"VIBRATION ANALYSIS OF HIGH SPEED RAILWAY TRACK STRUCTURE"

A DISSERTATION

SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by:

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CANDIDATE'S DECLARATION

I, Kiran Chholak , 2K17/STE/07 student of M.Tech Structural engineering , hereby declare that the project Dissertation titled **"VIBRATION ANALYSIS OF HIGH SPEED RAILWAY TRACK STRUCTURE"** which is submitted by me to the department of Civil engineering , Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without paper citation. The work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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I hereby certify that the Project Dissertation titled "**VIBRATION ANALYSIS OF HIGH SPEED RAILWAY TRACK STRUCTURE"** which is submitted by KIRAN CHHOLAK, 2K17/STE/07, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part of full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
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ACKNOWLEDGEMENT

With great pleasure and respect, I express my heartfelt gratitude to my supervisor, **Head of the department, Professor Nirendra Dev, Civil Engineering, Delhi Technological University** for his constant support, motivation and patience during my entire M.Tech dissertation. It was only due to his advice, thoughtful comments, constructive criticism, and continuous vigil over the progress of my work with a personal interest that it has taken this shape.

I would like to pay my deep sense of thankfulness to **Prof. Vikas Rastogi, Department of Mechanical Engineering, DTU** for providing lab facilities to me in the Design Centre Lab, Mechanical Department. I would like to convey a special thank you to all the Ph.D Scholars of Design Centre lab specially **Ms. Yamika Patel, Ph.D. Scholar, DTU** for all the help and guidance during my dissertation. Her thoughtful comment, advice and guidance were helpful for completion of my project.

I would also like to extend my sincere gratitude to **Professor Alok Verma** and **Dr. Shilpa Paul** for their motivation and support.

I would especially like to acknowledge my gratitude to my family and all my dear friends for their consistent support, valuable suggestions from time to time to make this project worthy.

I take this opportunity to express my gratitude to all those who have supported me in completing my fourth-semester project work as a part of my degree program.

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ABSTRACT

In this study, the vibration characteristics of high speed railway track are analyzed and to discover the correlation between anti-vibration slab mat mechanical characteristics and vibration isolation performance. When the train accelerates on the track, the train movement and static load propagate together, thus transforming the static load to a dynamic load. This transformation is caused by imbalance in between the rail surface and wheel. Anti-vibration slab mat is located among the concrete layers of slab track. High-speed railway track analysis, modeling of different track modal is carried out in SOLIDWORKS 18 and simulation in ANSYS18.1. To study the vibration of high speed railway track, two type of railway track modal considered for simulation, track structure with slab mat layer and without slab mat layer.

Various modal parameters of the mat layer of slab such as stiffness, material and d amping ratio are examined to show the effects acceleration response reduction of h igh speed railway track structure. Modal analysis and harmonic response analysis a re needed in ANSYS 18.1 for simulation.Modal analysis is performed to determine the natural frequency and corresponding mode prior to the harmonic response analysis. The acceleration of high speed railway track is reduced when slab mat layer introduced between in railway track modal. Results indicate that neoprene with lower stiffness property works better for the same damping ratio then butyl rubber. When constant damping ratio of neoprene layer is raised, the response of vibration of high speed railway track reduces as compare to butyl rubber.

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LIST OF ABBREVIATIONS

UIC - International Union of Railways

CAM – cement Asphalt mortar layer

HBL - Hydraulically Bonded Layer

ABL - Asphalt Bearing Layer

ATD - AsphalTragschicht mit Direktauflagerung - Asphalt rail span with direct Support

BBERS - Balfour Beatty Embedded Rail System

BES - Betontragschicht mit EinzelStützpunkten - Concrete bearing layer with individual support points

BTD - BetonTragschicht mit Direktauflagerung - Concrete supportive layer with direct support

BTE – Beton Tragschicht mit Einzelstützpunkten - Concrete bearing layer with individual support points

CBL - Concrete Bearing Layer

ERS - Embedded Rail Structure

FFC - Feste Fahrbahn Crailshein - Slab track Crailshein

FPL - Frost Protection Layer

FST - Floating Slab Track

HMA - Hot Mix Asphalt

LVT - Low Vibration Track

LWR - Long Welded Rail

PACT - Paved Concrete Track

SATO - Studiengesellschaft AsphalT Oberbrau - study group for asphalt superstructure

SBV - Schwellen mit BitumenVerguss (German) - Sleepers with bituminous poured mass

CHAPTER 1

INTRODUCTION

Most Indian cities are witnessing a fast rise in motor ownership, resulting in increased congestion, air pollution, and more energy consumption. Priority is provided to the development of public transport technologies to fix or enhance these urban transport issues. Urban railway system is regarded an efficient way to enhance travel structure and relieve traffic congestion in metropolis. Thus, in latest years, urban railways have developed rapidly. Rail transport is capable of huge rates of passenger and freight usage as well as energy efficiency, but is often less efficient and more resources-intensive when considering reduced rates of traffic than road transport.

The Indian Railway network extends over 116,000 km, with 13,000 passenger trains and 7,421 freight trains per day from 7,349 stations with 23 million passengers. India has the world's third biggest single-management rail network. As of 2016-17, the total length of India's rail network was 67,368 km. 49 percent of the paths are powered by electric traction of 25 KV AC, while 3 percent are double or multi-tracked. In the year ending March 2018, Indian railway carried 8.26 billion passengers and carried 1.16 billion tonnes of freight. In fiscal year 2017-18, Indian railway is anticipated to have revenue of 1.874 trillion (US$ 26 billion) composed of approximately 1.175 trillion (US$ 16 billion) in freight revenue and approximately $501.25 billion (US$ 7.0 billion) in passenger revenue, with a working rate of 96 percent.

These information show that Indian railways have a enormous burden in terms of velocity, maintenance of technology, and most significant passenger and freight loads. Our current railway lines are choked and operate well beyond their ability. The number of our trains has risen dramatically over the previous 20 years and has strained our tracks. In addition to raising the number of trains, it is necessary to increase the velocity of these trains.

Indian Railways has made countless attempts in latest years to upgrade the current rail system and develop service for high speed trains.

Recently launched Gatiman Express (takes 100 minute to cover the 188 Km with an average speed 112 km/h), has become the fastest train in India with a top speed of 160 km/h running between Delhi-Agra. Before Gatiman Express, Bhopal Shatabdi express (Delhi to Bhopal Habibganj) with top running speed of 150 km/h and covering 707 km in approximately 8 hours 30 minute was the fastest running trains in India.

According to international standards, India still has no high-speed rail, i.e. the average speed above 200 km/h. While comparing train velocity in India with other nation railways, India is lagging behind by an enormous technological and velocity margin as proposed by Table

Table 1: Comparison speed of train in India and Abroad

Country	Japan	France	Spain	Germany	Italy	South Korea	Taiwan	China	India
Maximum Operation Speed (Km/h)	320	320	300	300	300	300	300	300 (350)	160

The world's major countries' maximum operating velocity varies from 300 to 320km/h. In China, for a period of time, high-speed trains operate at 350 km / h, but the peak operating speed has been lowered and today it is 300 km / h.

These information shows that a great deal of effort is needed to match the Indian railway system with the international railway system. Our Honorable Prime Minister has introduced the "Bullet Train Project" with Japan's collaboration to make pace with the International High-Speed Rail Standards.

As per this project, India is aiming to introduce its bullet train in August 2022, which will run at a speed of 320 km/h, covering a distance of 509 km from Mumbai to Ahmadabad in approximately 2 hours. In addition to bullet train, Indian Railways are planning to establish a high speed rail network under a project Diamond Quadrilateral as shown in Fig. 1, connecting the four super-cities of India i.e. Mumbai, Delhi, Chennai and Kolkata.

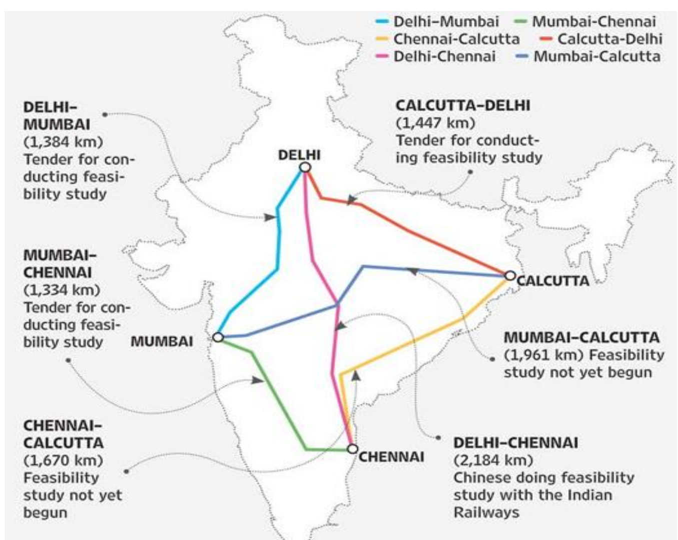


Figure 1: Diamond Quadrilateral of High Speed Rail Network

The Vision on Railways proposes to increase the Velocity on separate routes of frequent passenger trains to 160-200 km / h, resulting in a significant transformation of train travel. The Vision 2020 also aims to create at least four high-speed rail projects to provide 250-350 km / h bullet train infrastructure, One in each of the nation's areas and scheduling for at least eight more business, tourist and pilgrimage hub corridors.

Indian railway focuses on the adoption of technology and high speed trains, but it is still lagging in the research and development. There is a need to upgrade the old colonial track, which cannot meet the present ambition of running high speed train. In addition to it, new tracks, which are capable to meet the international standard of high speed railways, are required**.** Number of accidents because of derailment, poor track condition, and equipment failure, train operating and maintaining condition are certain issues which really urges to look into this area as a potential research problem.

For its benefits in velocity, convenience, security, flexibility, eco- friendly configuration, wide capacity, minimal power usage, all-weather transport, etc., the high-speed railway gives challenging competition to other modes of transport.

However, with growing train operating velocity, along with enhanced transportation density and loads, high-speed train and track interaction has been improved.

To readjust this transition in railway development, nations around the world also enhanced rail network technological advancement as well as fully implemented latest innovations, models, equipment, methods and modern railway engineering management methods. Consequently, the present railway track concept has originated. With the introduction of high-speed rail and heavy-duty rail, contemporary railways have been established to satisfy the rapid and high-speed requirement of transportation and the rapid and heavy-duty demand of freight transport.

When comparing standard railway track with high speed railway track, following features was discovered i.e. High-standard sub-grade, special foundation of sub-grade, welded rail durable and super-long continuous , scientific monitoring of maintenance work and also the organization of sustainable installations, rail and environment coordination.

Obviously, standard track mechanics and methods of structural analysis cannot meet the requirements of contemporary track evaluation and design. Over the year the computer technology evolved so much and different numerical method has also been developed which helps researcher to solve the problem of railway track mechanics which seemed very difficult to solve in the past and complex problems appearing in the way of railway modernization.

It can be concluded that High speed railways have lots of advantage for medium and long distance transport system in terms of comfort, time, energy saving ,environment friendly and speed. With increasing the speed of train, dynamic effects of train on track and ground also increases. In high speed train , velocity play a vital role in the vibration characteristics of rail track in such a way that when velocity exceed or reached the critical velocity, induces a strong vibration in the track which affect the safety and ride comfort of the train and sometime causes the derailment. Accordingly, enhanced dynamic stresses affect train safety and stability.

1.2 Dynamic loading:

Any load whose magnitude direction and position vary with load is considered as dynamic load. Following 3 types of dynamic loads are acted on the track due to moving vehicle:

i. Moving load of axle,
ii. Dynamic fixed point loads,
iii. Dynamic moving loads.

Axle loads are considered as dynamic loads for the track-subgrade-ground structure due to their moving train loading points, although insignificant to the dynamics of the automobile and constant in size. The track is subjected to heavy vibration as quickly as the velocity of moving loads of axle reaches the critical velocity of the track structure.

Dynamic fixed point loads are caused by the impact of trains that pass through fixed track irregularities, such as rail sockets, the welding slag of continuously welded rail and turnout frogs.

Dynamic moving loads: Irregularities at the wheel-rail contact interface create moving dynamic loads. The train-track dynamics study offers a strong basis for researching the complex wheel-rail connection and interaction mechanism, which offers vital sources for guiding and standardizing the design of vehicles and track structures.

1.3 Motivation

Indian railways focus on technology acceptance and high-speed trains, but research and development are still lagging behind. The old colonial track needs to be upgraded, which cannot fulfill the current high-speed train ambition. In addition, fresh tracks are needed, which are capable of meeting the global high-speed rail standards. India has vision 2020 to upgrade its tracks, improvement of speed 160-200 km/h and extending the rail network. India is in the initial phase to introduce high speed rail, so there are many challenges which need to be addressed properly in the earlier stage such as maintenance of high speed train, operating condition, accidents because of derailments equipment failure etc. The interaction between train and track structure has become more complicated with increased axle load, traffic density and wider engineering implementation of new trains and track structure. Dynamic force comes in to the action because of the increasing speed which introduced severe vibration in the railway track. The above phenomenon is particularly severe under high speed operation. When train velocity re aches some critical speeds, the train would induce a ground wave that causes strong vibration in t he structure of railway track. It can be concluded that high-speed railways have a lot of benefit in terms of convenience, time, power saving, environmentally friendly and speed for medium and long-distance transport systems but Increasing train velocity also improves the train's dynamic effects on track and floor. Moreover, there would be strong vibration and structure-borne noise of the adjacent structure along the railway line due to the propagation of wave through ballast and sub-grade layer of track. Thus, study of vibration Generated by train on both the ground surface and track needed to be studied, so that any major casualties can be avoided.

1.4 HIGH SPEED RAILWAY TRACK STRUCTURE:

Railway Track structure

The railway track structure is the structure consisting of rails which is mostly steel I-section profile, rail-pads, fasteners, sleepers, and ballast or non-ballast track and the bottom layer of sub-grade. It allows trains to move by offering their wheels with a reliable surface to roll over.

Rail track is a basic component of railway infrastructure and it is possible to classify its parts into two primary classifications: super structure and sub structure. The most evident sections of the track, such as rails, rail pads, concrete sleepers and fastening structures, are referred to as the superstructure, whereas the substructure is linked to a geotechnical structure composed of ballast, sub-ballast and fastening systems.

1.4.1 Conventional railway track structure: Railway track innovation has developed over a span of 140 years since the installation of first railway track on wooden ties. For much of this era, the standard track structure, frequently referred to as ballasted track system, composed of some of these sections which include rails, sleepers, ballast and sub-grade. Ballasted track model is shown in Fig.2

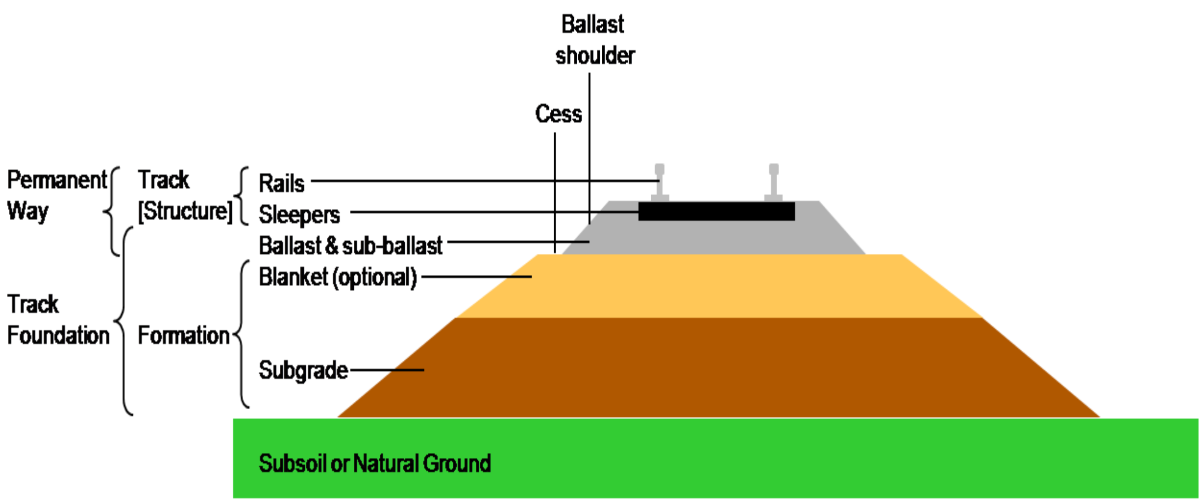


Figure 2: conventional track structure

1.4.2 Slab tack structure

The superstructure of the slab track consists of the elements of rails, base plates, fasteners, rail pads and concrete (and/or reinforced concrete) and the hydraulically bonded layer (HBL). The substructure is made up of the same components as the ballast path. Slab track is made of materials of high rigidity, where the ballast is removed from the structure and substituted with concrete components. The necessary elasticity (in standard track structure supplied by ballast) can be recovered by incorporating elastic components such as extremely elastic fasteners and/or elastic mats into the track framework. To satisfy the demands set by high-speed rail activities, slab track was created.

