared	08:57	3
5	Civil service collage	08:02	5	Mexico	08:59	4
6	Management institute	08:04	6	Leghar	09:01	4
7	Gurd shola 1	08:07	6	Stadium	09:03	4
8	Gurd shola 2	08:10	6	St.Estifanos	09:05	4
9	Megenagna	08:12	5	Bambis	09:07	4
10	Lemhotel	08:13	5	St. Urael	09:09	5
11	Hayahulet 1	08:15	5	Hayahulet 2	09:11	5
12	Hayahulet 2	08:18	5	Hayahulet 1	09:14	5
13	St. Urael	08:20	5	Lemhotel	09:16	5
14	Bambis	08:22	5	Megenagna	09:17	5
15	St.Estifanos	08:24	5	Gurd shola 2	09:19	4
16	Stadium	08:26	4	Gurd shola 1	09:21	4
17	Leghar	08:28	4	Management institute	09:23	3
18	Mexico	08:30	3	Civil service collage	09:26	3
19	Tegbared	08:32	2	St .michael	09:28	3
20	St. Lideta			c.m.c.	09:30	3
21	Coca cola	08:36	2	Meri	09:32	2
22	torhailoch	08:38	0	Ayat	09:34	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	09:44	1	torhailoch	10:41	1
2	Meri	09:46	1	Coca cola	10:43	1
3	c.m.c.	09:48	2	St. Lideta		
4	St .michael	09:50	2	Tegbared	10:47	1
5	Civil service collage	09:52	2	Mexico	10:49	2
6	Management institute	09:54	2	Leghar	10:51	2
7	Gurd shola 1	09:57	2	Stadium	10:53	2
8	Gurd shola 2	10:00	2	St.Estifanos	10:55	2
9	Megenagna	10:02	2	Bambis	10:57	2
10	Lemhotel	10:03	3	St. Urael	10:59	2
11	Hayahulet 1	10:05	3	Hayahulet 2	11:01	2
12	Hayahulet 2	10:08	3	Hayahulet 1	11:04	2
13	St. Urael	10:10	3	Lemhotel	11:06	2
14	Bambis	10:12	3	Megenagna	11:07	2
15	St.Estifanos	10:14	3	Gurd shola 2	11:09	2
16	Stadium	10:16	3	Gurd shola 1	11:11	2
17	Leghar	10:18	2	Management institute	11:13	2
18	Mexico	10:20	2	Civil service collage	11:16	1
19	Tegbared	10:22	2	St .michael	11:18	1
20	St. Lideta			c.m.c.	11:20	1
21	Coca cola	10:26	1	Meri	11:22	1
22	torhailoch	10:28	0	Ayat	11:24	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	11:34	2	torhailoch	12:31	2
2	Meri	11:36	2	Coca cola	12:33	2
3	c.m.c.	11:38	2	St. Lideta		
4	St .michael	11:40	2	Tegbared	12:37	3
5	Civil service collage	11:42	2	Mexico	12:39	3
6	Management institute	11:44	2	Leghar	12:41	3
7	Gurd shola 1	11:47	3	Stadium	12:43	4
8	Gurd shola 2	11:50	3	St.Estifanos	12:45	4
9	Megenagna	11:52	3	Bambis	12:47	4
10	Lemhotel	11:53	3	St. Urael	12:49	4
11	Hayahulet 1	11:55	4	Hayahulet 2	12:51	4
12	Hayahulet 2	11:58	4	Hayahulet 1	12:54	4
13	St. Urael	12:00	4	Lemhotel	12:56	5
14	Bambis	12:02	4	Megenagna	12:57	5
15	St.Estifanos	12:04	4	Gurd shola 2	12:59	5
16	Stadium	12:06	4	Gurd shola 1	13:01	4
17	Leghar	12:08	4	Management institute	13:03	4
18	Mexico	12:10	4	Civil service collage	13:06	3
19	Tegbared	12:12	3	St .michael	13:08	3
20	St. Lideta			c.m.c.	13:10	3
21	Coca cola	12:16	2	Meri	13:12	2
22	torhailoch	12:18	0	Ayat	13:14	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	13:24	2	torhailoch	14:21	1
2	Meri	13:26	2	Coca cola	14:23	2
3	c.m.c.	13:28	2	St. Lideta		
4	St .michael	13:30	2	Tegbared	14:27	2
5	Civil service collage	13:32	2	Mexico	14:29	2
6	Management institute	13:34	3	Leghar	14:31	3
7	Gurd shola 1	13:37	4	Stadium	14:33	3
8	Gurd shola 2	13:40	4	St.Estifanos	14:35	3
9	Megenagna	13:42	4	Bambis	14:37	3
10	Lemhotel	13:43	4	St. Urael	14:39	3
11	Hayahulet 1	13:45	4	Hayahulet 2	14:41	3
12	Hayahulet 2	13:48	4	Hayahulet 1	14:44	3
13	St. Urael	13:50	4	Lemhotel	14:46	3
14	Bambis	13:52	4	Megenagna	14:47	3
15	St.Estifanos	13:54	4	Gurd shola 2	14:49	3
16	Stadium	13:56	4	Gurd shola 1	14:51	3
17	Leghar	13:58	4	Management institute	14:53	3
18	Mexico	14:00	4	Civil service collage	14:56	3
19	Tegbared	14:02	3	St .michael	14:58	2
20	St. Lideta			c.m.c.	15:00	2
21	Coca cola	14:06	2	Meri	15:02	1
22	torhailoch	14:08	0	Ayat	15:04	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	15:14	2	torhailoch	16:11	2
2	Meri	15:16	2	Coca cola	16:13	3
3	c.m.c.	15:18	2	St. Lideta		
4	St .michael	15:20	2	Tegbared	16:17	3
5	Civil service collage	15:22	2	Mexico	16:19	3
6	Management institute	15:24	2	Leghar	16:21	4
7	Gurd shola 1	15:27	3	Stadium	16:23	4
8	Gurd shola 2	15:30	3	St.Estifanos	16:25	4
9	Megenagna	15:32	3	Bambis	16:27	4
10	Lemhotel	15:33	3	St. Urael	16:29	4
11	Hayahulet 1	15:35	3	Hayahulet 2	16:31	4
12	Hayahulet 2	15:38	3	Hayahulet 1	16:34	4
13	St. Urael	15:40	3	Lemhotel	16:36	4
14	Bambis	15:42	3	Megenagna	16:37	4
15	St.Estifanos	15:44	3	Gurd shola 2	16:39	4
16	Stadium	15:46	3	Gurd shola 1	16:41	4
17	Leghar	15:48	3	Management institute	16:43	4
18	Mexico	15:50	3	Civil service collage	16:46	4
19	Tegbared	15:52	2	St .michael	16:48	3
20	St. Lideta			c.m.c.	16:50	3
21	Coca cola	15:56	2	Meri	16:52	3
22	torhailoch	15:58	0	Ayat	16:54	0