Depending on the type of rail assistance, discrete rail support and continuous rail support, the slab track systems can be classified into 2 primary groups. Categorization can also be made on the basis of the manufacturing place, in this case precast / prefabricated devices (manufactured on a plant and transferred to the building site) can be named Or in-situ or cast-in-place building where the system concrete slab is poured on site.

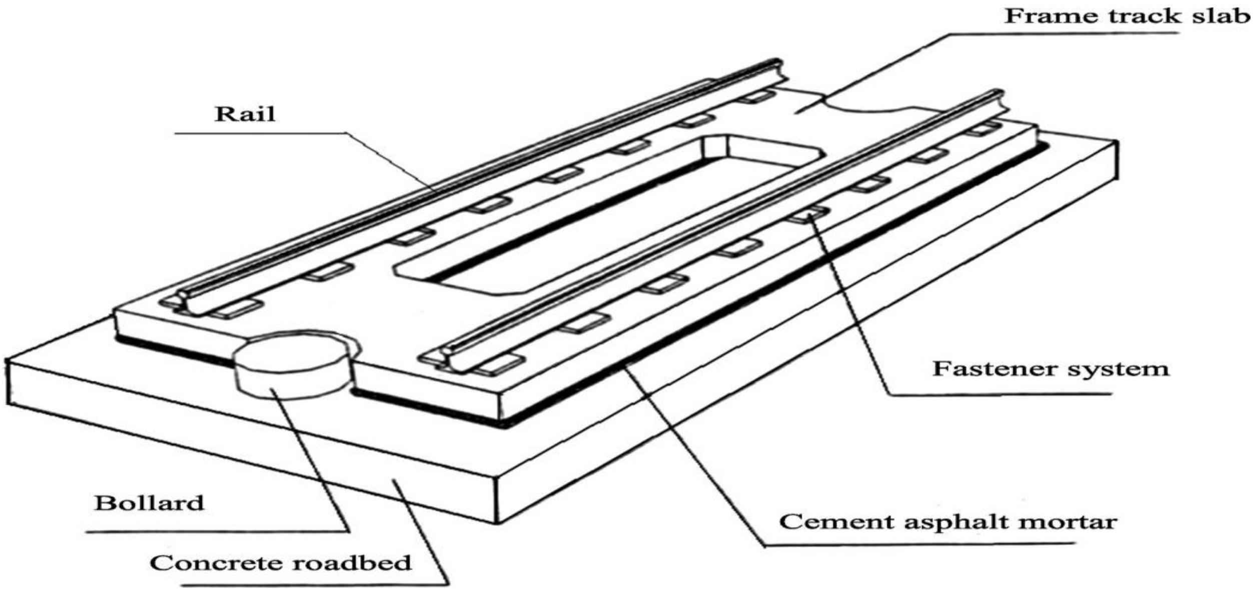


Figure 3: ballast less track structure

1.4.2.1 Different Components of slab track structure

Rail

The rails provide smooth operating surfaces for the train wheels and direct the wheel-sets in the direction of the path. Also the rails accommodate the loads of the wheel and spread the loads over the sleepers or supports. Longitudinal forces and Lateral forces from the wheel-sets are also transferred to the sleepers and further transferred into the track bed due to traction and braking of the train. A contemporary rail has a flat bottom and I section profile derives its cross section. The upper flanges of I section profile were converted into the rail head, as shown in Figure 4. UIC 60 international rail profile has been used in this thesis to simulate finite elements.

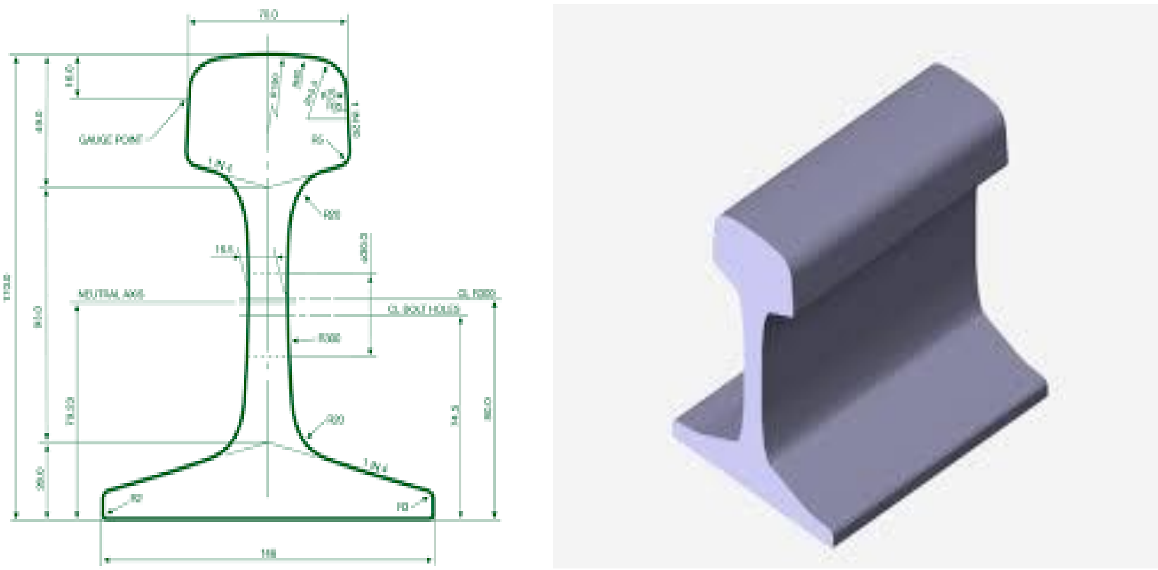
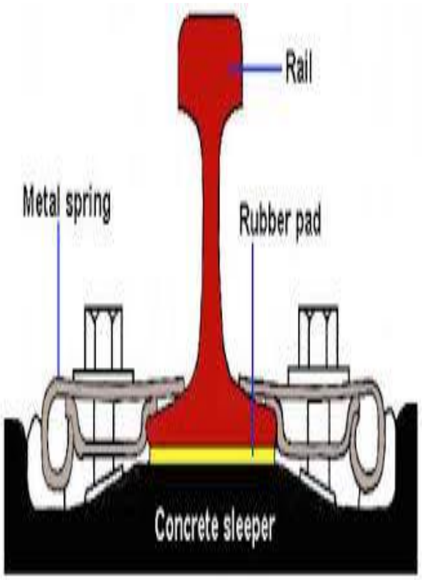


Figure 4: UIC 60 rail profile

Rail-pads and fastenings

Rail pad is a component that provides comfort between steel frame and the concrete surface. The rail load is transferred to sleeper and high frequency forces are filtered out. The rails are attached to the sleepers in a track structure. Rail-pads are generally placed between the rails and the sleepers. The rail-pads also influence the track's dynamic.

Rail fastenings are components that together form the structural connection between rail and sleeper. Using the fastening scheme, the rail is held onto the sleepers to guarantee the rails are fixed. The selection of fastening relies heavily on the rail's sleeper type and geometry.



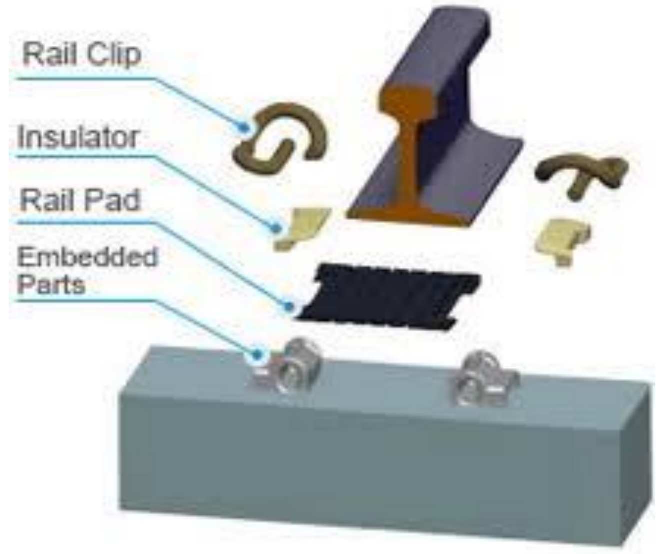


Figure 5: Rail-pads

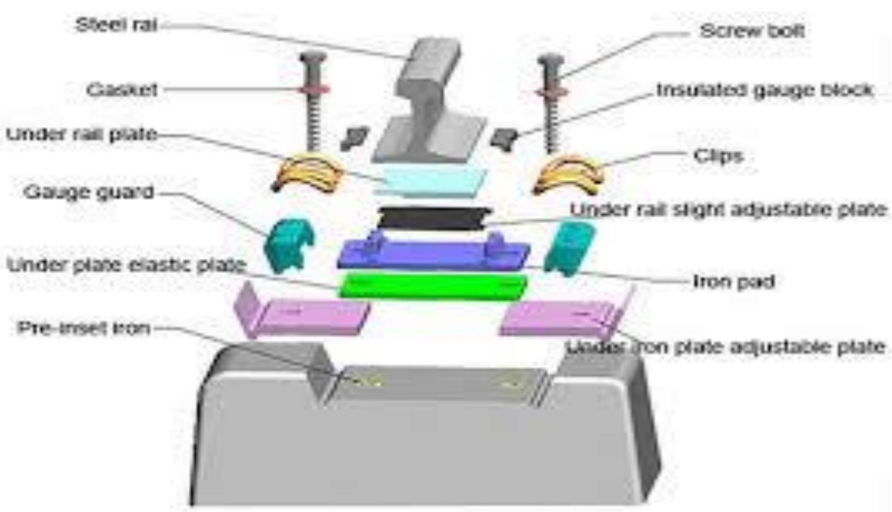


Figure 6: Rail fastenings

Slab track system

Around the world various slab track system developed, divided into major grouped continuous and discrete rail support system. In addition, these two track system are grouped into four and two subgroups listed in the table 2.

Table 2: Discrete rail track support system

Discrete Rail track support system			
Prefabricated concrete Slabs system	Monolithic design	Sleepers or blocks in Concrete	Sleepers on the Asphalt concrete roadbed
Shinkansen Bögl ÖBB-Porr IPA	Lawan tarck (Rasengleis) FFC BES hochirtf	Rheda Rheda- Berlin Rheda 2000 Zublin Stedef SONNEVILLE-LVT Heitkamp SBV WALO	ATD BTD SATO FFYS GETRAC WALTER

Table 3: Continuous rail track support system

Continuous Rail track Support system	
Embedded railway structure (ERS)	**Clamped and Continuously Supported Rail**
Deck Track INFUNDO-Edilon BBERS	Track Cocon ERL Vanguard KES SFF Saargummi

Brief Introduction of Some Important Slab Track System:

Discrete Rail support

Whenever the ongoing track has been mounted upon support points (usually mounted on sleepers), the slab track structure belongs to the discreet category of rail system support as shown above table 2.

Prefabricated concrete slabs

This slab track category consists of strengthened rope-stressed concrete slabs that preserve the orientation and label of both rail lines at the same time (UIC report15). In many locations around the globe, prefabricated slabs can be discovered, e.g. Japan, Germany, Taiwan, Italy, China.

Shinkansen slab track system

This slab track project was first created and used in Japan in 1972. It comprises of a sub-layer stabilized with cement and configuration slabs in longitudinal and lateral dimensions of 4.95 m x 2.34 m x 0.19 m and 0.16 m dense in low-pretension tunnels. These slabs weigh about 5 tonnes and all are fixed on upper edge of a hydraulically bonded surface (HBL), a minimum 40 mm thick bituminous mortar is injected under the slab, with the exception of a few situations in which a rubber mat is used in certain anti-vibration versions. The slabs have been kept lengthwise and horizontally by concrete cylinders (dowels) which have been tightly connected to the structural concrete of the bearing plate. Details can be discovered on the shinkansen slab track scheme in fig.7:

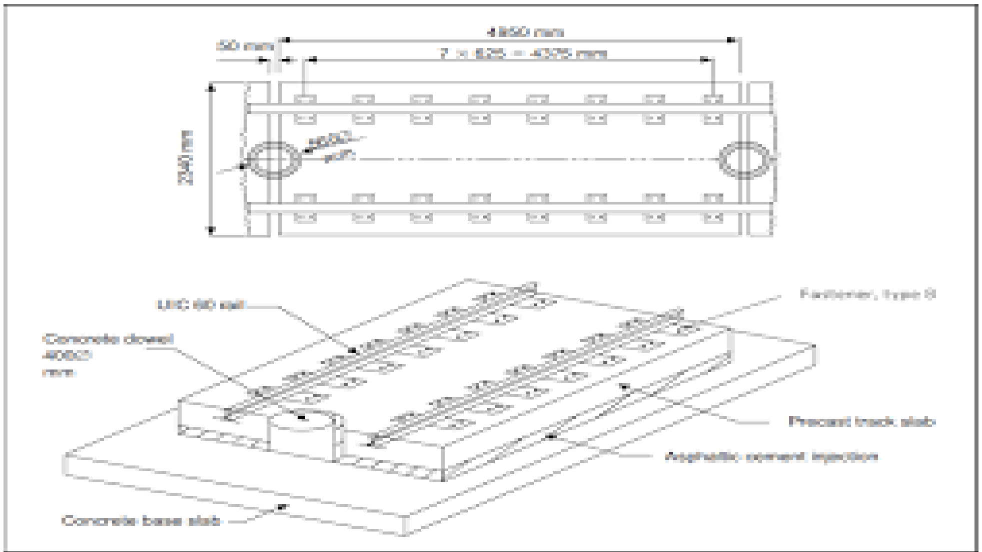


Fig.7: slab track system of shinkansen

The design of this structure involves slabs with hollows in the center as shown in figure 8 in order to improve the location of the bitumen mortar and also save material and make the slab lighter, the recent Shinkansen designs are slightly thicker at 220 mm and have a space around 2860mm x 800 mm rails.

Figure 8: frame-shaped Shinkkansen slab track system

Bögl System

The Bögl plate track system was developed and first used in Germany in 1977. This prefabricated system consists of 200 mm thick, 6450 mm long and 2550 or 2800 mm broad steel fiber concrete (B55 or C45/55) plates with a complete building depth of 475 mm as shown in the figure 9.

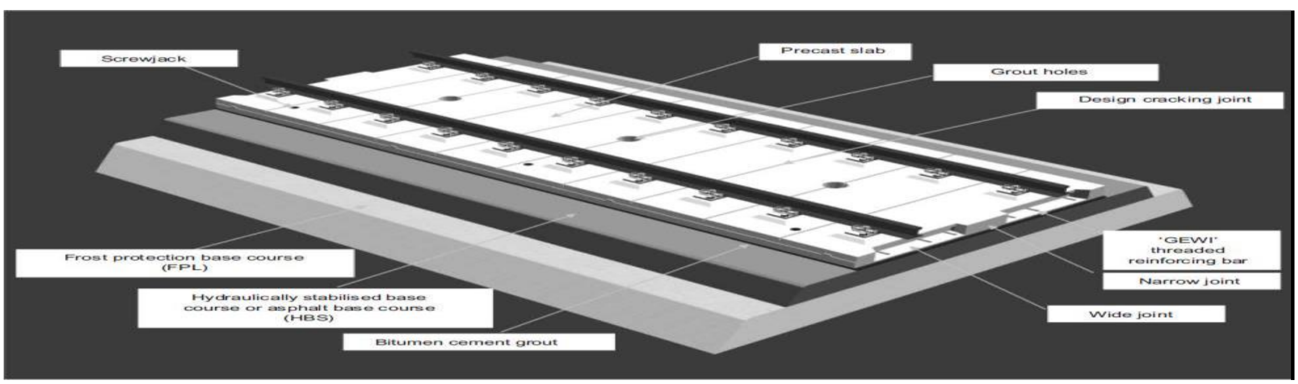


Figure 9: Bogl slab track system

The plates are pre-stressed laterally and strengthened longitudinally by the ' GEWI ' bars. These 44 prefabricated plates are constructed with unique breakpoints arranged between the support points to avoid the development of random cracks in the slab. Because of these specifically constructed cracking points, this structure is transformed into a system of many large sleepers joined together. Special screw jackets (spindles) incorporated in the slabs as shown in fig.10 ensure simple and quick adjustment of the slabs.

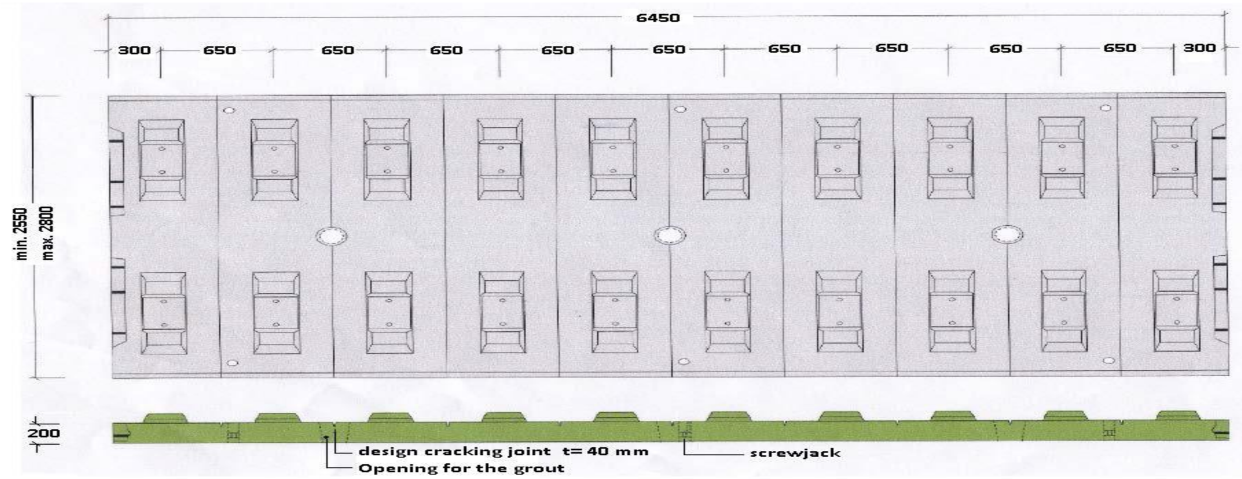


Figure 10: Geometrical characteristics of the Bögl concrete slab

Sleepers or blocks in Concrete

Rheda system

The Rheda model is among the most widely used slab track structures in different types. In 1972, the first Rheda track structure was built at station Rheda-Wiedenbruck ,Germany. In rheda slab track sleepers are enclosed in concrete, vertical and horizontal modifications are made to adjust the track position. Rheda structures are supported by a hydraulically connected layer (HBL) and protective frost layer (FPL). The Rheda model is quite adaptive, enabling modifications in layout and improvements to satisfy each project's requirements. It could therefore be discovered on earth in tunnels, bridges and structures.

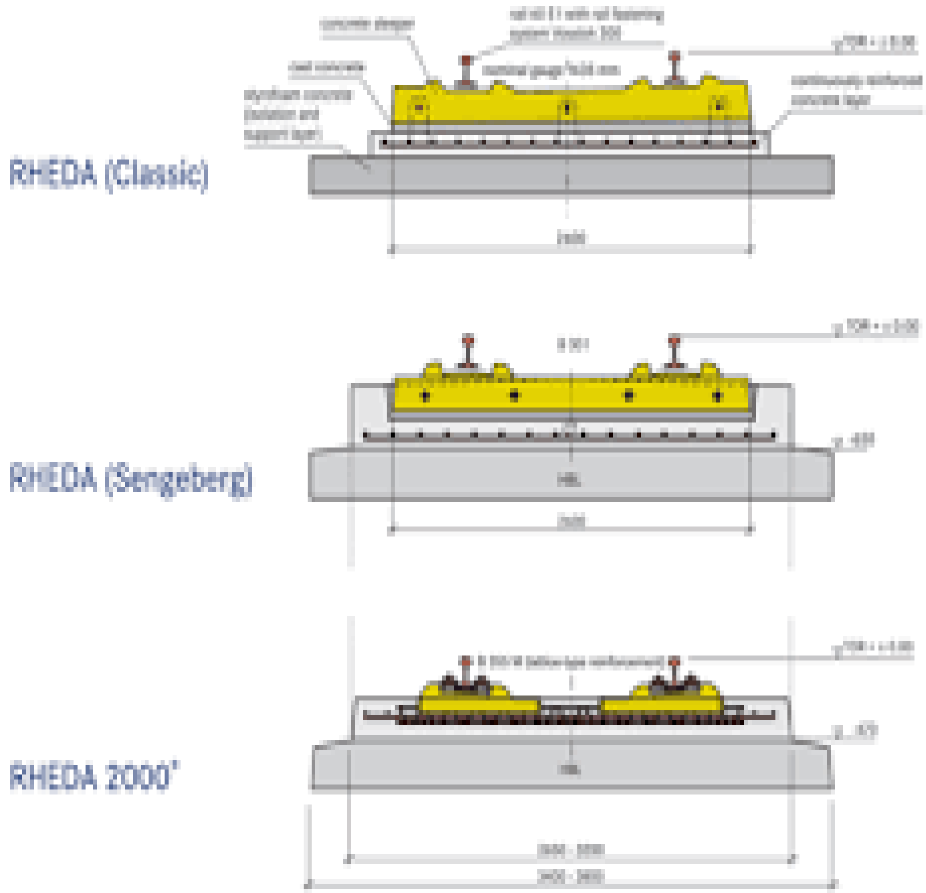


Figure 11: Rheda system

Cement Mortar Layer of Asphalt

Main component of the slab track structure, the cement asphalt (CA) mortar layer ensures stability, durability and cost maintenance. With the benefits of high speed, heavy traffic flow, excellent comfort, and high level of protection, high speed rail plays a major role in the train system and considerably promotes transportation effectiveness and economic development. For high speed train slab track structure system is the most important structure as it guarantees a train operation's safety and stability. The CA mortar layer in the slab track is a flexible layer between the track slab layer and the concrete base, preserving geometric integrity and absorbing the railway disturbance. CA mortar layer is therefore important for the durability of the slab track structure, stability and comfort of a high-speed rail network. CA mortar is a composite material consisting of cement, emulsified asphalt, fine aggregate and a variety of responsive additives.

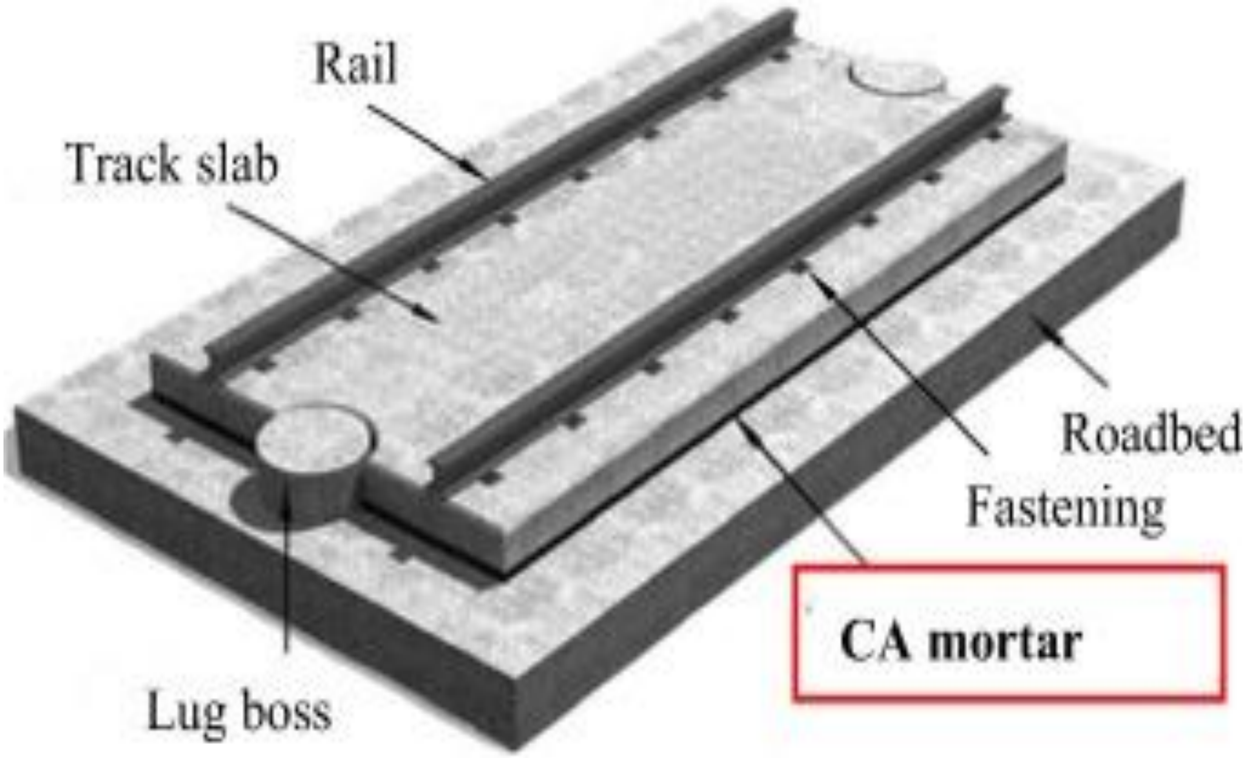


Figure 12: Cement Asphalt mortar layer

Hydraulically Bonded Bearing Layer:

Hydraulic bound layer (HBL): Hydraulic bound layer method is a method of soil stabilization where a base layer is prepared between the ground surface and the ballast-less track that can withstand the track load. HBL is a family of cement-bound layers in which binders produced from: Cement, lime, calcium sulfate, finely ground blast-furnace slag, wind-cooled steel slag or coal fly ash is used in this technique. These binders are known as hydraulic binders in the presence of water. A hydraulically bonded bearing layer is a mixture of aggregates with a bonding agent; placed under the concrete or asphalt layer and contributes to the overall bearing capacity of the whole system. It uses a mixture of mineral aggregates such as sandstone, crushed sand and chips of stone. The average size of grain should not greater than 32 mm and Portland cement is used as a bonding agent and contains approximately 110 kg / m^3. The edges of the hydraulically bonded layer should be built with >4% tendency towards the outside to avoid water infiltration between the hydraulically bonded layer of the bearing and the concrete and asphalt layer.

Figure 13: Hydraulically bonded bearing layer

1.4.2 Merits of Slab Track Structure

The designed slab track has benefits of very low maintenance requirements combined with increased service span and greater stability of the structural track.

- ✓ During its life cycle tamping, track lining and ballast cleaning are not required to be done and therefore the outcomes for repairs are done at decreased price of about 20-30 percent compared to ballast track repairs.
- ✓ Lower costs of traffic obstacles and higher life cycle approximately 50-60 years compared to ballast tracks (30-40 years) and also complete replacement at the end of service tenure.

- ✓ More pocket-friendly line positioning (since smaller curves can be applied at high altitude and high altitude deficiency), reduced structural height and weight.
- ✓ The absence of appropriate ballast track aggregates in a certain region may also result in the construction of a slab track.
- ✓ In cases where noise emission and vibration levels do not cause issues and are acceptable, the slab track may also be more appropriate.
- ✓ Better distribution of load, thus reducing subsoil dynamic load and pressure of unconfined soil and sub-grade levels.
- ✓ Car wear and tear are lowered through excellent track geometry retention

1.4.3 Demerits of Slab Track Structure

Among the various demerits of slab track structure the high costs of investments along with the lengthy production and installation duration needed for its making and assembly as well as the very few options available for post-construction fixes and the higher airborne vibration emissions are some of the exclusive reasons why slab track is not the preferable type of track used.

- ✓ Due to the operational organization influence which is purely responsible for the construction of tracks, the lower maintenance cost sometimes results in wrong selection of designs as well. A part or all of a track's construction costs are usually covered in many railways by government financial subsidies for amounts invested in infrastructure
- ✓ The decline of the geometry of the track may happen very unexpectedly and unpredictably if the operational limit of the concrete slab track is reached. Thus, the slab track's operational strength could be compared to rail fracture.
- ✓ Due to its rigid framework, the slab track is guaranteed to last for a great span nearly 50 to 60 years. The behaviour of these slab tracks after its building does not allow simple modifications and repairs. This implies that its quality must be closely checked and reassured during installation, since some deficiencies in quality would stay for the entire life cycle therefore, high-cost corrections should be taken to nullify them.
- ✓ Ballast-less track needs homogeneous sub-layers capable of carrying the loads imposed with settlements that are minor This implies that extreme concern should be given in the foundation preparations in many instances and particularly in earth structures

- ✓ There are not many opportunities after building to apply any innovation or future updates.
- ✓ It is not possible to build a slab track in soft clays, earthquake regions or soft peat layers.
- ✓ Special attention is needed for transitions between ballast track and ballast- less track.
- ✓ In many cases, new production and repair mechanisms are needed.

1.5 VIBRATION INDUCED BY TRAIN

The phenomenon of vibration resulting due to train conjunction can be defined as wave propagation through buildings and the ground. For example, the generated vitality can cause disturbance and interference in important equipment for people. Motion of train produces a response at certain locations from the surrounding environment. This reaction relies on railway track quality, foundation type and train type. These variables determine the amount of vibration. A comprehensive description of vibration-related variables can be discovered in the following tables 4:

Table 4: Vibration Source Factors and Effects

FACTORS	**EFFECTS**
Vehicle suspension	When the suspension is steep in the downward direction, the efficient vibration forces will be greater. On transportation vehicles, mostly the main suspension impacts the vibration concentrations, there is no obvious impact on the secondary suspension supporting the vehicle body.
Surface of Track	Hard track sometimes causes vibration problems. Maintaining a soft surface may decrease the level of vibration.
Track support system	On rail systems, one of the main elements in determining ground-borne vibration concentrations is the track support system. A track that has been strictly connected to a concrete track bed creates the greatest vibration rates.
Wheel condition	The roughness of the wheel and the flat places are the main cause of the

	metal wheel / steel train vibration
Speed of Train	Greater velocities lead in greater vibration rates as conceptually anticipated.
Structure of Track	The overall principle -of-thumb is that the reduced the vibration levels, the stronger the structure of the track.
Depth of source of vibration	While the origin is underground relative to the earth's surface, there are important variations in the vibration features.
Depth of frost	There is some sign that when the floor is frozen, the propagation of vibrations is less effective.
Position of water table	The presence of the water table is often expected to have a significant effect on ground-borne vibration, but a definite relationship can not be demonstrated to date.
Rock layers	When the bedrock depth is 25 feet and otherwise less, vibration rates are quite often large close to the track level. Rock-based tunnels will lead in reduced amplitudes of vibration near the tunnel. The vibration rate in the rock does not attenuate as quickly as it does in the soil due to effective propagation.
Layering of Soil	Soil layers might have a considerable however unexpected impact on the vibration concentrations as each layer has considerably distinct dynamic features.
Type of soil	Vibration rates in rigid clay type soils are usually anticipated to be greater than in loose sandy soils.

Adding some extra data about certain variables is essential. The notion of critical speed was created by vibrations in soft soils, because velocity of propagation for each type of soil is unique. By increasing train traffic speed, this velocity is either equal or surpassed, resulting in the vibration phenomenon being amplified.

The way loads are transferred to the infrastructure is another significant consideration. Today, the manner in which rail vehicles are intended to discriminate among suspension loads and non-suspension loads it is essential to note, however, that despite having considerably higher suspension loads than non-suspension loads, the experiments conducted confirm the vibration end products exactly from train non-suspension loads. Depending on instances like this, many system parts can cause the source of vibration. However, there is a natural resonant frequency in each portion of the structure. One of the key points of this research is the analysis of the frequency domain phenomenon. Nevertheless, it is not yet well defined the variety of appropriate frequencies. The fact that there are restrictions and rules for vibrations of train traffic therefore, it enables comparison with threshold values regarding harm to the construction, human being and interference with the equipment.

The aim is to assess the scenario on the basis of legal measures and to obtain a stronger picture of in situ circumstances. Vibrations can cause discomfort, complaints, absenteeism and health damage. The impact of the visual appearance of long term damage to their frameworks and recognizing that a greater repeated schedule is possible leads to an even greater rate of discomfort for people living.

The mechanical energy generated at the wheel and rail contact area is the most appropriate cause of vibration. The source intensity depends on the impedance of the wheel in conjunction with the bogie and the loaded carriage, the impedance of the rail in conjunction with the sleepers or the full design of the track structure and the soil's structural situation.