No	Station	Time	Loading condition	Station	Time	Loading condition
1	Ayat	17:04	1	torhailoch	17:59	2
2	Meri	17:06	2	Coca cola	18:01	2
3	c.m.c.	17:08	2	St. Lideta		
4	St .michael	17:10	3	Tegbared	18:05	3
5	Civil service collage	17:12	3	Mexico	18:07	4
6	Management institute	17:14	3	Leghar	18:09	4
7	Gurd shola 1	17:17	3	Stadium	18:11	4
8	Gurd shola 2	17:20	4	St.Estifanos	18:13	5
9	Megenagna	17:22	5	Bambis	18:15	5
10	Lemhotel	17:23	5	St. Urael	18:17	5
11	Hayahulet 1	17:25	6	Hayahulet 2	18:19	5
12	Hayahulet 2	17:28	6	Hayahulet 1	18:21	5
13	St. Urael	17:30	6	Lemhotel	18:23	5
14	Bambis	17:32	6	Megenagna	18:26	5
15	St.Estifanos	17:34	6	Gurd shola 2	18:29	5
16	Stadium	17:36	6	Gurd shola 1	18:31	4
17	Leghar	17:38	5	Management institute	18:34	4
18	Mexico	17:40	5	Civil service collage	18:36	4
19	Tegbared	17:42	5	St .michael	18:38	4
20	St. Lideta			c.m.c.	18:40	4
21	Coca cola	17:46	4	Meri	18:43	2
22	torhailoch	17:48	0	Ayat	18:46	0