1.6 SOFTWARE

1.6.1 STRUCTURAL ANALYSIS

ANSYS is structural analysis software which allows complicated structural modeling issues to be analyzed and design choices to be made better and quicker. With the Finite Element Analysis (FEA) tools available in the suite, multiple design scenarios are analyzed and parameterized to use and automate solutions for problems related to structural mechanics. To optimize the product designs and decrease physical test expenditures ANSYS is used in the entire sector. Simulation of complex components and material behavior can also be accomplished by using built-in models, user-defined material models or material designer to create representative volume parts (RVEs). It would not be essential to modify designs with very large variation by altering unreasonably to specific solvers. The capability of Non-Linear Adaptive (NLAD) immediately addresses challenging simulations by remediating the solution as it progresses.

FEA simulation is commonly used by designers and mechanical design technicians to obtain understanding into component, sub-assembly and system structural performance, including vibration and effect impacts. While CAD-embedded FEA instruments can manage simpler settings, sophisticated simulation tools are often required to increase non-linear material fidelity or contact definitions, More mesh setting control or a host of other problems.

1.6.3 COMPLETE STRUCTURAL ANALYSIS SOLUTION

A full variety of analytical instruments are accessible to evaluate single load instances, vibration or transient analysis; materials, joints and geometry can also be examined linear and nonlinear behavior. Using ANSYS Autodyne and ANSYS LS-DYNA, advanced solver technology allows simulations of drop, effect and explosion. ANSYS AQWA offers industry-specific skills for technicians designing marine environments in conjunction with offshore simulation skills in ANSYS Mechanical.

1.6.3 VIBRATION ANALYSIS

Vibration may be an undesirable side effect of cheap product design or the environment in which the product operates. It can greatly affect durability and fatigue, resulting in shorter service life. To recognize how designs react to events such as brake squealing, earthquakes, transportation, and acoustic and harmonic Loads to predict product and component behavior patterns. ANSYS Mechanical simulations can provide this knowledge and help solve the toughest problems of vibration.

1.6.4 **3D CAD MODELLING SOFTWARE**

SOLIDWORK

SolidWorks is a computer-aided (CAD) and computer-aided (CAE) computer modeling program running on Microsoft Windows. SolidWorks is software for solid modeling that enables to develop 3-dimensional products. General rule, the method is to sketch 2-dimensinoal profiles and then use techniques such as extruding and lofting to create the solid form. This helps to draw or model any easy or complicated mechanical shape. By using SOLIDWORKS software speed up the design process of very complicated modal therefore, 3D solid modeling has evolved as one of the main aspect for product development, acting as the building block of design, simulation and manufacturing of any part products. The resulting project is used for further simulation and evaluation as an input for Ansys workbench in this thesis.

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CHAPTER 2

LITERATURE REVIEW

C J R et. Al [2] have Studied the correlation between the mechanical features of the anti-vibration slab mat and the efficiency of vibration isolation. The train motion and static load propagate together when the train accelerates on the path, transforming the static load into a dynamic load. The anti-vibration mat design was manufactured in SolidWorks and simulated in ANSYS Workbench. The results acquired will be analysed using vibration nomograph to identify the acceptable vibration levels for human comfort.

Hemsworth, B. [5] have studied the project RENVIB has been sponsored by the Union of International Railways to further the knowledge on train-induced ground vibration. The long-term aim is to develop a general model that will predict the vibration caused by trains operating in tunnels and on the surface. Using slab track is advantageous but expensive and leads to rise in ground-borne noise unless there is extra resilience. Wilson G. P.et al [4] in this paper the focus is on two methods of controlling the vibration radiated by the transit structure. First is the use of floating slab track beds, a method that has proven to be very effective at reducing vibration at frequencies above the resonance frequency of the floating slab system. Second is to modify the design of transit car bogies such that the wheel/rail forces are reduced.

Krylov V [6] ground vibrations generated by superfast trains are studied theoretically, taking into account the contribution of each sleeper of the track subjected to the action of the carriage wheel axles. The results are illustrated by numerically calculated graphs of spatial distributions and frequency spectra of ground vibrations generated by trains moving with different speeds.

Xiang J et al.[3] have proposed a theory of spatial vibration of high-speed train and slab track system. The high-speed train is modelled as a multi-rigid body system and the potential energy of spatial vibration of the train is deduced. The equations of spatial vibration of the system are solved by the Wilson-θ direct integration method.

M. Monteiro [7] a set of research studies that were made with the intent of studying vibrations created by the circulation of trains. The purpose of measuring vibrations induced by train circulation .The next step was to develop a whole set of analysis tools in Matlab, meticulously incorporating digital filters for signal processing.

Cai Y et. al.[8] have demonstrated the effect of dynamic wheel-rail interaction on the ground vibration generated by moving train, at below and above the critical speed. Fast and Fourier transform used to solve the governing differential equation and result shows that vehicle speed below critical speed dominate the axle load for ground displacement response and the dynamic load for ground surface acceleration. Above the critical speed effect of dynamic load on ground displacement and surface acceleration is negligible compare to axle load.

T .Xin et. Al [9] reducing slab track vibration into bridge using elastic materials in high speed railway in this paper, the problem of vibration transmission from slab track structures into bridge is studied by theoretical analysis. A vehicle–track–bridge coupling system dynamics model is established based on a multi-body dynamics theory and a finite element method. The system model consists of vehicle model, track–bridge model and wheel/rail interaction model. The vehicle model is established based on the multi-body dynamics theory, and the tack–bridge model is established by the finite element method. The vehicle model and track–bridge model are coupled through wheel/rail interaction model, and the track irregularities are included. The system dynamic responses are calculated, and the effectiveness of elastic materials in vibration reducing is discussed. The results demonstrate that elastic materials like slab mat layer inserted between slabs tracks can reduce vibration transmitted from track into the bridge. The track with slab mat layer lead to much smaller vibration on the bridge. Slab mat layer affects less on wheel/rail force and bridge displacements than on rail displacement and slab displacement, and it also results in rail and slab acceleration variation.

Montella G et al.[10] ground-borne vibrations induced and influenced by subway trains on people and building structures. The transmission of ground vibrations from a train to the surrounding area is a complex issue that depends on a large number of factors.It focuses on examining the dynamic and static actions of a new railway floating-slab track system produced from recycled rubber by incorporating elastic components. A linear 3-D finite element model was developed using the finite element software code Abaqus.

Sol-Sánchez et al [12] this paper discusses the problems associated with track stiffness, geometry degradation, and vibrations, and at the same time, studies the characteristics of elastic elements as well as the research carried out to test and evaluate their effectiveness. After reviewing and analysing a wide range of research initiatives, this paper proposes a set of recommendations and guidelines for the use of elastic elements in railway infrastructure as well as highlighting a series of possible further investigations. the decrease of rail pad stiffness can reduce the vibrations and noise from sleepers and ballast particles, whilst these types of pads can simultaneously allow for a more homogeneous distribution of stiffness throughout the track and a lower effect of the loads transmitted to under layers. When under ballast mats are used it could be necessary to determine the maximum possible reduction of ballast thickness that would not modify track behaviour.

Xinwen et. al.[13] have studied on the vertical vibration of High Speed Railway with dynamic flexibility method. Combined with the pseudo excitation method, solution of the random dynamic response is presented to calculate the receptances of ballast less track and subgrade under the random track irregularity. ANSYS is used as simulation software in this research.

Sole, Jet al [14] good practices in railway vibration prediction using empirical and hybrid models. Empirical and semi-empirical (hybrid) models are commonly used in the prediction of vibratory impact of future railway lines. This paper focuses on the potential impact that a number of details can have on the accuracy of this type of vibration predictions, particularly when experimental assessment of vibration transmission characteristics is carried out. These aspects include different alternatives for installation of vibration transducers, use of different artificial vibration sources, ground borne noise estimation from vibration levels and also the role of some particular surface characteristics in the test site. A number of good practices concerning these aspects are summed up and suggested as a conclusion to help in improving the quality of future vibration predictions basedon this sort of models.

Sadeghi, J. [16] field Investigation on Vibration Behaviour of Railway Track Systems Vibration behaviours of the railway track system were studied in this research. Natural frequencies as well as mode shapes of a railway track system in different track components'.Conditions were obtained. Results obtained, tracks with timber sleepers have substantially lower natural frequencies in comparison with those with concrete sleepers. The mode shapes obtained from the concrete sleeper track show a symmetric vibration. In other words, both parallel rails vibrate in exactly the same way. Such a symmetrical vibration was not observed in the timber sleeper track. This indicates that concrete sleepers cause a better uniformity in the track support system and in turn, a b better passenger comfort and safer operations. Comparisons of the natural frequencies of tracks with rigid and flexible fastening systems indicates that tracks with a rigid fastening system have higher natural frequencies particularly at the third to fifth modes. These differences are less when using timber sleepers. In other words, the effect of using flexible fastening system on vibration behaviour of track is more considerable in concrete sleeper track when compared with timber ones.

Ono K et. al [17] analysis of railway track vibration - The theoretical analysis of the vibrations in the track under the wheel study that consist of three kinds of modes. The first kind is a steady vibration with a definite frequency, the second kind is a group of waves propagating lengthwise along the track and the third kind is a group of propagating waves which are transmitted downwards into the roadbed. The second and the third kinds have no definite frequencies; only the ranges of the frequencies are defined. The amplitudes of vibrations, their velocities and the accelerations generated in the railway track due to an application of an impulse from the wheel or induced by the unevennesses on the surfaces of the wheels and the rails have been analyzed here theoretically.

Van Leeuwen et al. [18] vibration nuisance caused by railways can be divided into feasible vibrations for a human being and low-frequency noise produced by vibrations. Both contribute to a higher level of discomfort for inhabitants. The frequency range for feasible vibrations is from about 1 Hz to 80 Hz, and the audible noise has a theoretical frequency range starting at 10 or 20 Hz up to the higher frequencies. There is an overlap in which an average human is more sensitive to audible noise than to perceptible vibrations. Determining the strength of the vibrations and the strength of the accompanying low frequency noise somewhere in the construction is especially complicated. The strength of the vibration for feasible vibrations and for structure-borne low-frequency noise can be measured on the foundation of the building and by using a predetermined realistic $H_{building}$ transmission factor, practical values for the strength of vibrations and low-frequency noise will be determined.

Konowrocki, R et al [21] this paper presents the results of vibration measurements on railway during passages of a train at a constant speed. The measurements have been performed on a railway track at straight and curve sections as well as and inside the train on the floor. Higher vibrations on curves can be resulted from the wear of railway track which was caused by centrifugal forces influenced by the passages of the train, deformations of wheels, wheel-sets and rails, different linear velocity of wheels on curves and rotary oscillations of wheel-sets.

X Yang et al [25] have studied to reduce the ground-borne vibration caused by wheel/rail interaction in the ballast-less track of high speed railways, viscoelastic asphalt concrete materials are filled between the track and the subgrade to attenuate wheel/rail force. A high speed train-track-subgrade vertical coupled dynamic model is developed in the frequency domain. The track and subgrade system is considered as a multilayer beam model in which layers are connected to each other with springs and damping elements. The vertical receptance of the rail is discussed and the receptance contribution of the wheel/rail interaction is investigated. Combined with the pseudo excitation method, a solution of the random dynamic response is presented. The random vibration responses and transfer characteristics of the ballastless track and subgrade system are obtained under track random irregularity when a high speed vehicle runs through. The influences of asphalt concrete layer's stiffness and vehicle speed on track and subgrade coupling vibration are analyzed. The frequency band of the vibration energy spectrum of rail is wider than that of the slab and subgrade, and the frequency band of the vibration energy spectrums of slab and subgrade is mainly concentrated in the low frequency around 43Hz. The stiffness of ACL has relatively less influence on rail vibration than on the ballast bed and subgrade vibration. The higher the train speed, the larger the amplitude of resonance peak of the track-subgrade vibration power but the lower the frequency of resonance peak of them.

Feng, H.[27] in this is paper study the influence of design parameters on dynamic response of the railway track structure by implementing Finite Element Method (FEM). According to the complexity, different railway track systems have been simulated, including: Beam on discrete support model, Discretely support track including ballast mass model and Rail on sleeper on continuum model. The main part of the finite element modeling involves the steady-state dynamic analysis, in which receptance functions were obtained and used as the criterion for evaluating the dynamic properties of track components. Dynamic explicit analysis has been used for the simulation of a moving load, and the train speed effect has been studied.

Yalcin, N et al [29] in this study, the vibration characteristics of railway vehicle and track are analysed. The vibration levels are one of the main parameters that should be taken into account during the design stages of railway vehicle and track systems. And the vibrations in the low frequency range cause discomfort for the passengers. Also, types of the railway track structure affect the vibration levels. Two railway tracks are considered as mass-spring damper systems. When the rail vehicle is traveling on a slab track and ballasted track, the displacements and accelerations of vehicle body and passenger seat are analysed for time history and frequency response. The vibration characteristics of the two types of track Structures are compared according to vibration levels. It is observed from the studies that vertical responses of ballasted track caused by the vehicle-track interaction are higher than the slab track structure. This is because the rigidity and damping characteristics of the two types of track structure. Since the vehicle speed increases, track responses are also increases due to the high frequency of vibrations caused by high operating speeds. To minimize vibrations encountered on tracks the rail-pad, ballast and foundation properties should be defined accurately. The damping and rigidity of rail-pad has an important role on vibration characteristics of the track. The low frequency vibrations are critical for passenger comfort and vehicle dynamics.

CHAPTER 3

METHODOLOGY

To evaluate the dynamic response of High-Speed railway track following steps has been followed which is shown in the flowchart.

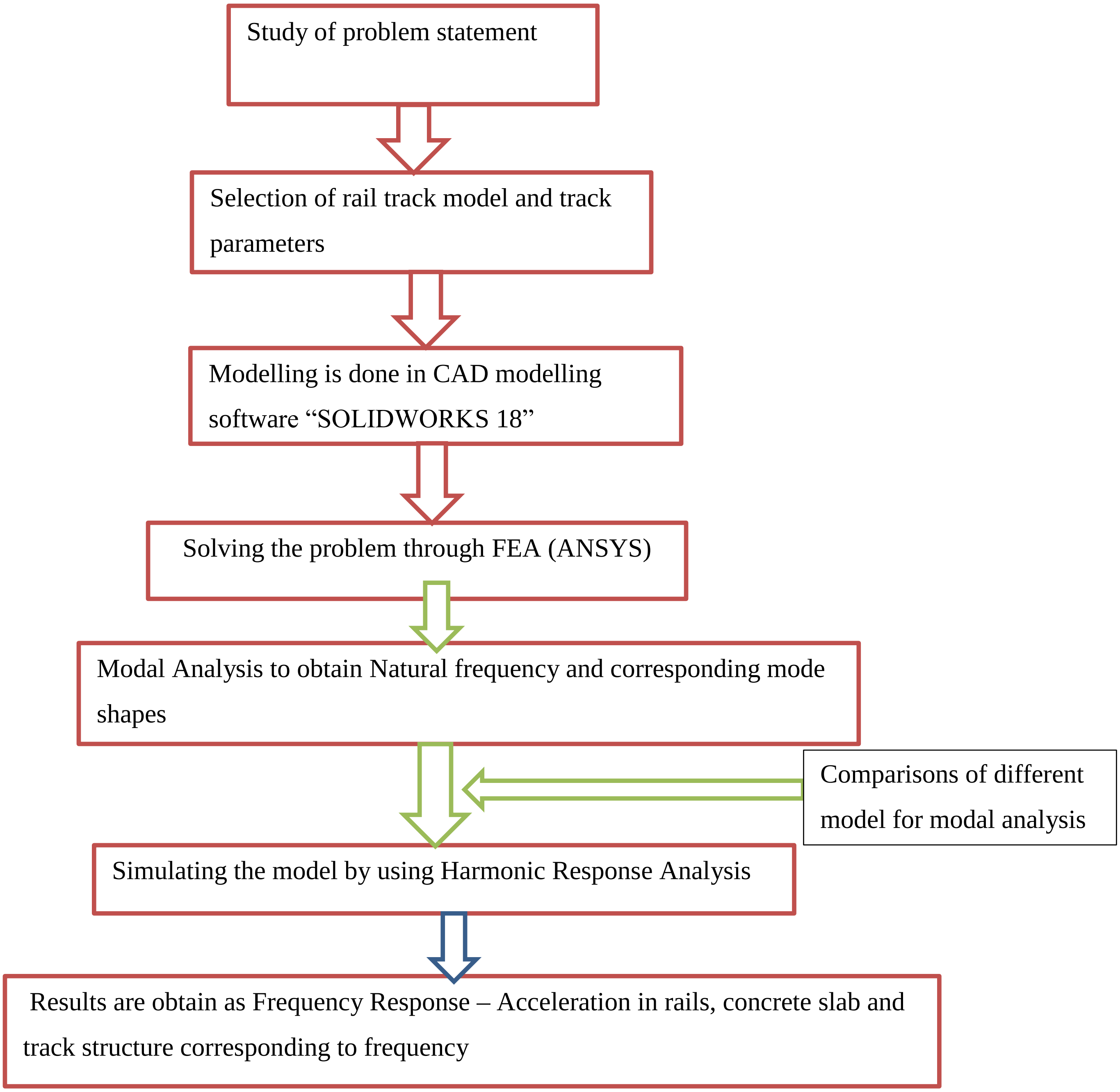

Figure 14: Flowchart describing process flow of analysis

Study of problem statement:

To study the frequency response of high speed railway track different track modal has been to used.