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	19:04	1	torhailoch	20:01	1
2	Meri	19:06	1	Coca cola	20:03	1
3	c.m.c.	19:08	1	St. Lideta		
4	St .michael	19:10	1	Tegbared	20:07	1
5	Civil service collage	19:12	1	Mexico	20:09	1
6	Management institute	19:14	1	Leghar	20:11	1
7	Gurd shola 1	19:17	1	Stadium	20:13	1
8	Gurd shola 2	19:20	1	St.Estifanos	20:15	1
9	Megenagna	19:22	2	Bambis	20:17	1
10	Lemhotel	19:23	2	St. Urael	20:19	1
11	Hayahulet 1	19:25	2	Hayahulet 2	20:21	1
12	Hayahulet 2	19:28	2	Hayahulet 1	20:24	1
13	St. Urael	19:30	2	Lemhotel	20:26	1
14	Bambis	19:32	2	Megenagna	20:27	1
15	St.Estifanos	19:34	2	Gurd shola 2	20:29	1
16	Stadium	19:36	2	Gurd shola 1	20:31	1
17	Leghar	19:38	2	Management institute	20:33	1
18	Mexico	19:40	1	Civil service collage	20:36	1
19	Tegbared	19:42	1	St .michael	20:38	1
20	St. Lideta			c.m.c.	20:40	1
21	Coca cola	19:46	1	Meri	20:42	1
22	torhailoch	19:48	1	Ayat	20:44	1

No	Station			Station		
		Time	Loading condition		Time	Loading condition
1	Ayat	21:04	1	torhailoch	22:00	0
2	Meri	21:06	1	Coca cola	22:02	0
3	c.m.c.	21:08	1	St. Lideta		
4	St .michael	21:10	1	Tegbared	22:04	0
5	Civil service collage	21:12	1	Mexico	22:06	0
6	Management institute	21:14	1	Leghar	22:10	0
7	Gurd shola 1	21:17	1	Stadium	22:13	0
8	Gurd shola 2	21:20	1	St.Estifanos	22:14	0
9	Megenagna	21:22	1	Bambis	22:17	0
10	Lemhotel	21:23	1	St. Urael	22:18	0
11	Hayahulet 1	21:25	1	Hayahulet 2	22:21	0
12	Hayahulet 2	21:28	1	Hayahulet 1	22:24	0
13	St. Urael	21:30	1	Lemhotel	22:26	0
14	Bambis	21:32	1	Megenagna	22:27	0
15	St.Estifanos	21:34	1	Gurd shola 2	22:30	0
16	Stadium	21:36	1	Gurd shola 1	22:32	0
17	Leghar	21:38	1	Management institute	22:33	0
18	Mexico	21:40	1	Civil service collage	22:35	0
19	Tegbared	21:42	1	St .michael	22:36	0
20	St. Lideta			c.m.c.	22:38	0
21	Coca cola	21:46	1	Meri	20:39	0
22	torhailoch	21:48	0	Ayat	20:38	0

Appendix B

Fatigue life results on different conditions

B.1 At condition0

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 146

B.2 At condition1

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 146

B.3At condition2

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	3.1462e+005 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	3.0126e+005 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	4.8652e+005 cycles
Minimum Occurs On	Part 146

B.4At condition3

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.0037e+005 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.1369e+005 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	6 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	2.9377e+005 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	4 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.3755e+005 cycles
Minimum Occurs On	Part 146

B.5At condition4

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	41438 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	46358 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	5.0537e+005 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.0975e+005 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	2.9881e+005 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	5.7866e+005 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	57632 cycles
Minimum Occurs On	Part 146

B.5 At condition5

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	21812 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	4 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	27006 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.9365e+005 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	4 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	59471 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.3976e+005 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.7285e+005 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	4.3803e+005 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	31368 cycles
Minimum Occurs On	Part 146

B.6 At condition6

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	13688 cycles
Minimum Occurs On	Part 174

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	17131 cycles
Minimum Occurs On	Part 256

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.1676e+005 cycles
Minimum Occurs On	Part 157

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	6 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	35823 cycles
Minimum Occurs On	Part 140

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	4 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	84223 cycles
Minimum Occurs On	Part 205

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.0645e+005 cycles
Minimum Occurs On	Part 153

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	2.0138e+005 cycles
Minimum Occurs On	Part 179

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	19184 cycles
Minimum Occurs On	Part 146

B.7 At condition6 with reinforcement

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	3 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	54487 cycles
Minimum Occurs On	Part 174

Section Planes | **Details of "Life"** | Manage Views

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	2.7465e+005 cycles
Minimum Occurs On	Part 146

Section Planes | **Details of "Life"** | Manage Views

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	1.e+006 cycles
Minimum Occurs On	Part 264

Details of "Life"

Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Type	Life
Identifier	
Suppressed	No
Integration Point Results	
Average Across Bodies	No
Results	
Minimum	5.4765e+005 cycles
Minimum Occurs On	Part 140