Selection of Parameters:

Track Structure Details:

Rail: UIC 60 rail profile has been used in this thesis for analysis of dynamic response of high speed train.

Table 5: Geometry parameters Details:

Parameters	Slab	CAM Layer	Subgrade	Foundation
Material	concrete	Cement Asphalt mortar	HBL	soil
Length(mm)	6450	6450	6450	6450
Width(mm)	2550	2550	2950	7.45
Thickness (mm)	200	40	300	4000

Geometrical Modeling Track Structure

Modeling of 3D railway track structure has been done by using CAD modeling software “SOLIDWORKS18” as shown in figure and save this model in STEP formats for simulation in ANSYS 18.1.

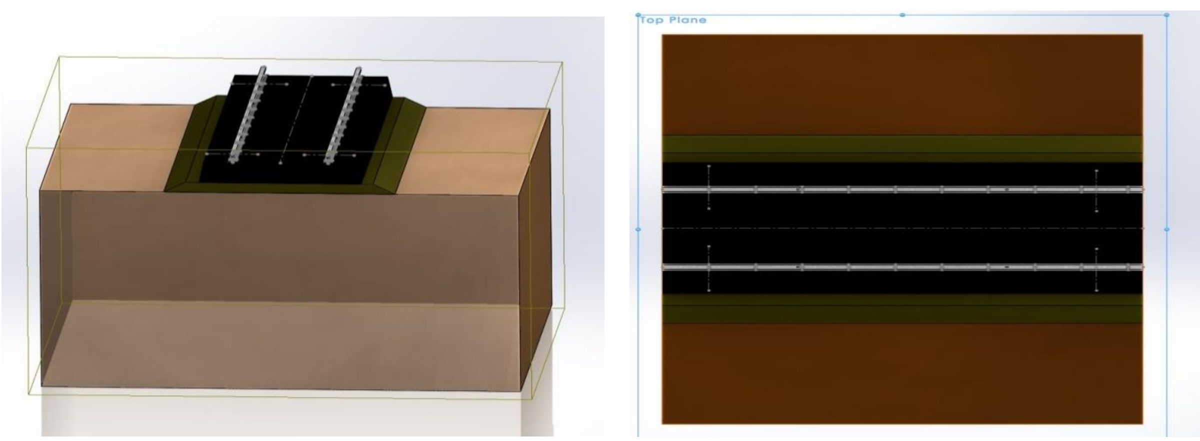

Figure 15: 3D and top view of modal 1 of railway track structure

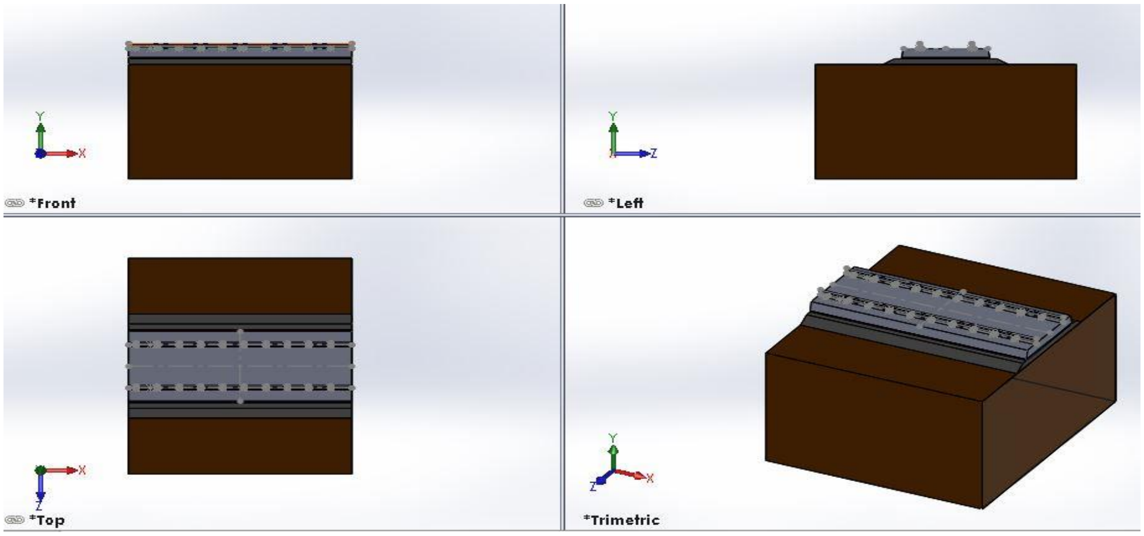

Figure 16: All view of modal 2 of railway track structure

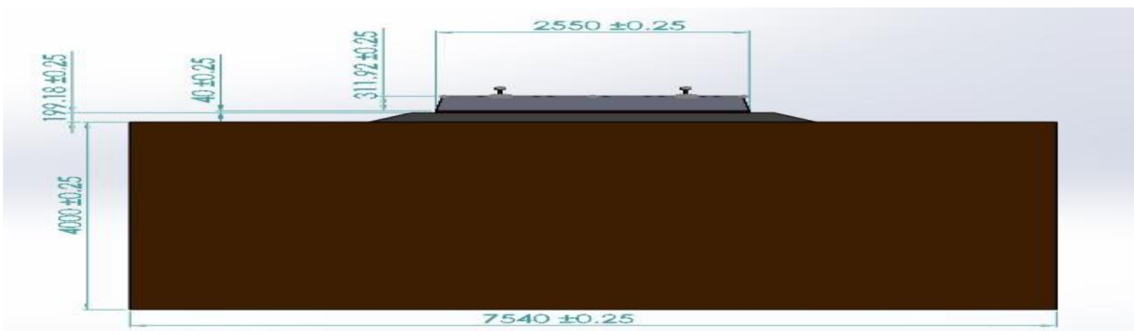

Figure 17: front view of modal 2 of railway track structure with dimension details

A layer of slab mat is also design of 40mm thickness has been used to analysis the effect of layer of slab mat on frequency response by varying its properties.

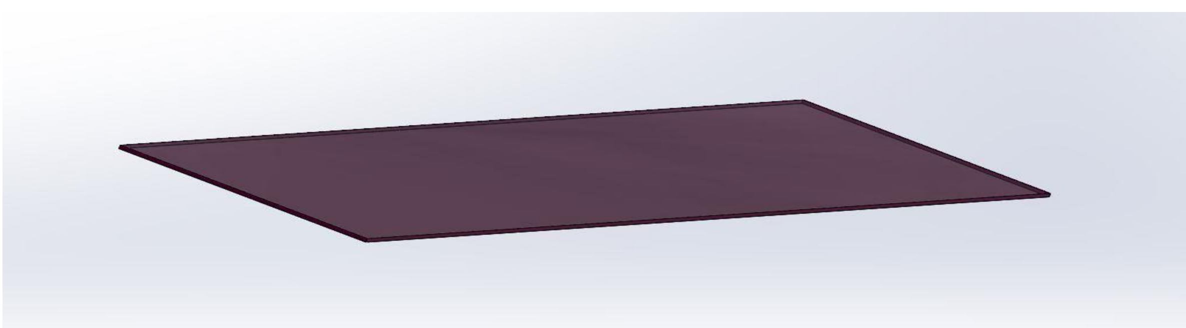

Figure 18: 3D model of slab mat in SOLIDWORKS with units of mm

Modal 1 is comprises of rails, slab layer and subgrade layer and foundation.

Modal 2 is comprises rails, rail-pads, a concrete slab layer, slab mat layer subgrade layer and foundation.

Numerical Analysis

For Numerical Analysis first import geometry model from SOLIDWORKS STEP file for two step analysis has been performed which model analysis has followed by Harmonic Response analysis .Following steps are follow for complete dynamic analysis of railway track structure:

Attach Geometry

Model Geometry has been imported in Design Modeler application form SOLIDWORKS STEP file formats in ANSYS 18.1.

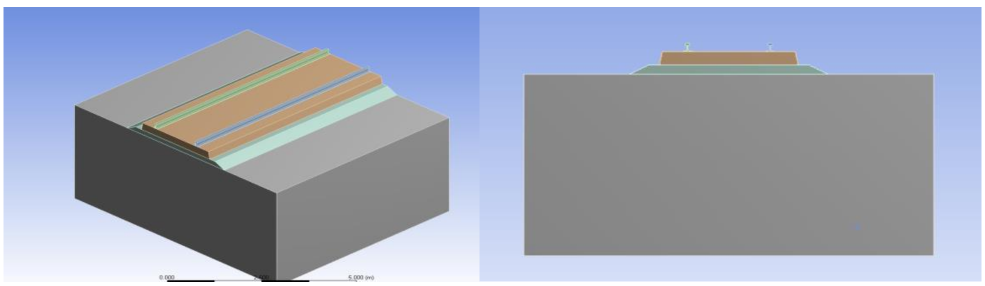

Figure 19: 3D & Front view of modal 1railway track structure model

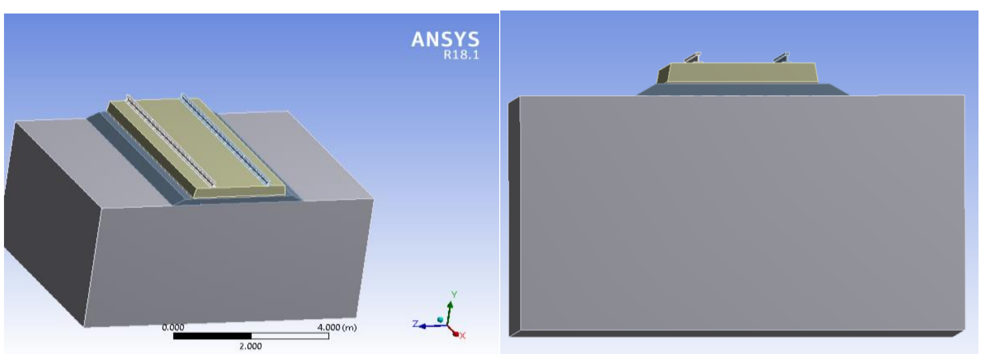

Figure 20: 3D & Front view of modal 2 railway track structure model

Define Meshing:

Meshing is an integral component of the simulation method of computer engineering. The mesh affects the solution's precision, convergence, and velocity. In addition, the time it takes for a model to be created and mesh is often a significant portion of the time it takes to obtain results from a CAE solution. Therefore, the fine the meshing instruments are more accurate and automated, better the answer. Meshing is described as the method of splitting entire component into a set of components which divide the continuous body into a finite amount of components. So, whenever the load is applied to the component, the load is evenly distributed as meshing.

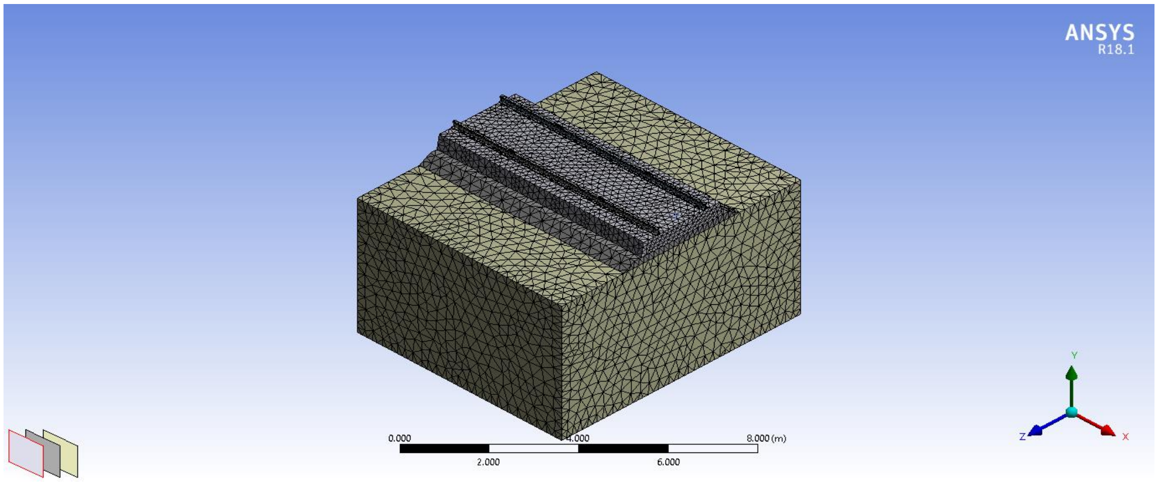

Figure 21: Meshing of 3D model using tetrahedrons method

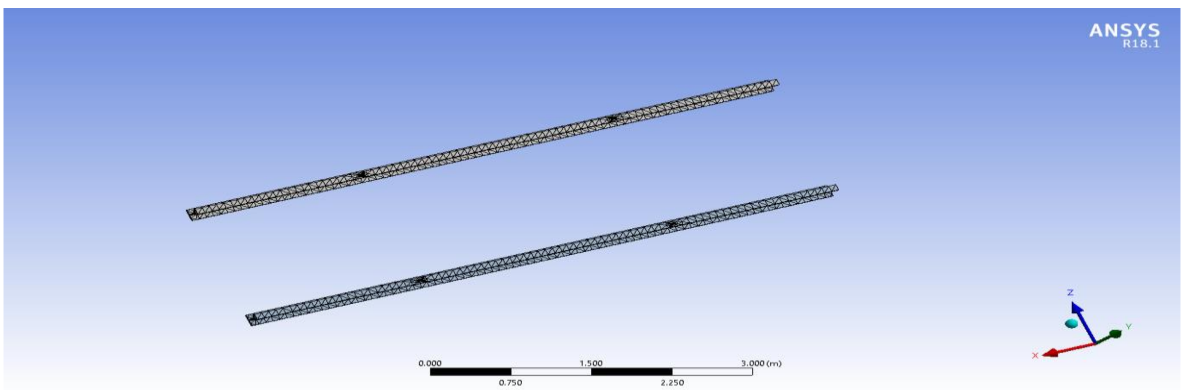

Figure 22: Meshing of rails using tetrahedrons method

Meshing details:

Table 6: mesh details

<table>
<tr><th colspan="4">Sizing</th></tr>
<tr><td>Size function</td><td colspan="3">Adaptive</td></tr>
<tr><td>Relevance center</td><td colspan="3">Fine</td></tr>
<tr><td>Element size</td><td colspan="3">.05mm</td></tr>
<tr><td>Initial size seed</td><td colspan="3">Assembly</td></tr>
<tr><td>Transition</td><td colspan="3">Fast</td></tr>
<tr><td>Span Angle center</td><td colspan="3">Fine</td></tr>
<tr><td>Automatic Mesh based Defeaturing</td><td colspan="3">On</td></tr>
<tr><td>Defeature size</td><td colspan="3">.05mm</td></tr>
<tr><td>Minimum edge length</td><td colspan="3"></td></tr>
<tr><th colspan="4">Statistics</th></tr>
<tr><td>Nodes</td><td colspan="3">72596</td></tr>
<tr><td>Elements</td><td colspan="3">36768</td></tr>
<tr><th colspan="4">Mesh controls</th></tr>
<tr><td>Object name</td><td colspan="3">Patch conforming method</td></tr>
<tr><td>Object name</td><td>Patch conforming method</td><td>Body sizing</td><td>Body sizing</td></tr>
<tr><td>state</td><td colspan="3">Fully define</td></tr>
<tr><th colspan="4">Scope</th></tr>
<tr><td>Scoping method</td><td colspan="3">Geometry selection</td></tr>
<tr><td>Geometry</td><td>5 bodies</td><td>2 bodies</td><td>1body</td></tr>
<tr><th colspan="4">Definition</th></tr>
<tr><td>Suppressed</td><td colspan="3">No</td></tr>
<tr><td>Method</td><td colspan="3">Tetrahedrons</td></tr>
<tr><td>Algorithm</td><td colspan="3">Patch conforming</td></tr>
<tr><td>Order of Element</td><td colspan="3">Quadratic</td></tr>
</table>

Assign Material Properties:

Define material characteristics in ANSYS engineering information for each track structure component. The ANSYS engineering data library includes material characteristics of polyethylene material structural steel, concrete and rail pads. The material characteristics of butyl rubber and neoprene have been added to the Cambridge University Engineering Department's Data Book and material properties of CAM layer, HBL layer and foundation layer have been taken from a research paper [3].

Table 7: Material properties in the railway track model for all components

Components	Material	Density $\rho(Kg/m^3)$	Young's modulus E(MPa)	Poisson's ratio (μ)
Rail	Structural steel	7850	200000	0.3
Rail Pad	Polyethylene	950	1100	0.42
Slab	Concrete	2300	30000	0.18
CAM Layer	CAM	1800	8000	0.28
Slab mat	Butyl rubber Neoprene	900 1230	1 0.7	0.45 0.48
HBL layer	Composite material	2400	23000	0.25
Foundation layer	Soil	1800	100	0.3

Boundary Conditions:

The track structure considered as a simply supported beam. According to research an elliptical contact patch is produced at the wheel rail interface so an elliptical contact patch of dimension 24mmX12mm is modeled at the wheel rail interface at a distance of 5.65 m on each rail surface.

Stationary vertical wheel load is considered in this study, a static load of 80 KN considered for analysis. Dynamic effect of static load is applied as considering the dynamic load amplification factor (DLMF) value 2.7 for train moving with 270 km/h [1].

$$\text{DLMF} = \frac{maximum\ \ dynamic\ load\ act\ on\ track}{maximum\ static\ load\ applied}$$

So, 216 KN load is applied on that contact patch for including the dynamic effect of moving train. For Harmonic response analysis 216 KN force is applied for analysis.

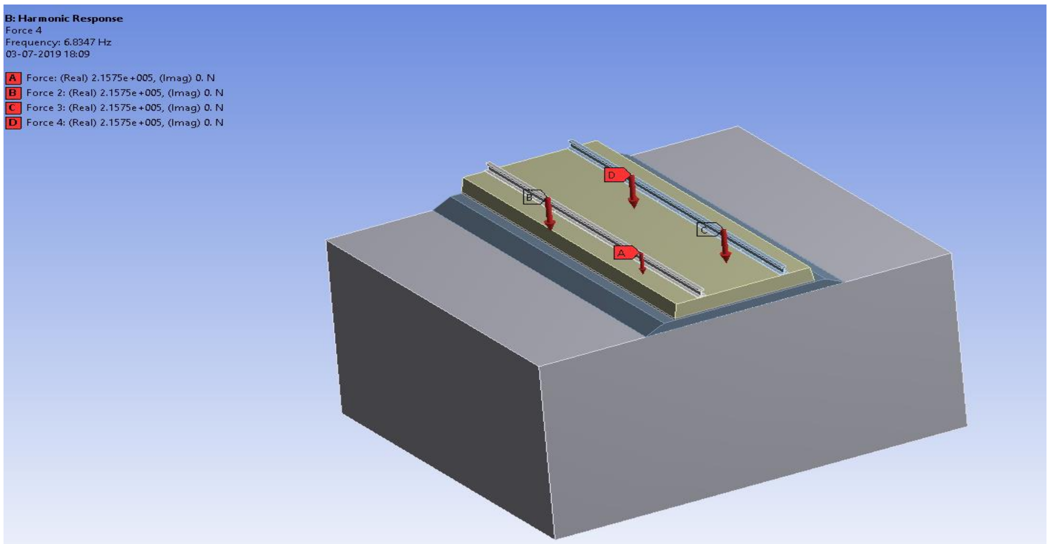

Figure 23: Rail with load condition

For dynamic analysis of railway track structure support condition is also define, a fixed support has been set at the bottom most layer of track structure.

Table 8: Support and loading setting in harmonic response

Type	Fixed support	force
Suppressed	No	
Define by		Components
System of Coordinate		Global System of Coordinate
X Coordinate		0 N
Y Coordinate		-216000 N
Z Coordinate		0 N
X Phase Angle		0^{0}
Y Phase Angle		0^{0}
Z Phase Angle		0^{0}

Modal analysis:

Dynamic properties of railway track structure is investigated by using modal analysis**,** as we know the dynamic properties of any modal is study in both time domain function and frequency domain function. Modal analysis is done to determine the natural frequency and corresponding mode shapes. Every mode is defined in terms of its modal parameters like's natural frequency and mode shape which is a displacement pattern at a particular natural frequency.

ANSYS workbench 18.1 has been used to modal analysis for determine natural frequency and mode shapes. For Mode shapes 15 number of modes is assign in the modal analysis setting. In this thesis frequency domain function is used to determine natural frequency and made shapes.

Table 9: Modal analysis setting

Object name	Analysis Settings
State	Fully define
Options	
Maximum modes to find	15
Limit search to range	No
Solver controls	
Damped	No
Solver type	Program controlled
Rotor dynamics controls	
Carioles effect	Off
Output controls	
Stress	No
Strain	No
Nodal forces	No
Calculate reactions	No

Harmonic Response Analysis (Vibration Analysis):

Harmonic response Analysis is a linear analysis. Loads and displacement are sinusoidal in harmonic response analysis to determine the steady state response of linear structure at different frequencies and get the response curve with frequency variation, such as acceleration v/s frequency curve, displacement v/s frequency curve, velocity v/s frequency curve, stress v/s frequency curve, strain v/s frequency curve. Transient vibration which is generally appearing at the moment of stimulation is not considered in harmonic response analysis. User defined parameter for analysis is harmonic load, which is applied in the form of force, forced displacement and pressure. In ANSYS workbench 18.1 for harmonic analysis FULL METHOD and MODE SUPERPOSITION METHOD are available as solution techniques. In this thesis mode superposition method is used for simulation, and response curve with frequency variation as acceleration v/s frequency has been obtain.

Table 10: Harmonic response analysis setting

Object name	Analysis Settings
State	Fully defined
Options	
Spacing of Frequency	Linear
Minimum of Frequency Range	0 Hz
Maximum of Frequency Range	100 Hz
Intervals of Solution	10
Method of Solution	Mode superposition method
Include residual vector	No
Cluster result	No
Modal frequency range	Manual
Minimum frequency	It vary according to modal type

Maximum frequency	It vary according to modal type
Store results at all frequencies	Yes
Rotor dynamics controls	
Cori oils effect	off
Output controls	
Stress	Yes
Strain	Yes
Nodal forces	No
Calculate reactions	Yes
Expand results from	Program controlled
Expansion	Harmonic solution
Damping controls	
Constant damping ratio	.01

Mode superposition method:

Mode-superposition technique is a technique of characterizing the dynamic response of a structure to transient analysis or Harmonic Analysis excitation by using the natural frequencies and mode shapes from modal analysis.

The general equation of motion is provided in order to study a harmonic analysis:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = F$$

This equation has following assumptions:

- ✓ [M] –Mass matrix constant
- ✓ [C] – Damping matrix constant
- ✓ [K] – Stiffness matrix constant
- ✓ Behaviour of elastic material is assumed to be linear
- ✓ Theory of small deflection is consider, and nonlinearities not included

- ✓ [C] Damping must be considered. If the excitation frequency W is about the natural frequency w of the system, the response is endless at resonance.
- ✓ The { F } force or { x } displacement is sinusoidal at a defined W frequency,

  Analysis of free vibration is conducted; simulation can recognize what the natural frequencies of the structure are. In a harmonic analysis, the maximum response will be equal to the natural frequencies of the structure. Since the frequencies of nature are known, simulation can cluster results close natural frequencies instead of using evenly spaced results.
- ✓ With the following exceptions, structural loads and supports can also be used in harmonic analyses:
  - Thermal loads are not supported
  - Rotational Velocity is not supported
  - The Remote Force Load is not supported
  - The Pretension Bolt Load is non-linear and cannot be used
  - The Compression Only Support is not linear and should not be used. If present, it behaves similar to a Frictionless Support
  - All structural loads will vary sinusoidal at the same excitation frequency.

CHAPTER 4

Results and Discussion

To determine frequency response curve with frequency variation as acceleration v/s frequency first modal analysis and then harmonic response analysis have been conducted in ANSYS Workbench. For distinct stiffness and damping ratio the simulations has been repeated. The results have been plotted in Excel graphs to describe the interaction between specific slab mat parameters and their vibration reduction impact.

Modal analysis results:

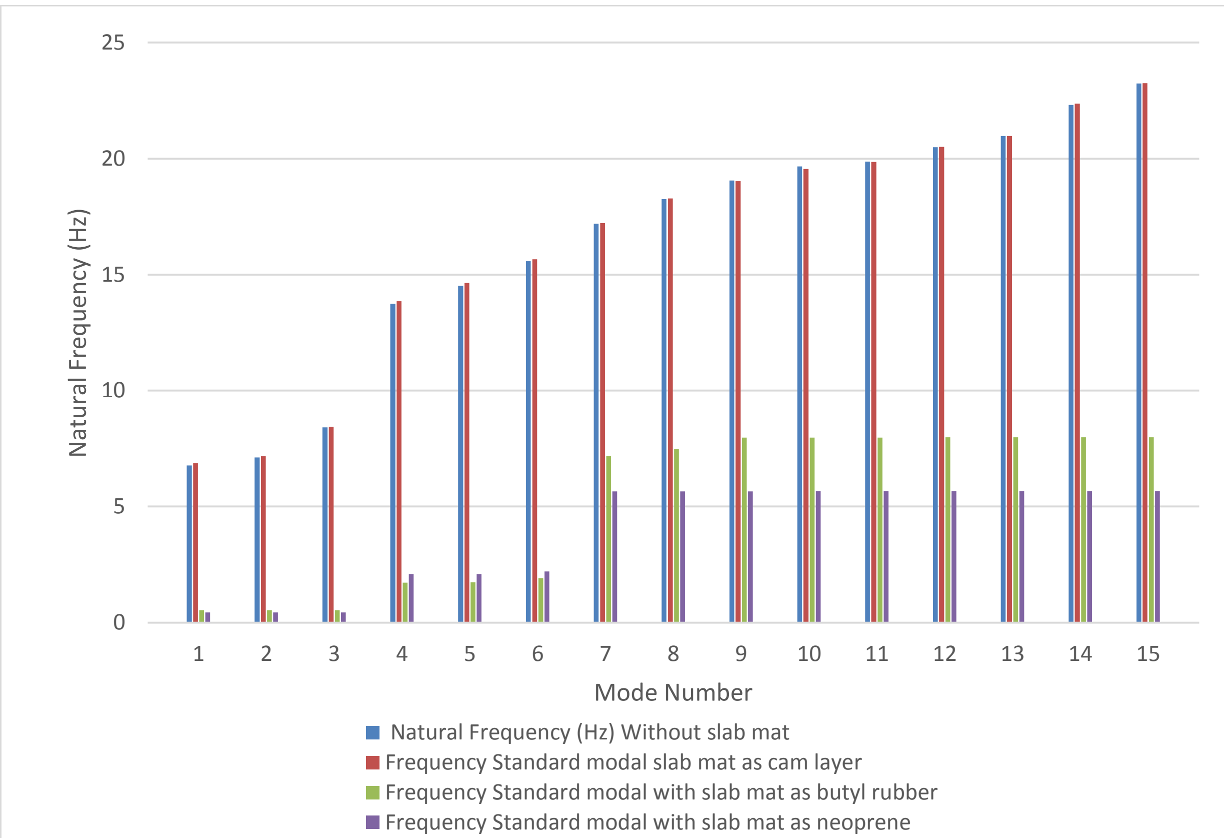

Figure 24: Mode number and natural frequency in different rail track modal

From modal analysis natural frequencies and mode shapes corresponding to these frequencies are obtain for various rail track structure. The results of all rail track structures modal, find out the maximum natural frequency occurs in the standard rail track structure in which as CAM layer provided and minimum natural frequency in standard rail track in which slab mat is provided as neoprene. Here some mode shapes are representing corresponding to maximum natural frequency that is mode shapes of standard rail track structure in which CAM layer provided as that is in standard rail track modal:

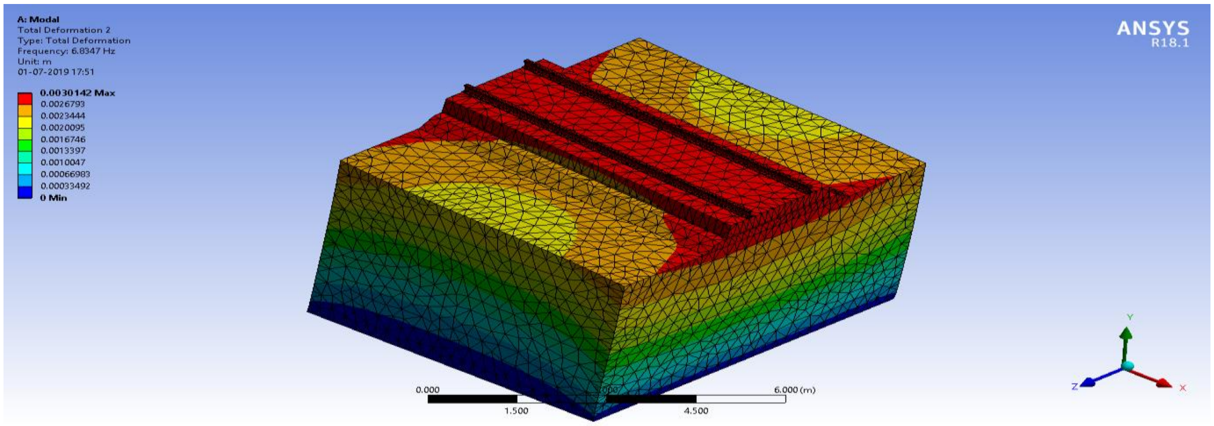

Figure 25: Mode Shape 1 at Natural Frequency 6.847 Hz

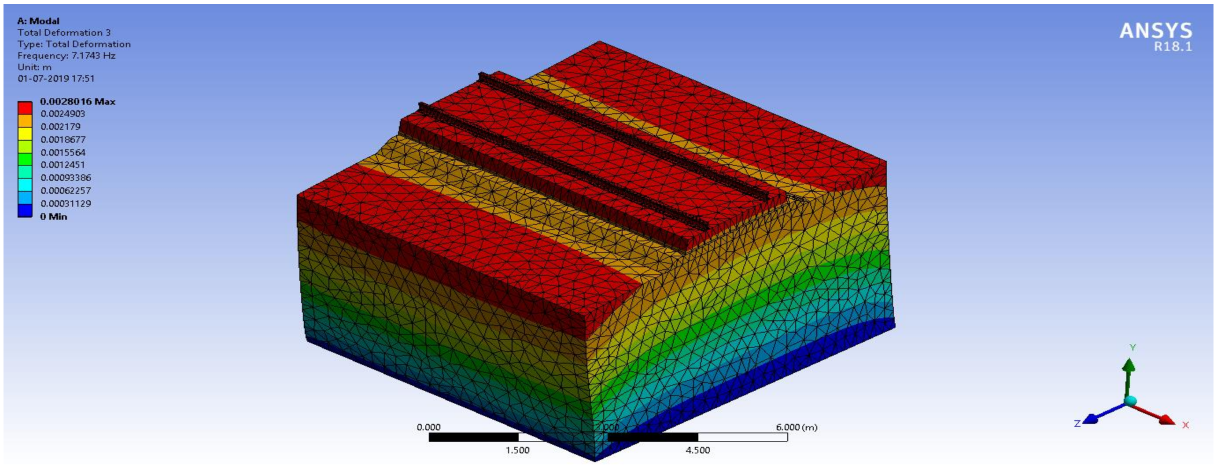

Figure 26: Mode Shape 2 at natural Frequency 7.1743 Hz

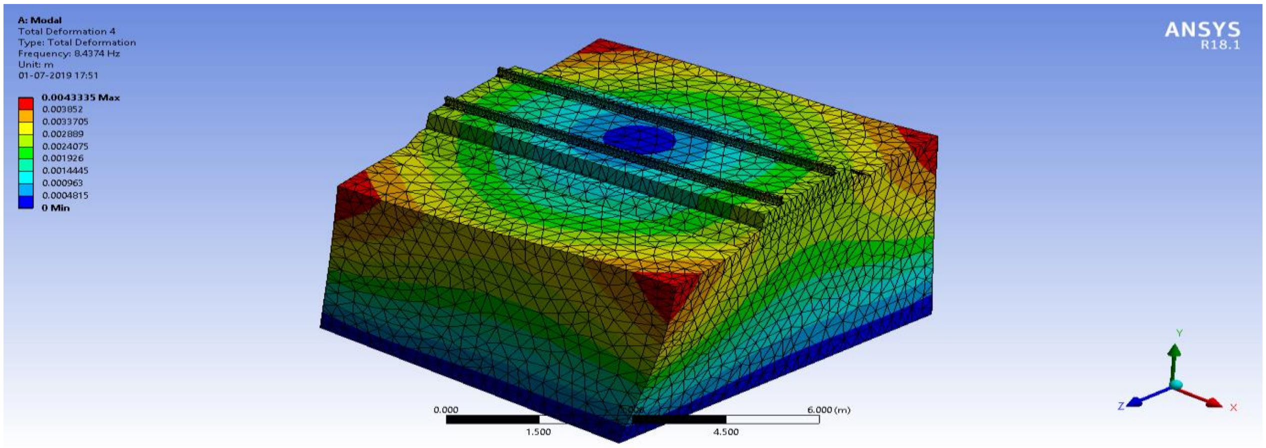

Figure 27: Mode Shape 3 at Natural Frequency 8.4374 Hz

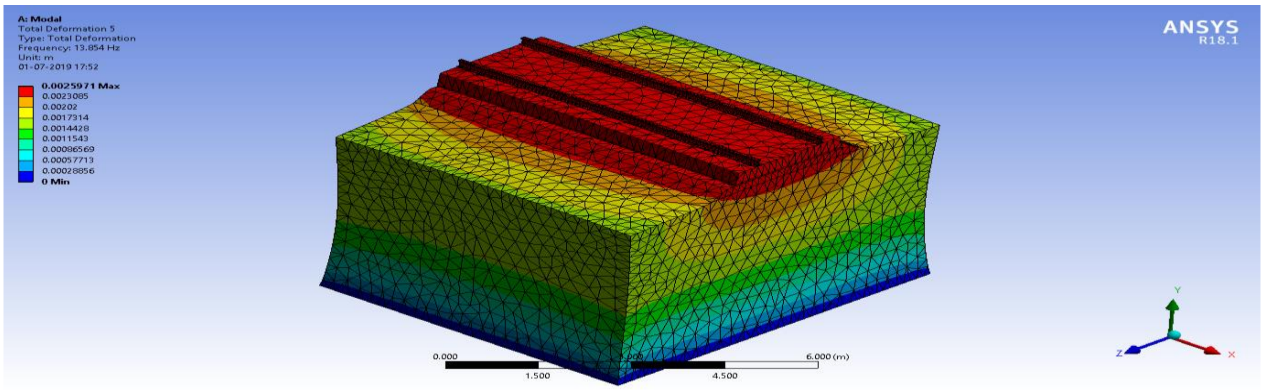

Figure 28: Mode Shape 4 at Natural Frequency 13.854 Hz

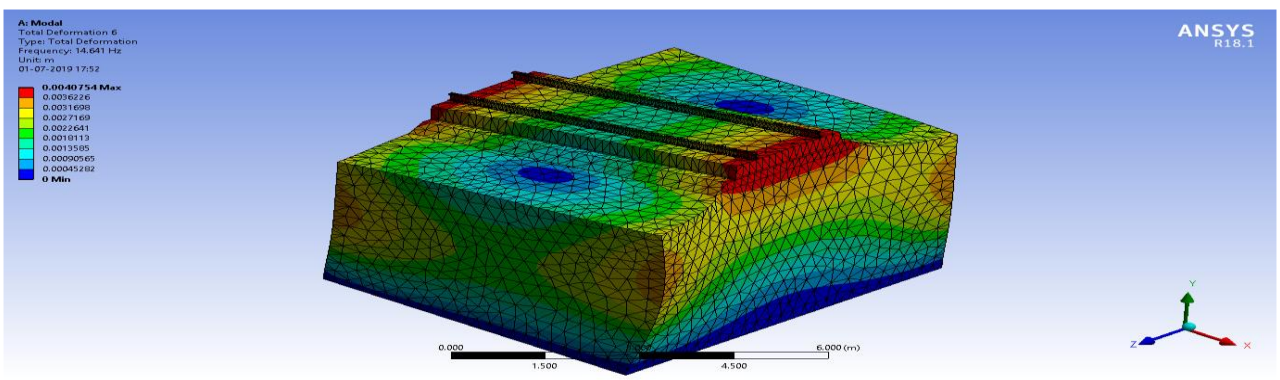

Figure 29: Mode Shape 5 at Natural Frequency 14.641 H

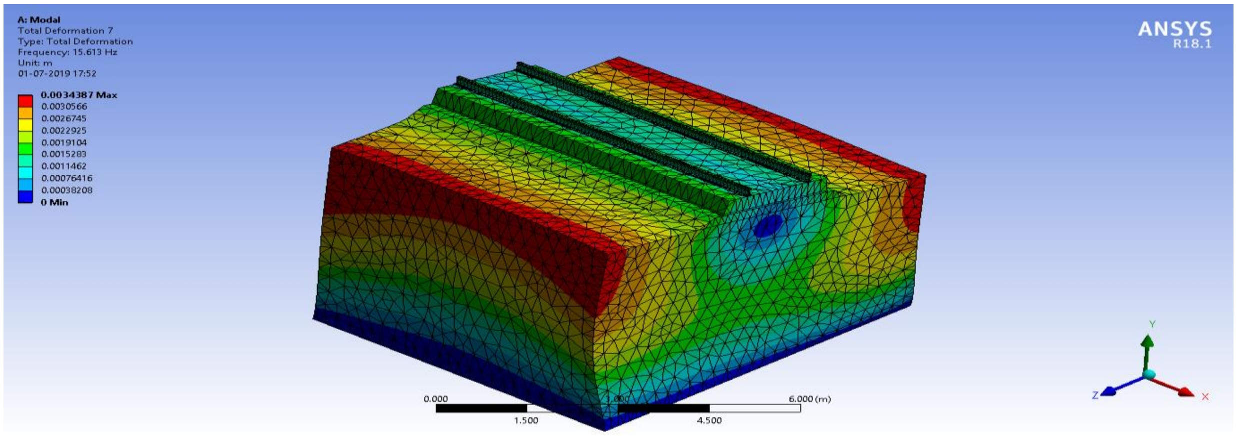

Figure 30: Mode Shape 6 at Natural Frequency 15.653 Hz

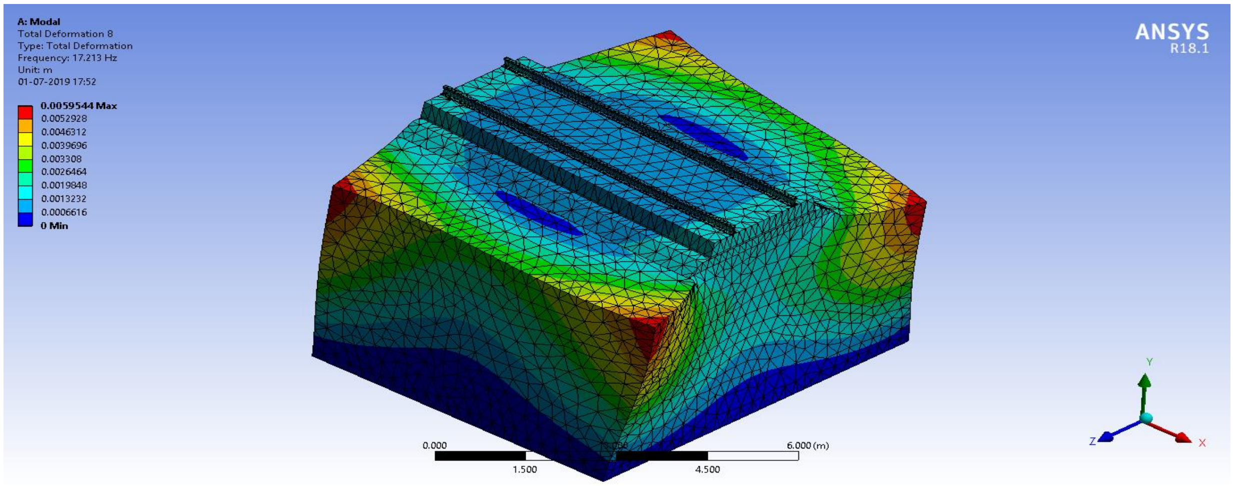

Figure 31: Mode Shape 7 at Natural Frequency 17.213 Hz

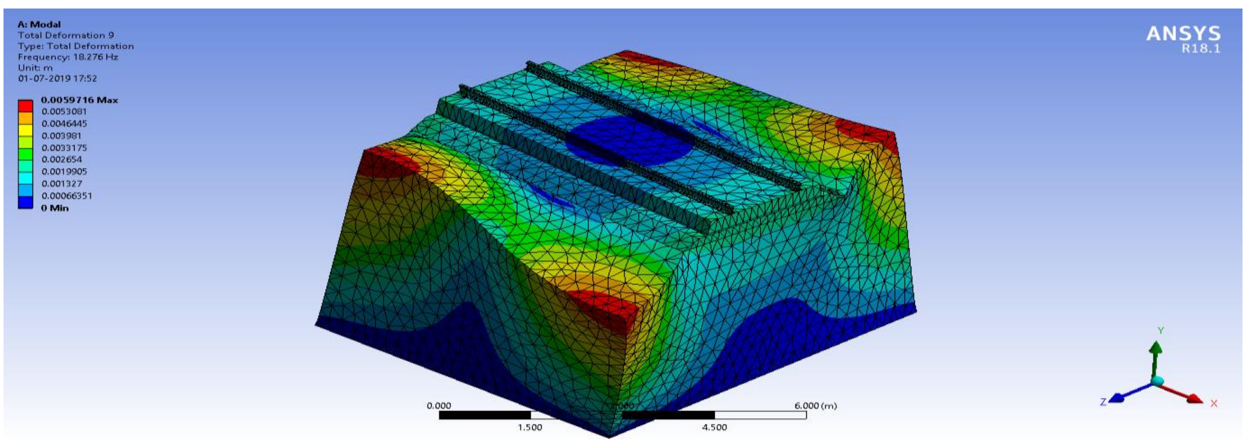

Figure 32: Mode Shape 8 at Natural Frequency 18.276 Hz

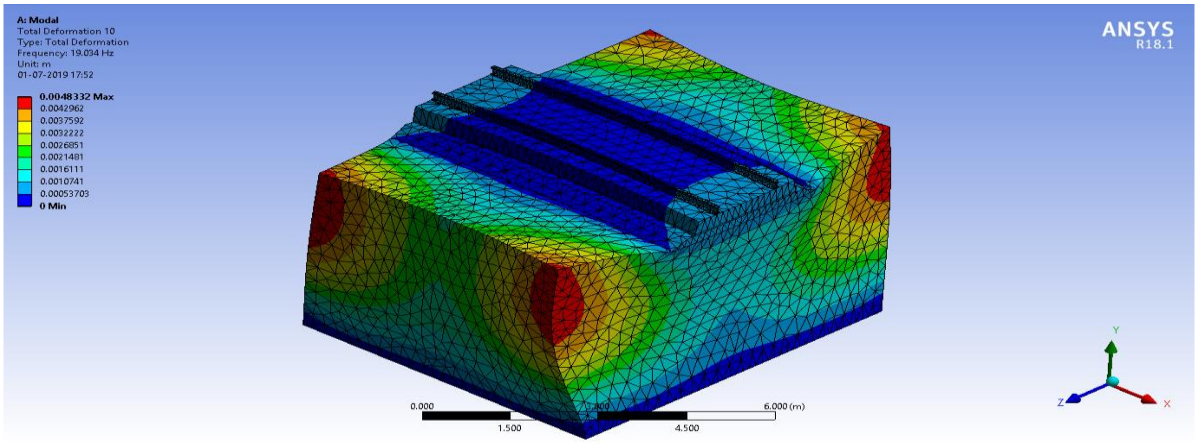

Figure 33: Mode Shape 9 at Natural Frequency 19.034 Hz

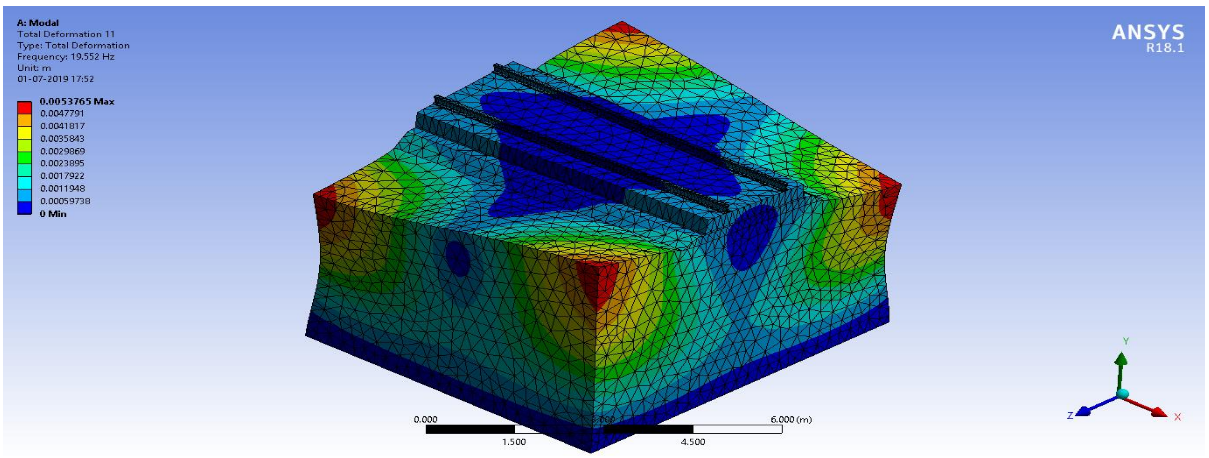

Figure 34: Mode Shape 10 at Natural Frequency 19.552 Hz

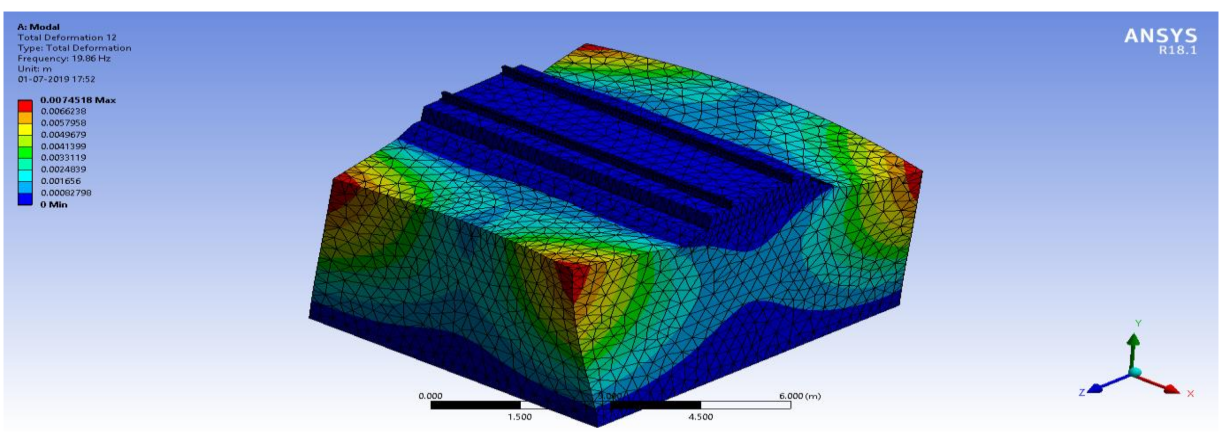

Figure 35: Mode Shape 11 at Natural Frequency 19.86 Hz

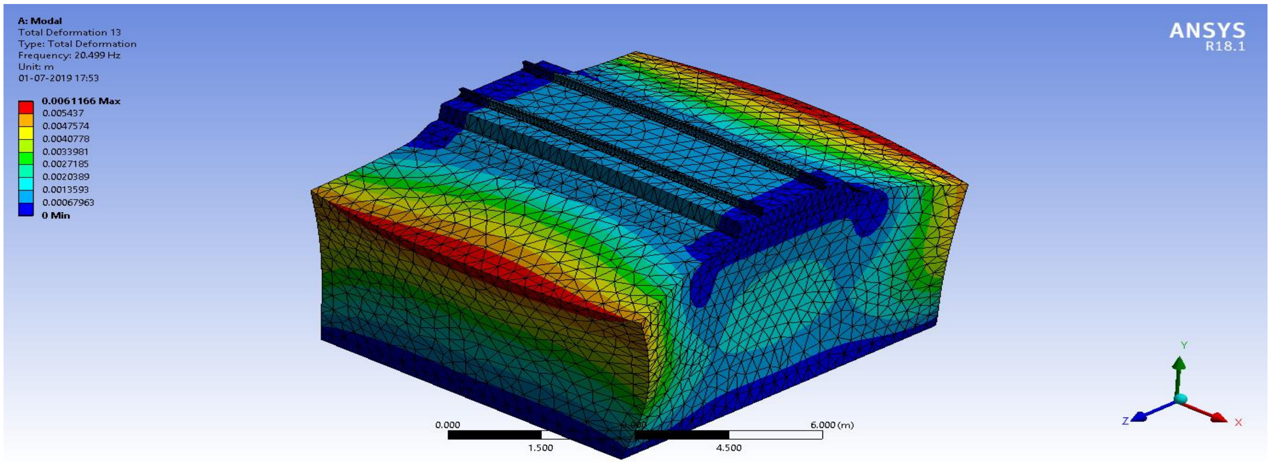

Figure 36: Mode Shape 12 at Natural Frequency 20.499 Hz

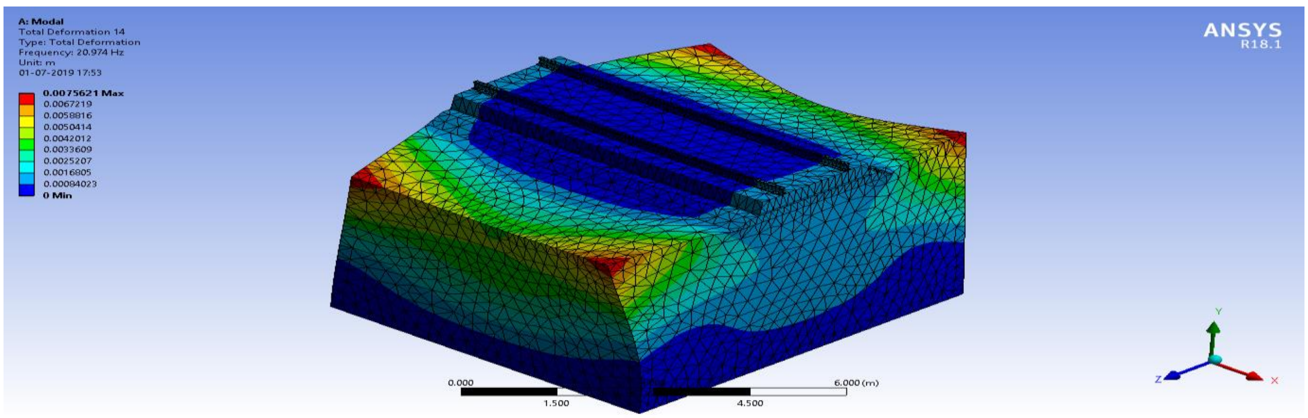

Figure 37: Mode Shap13 at Natural Frequency 20.974 Hz

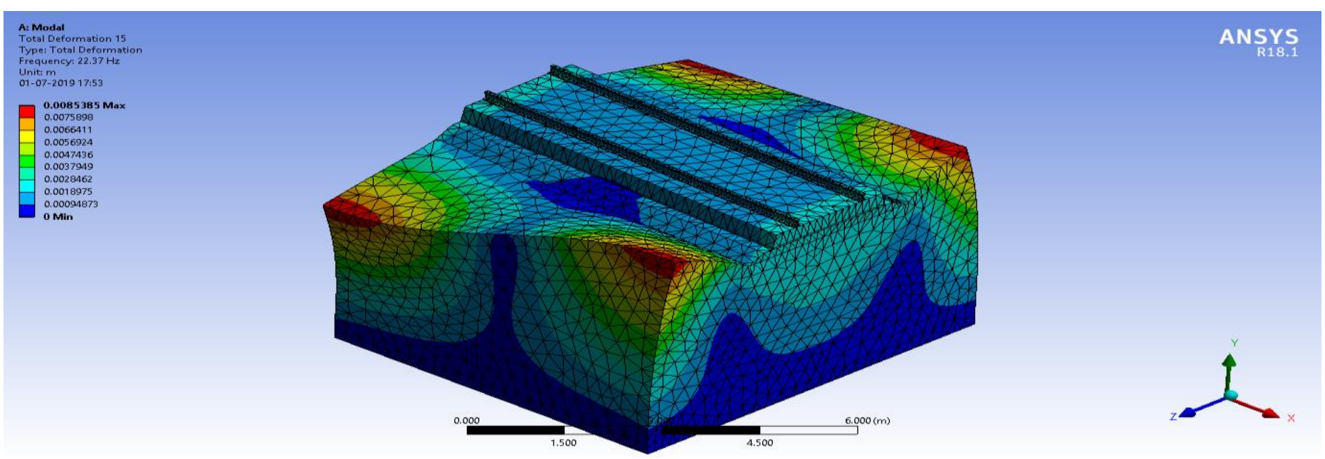

Figure 38: Mode Shape 14 at Natural Frequency 22.37 Hz

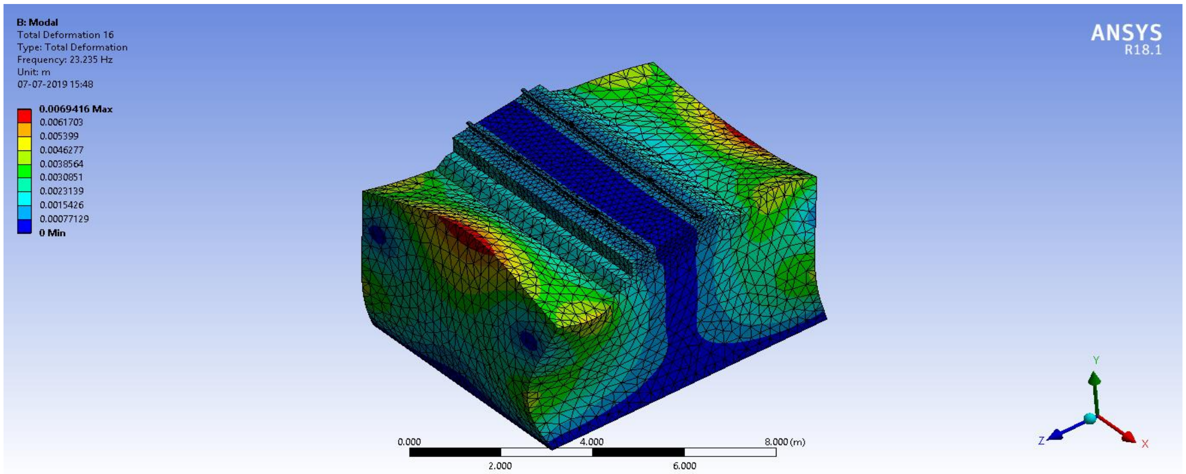

Figure 39: Mode Shape 15 at Natural Frequency 23.254 Hz

Harmonic response analysis:

To study the impact of vibration, acceleration in rails, concrete slab layer and complete track structure have been considered to represent the variations. Various modal of rail track structure have been considered to analysis variation in acceleration.

Rail track structure without slab mat

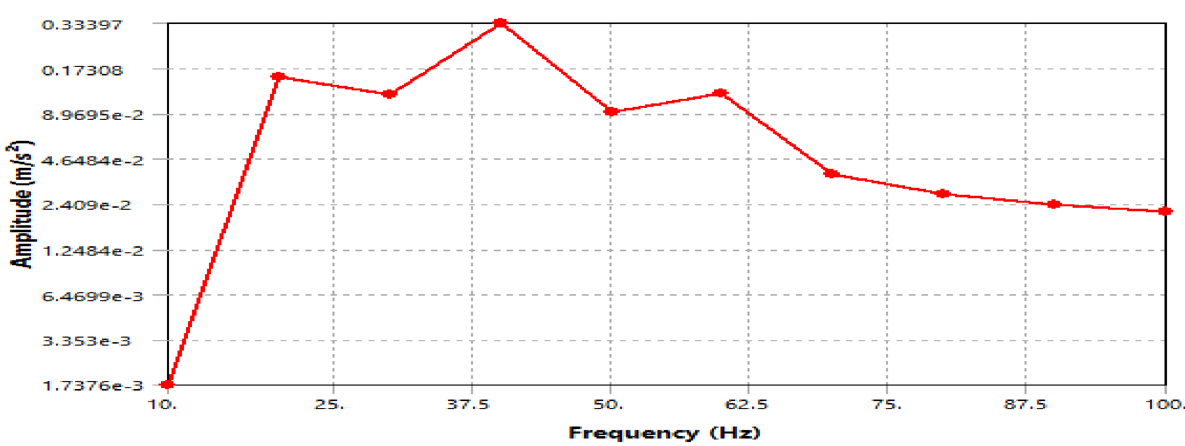

Figure 40: Acceleration v/s frequency curve for rail

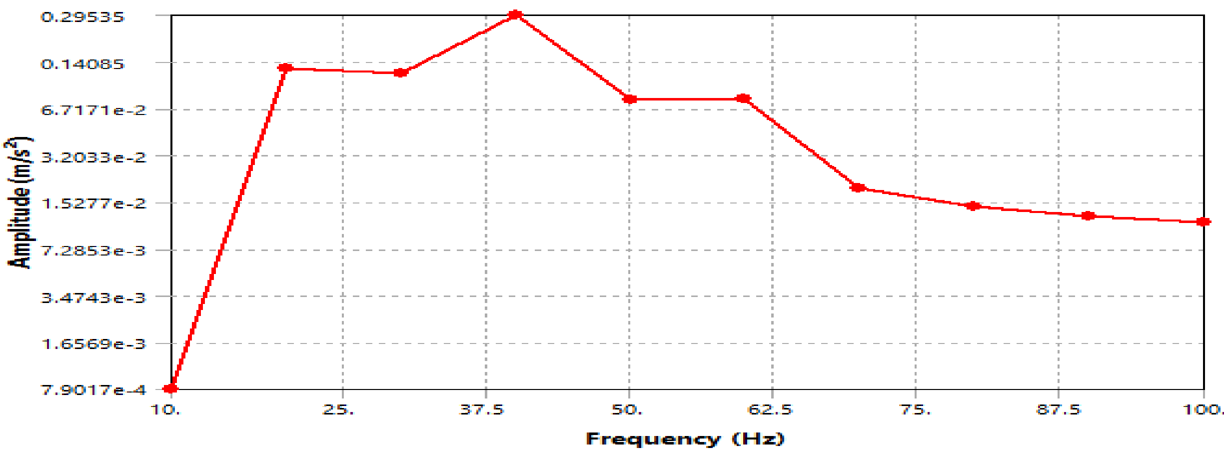

Figure 41: Acceleration v/s frequency curve for slab:

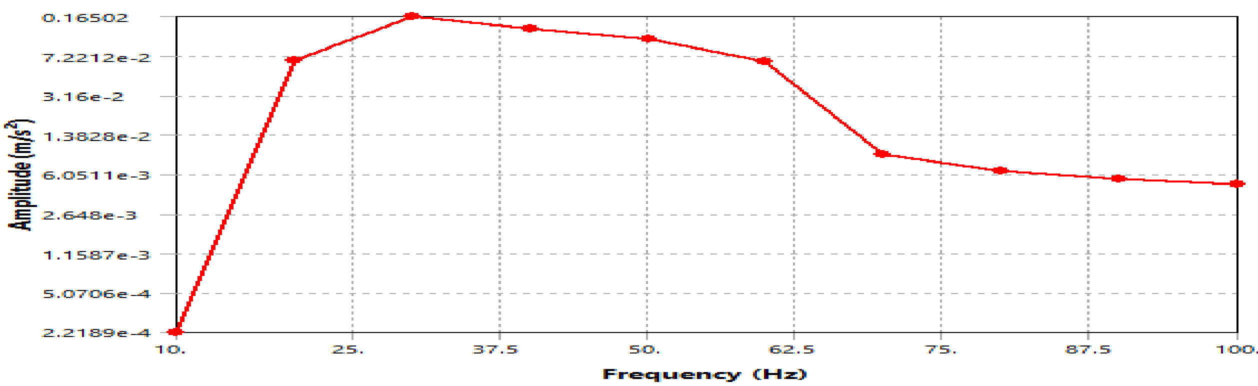

Figure 42: Acceleration v/s frequency curve for track structure

In high speed railway track without slab mat, excitation occurs in the rail and concrete slab at frequency 40 Hz and track structure at frequency 30 Hz. Maximum acceleration occurs at 40 Hz frequency and its response magnitude is 0.33397 m/s^{-2} and0.29535 m/s^{-2} in rail, slab respectively and in track structure maximum acceleration occurs at a frequency of 30 Hz and its response magnitude 0.16502 m/s^{-2}. This acceleration response is decreased with higher frequency.

Rail track structure with slab mat:

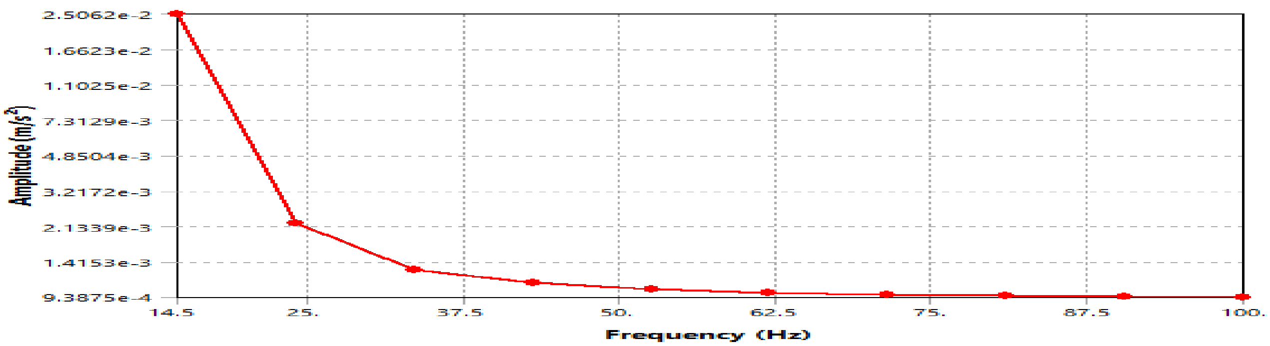

Figure 43: Acceleration v/s frequency curve for rail:

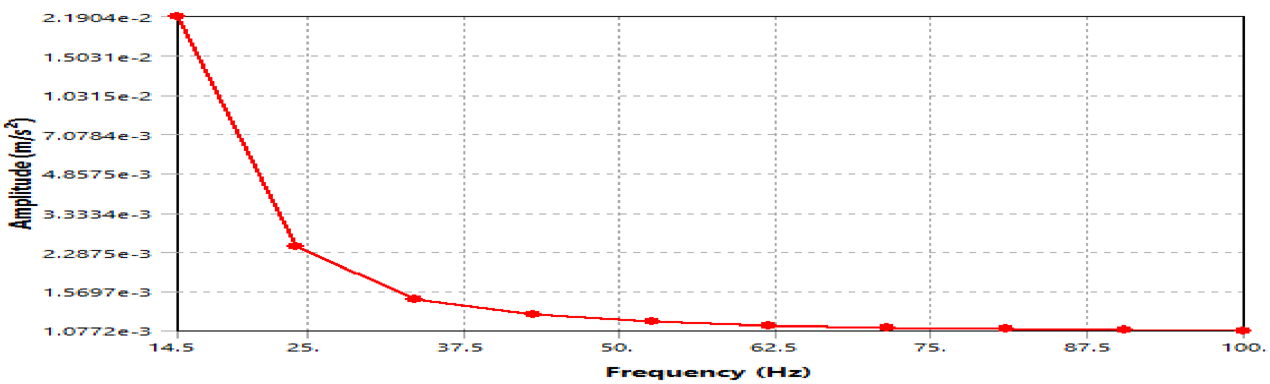

Figure 44: Acceleration v/s frequency curve for concrete slab

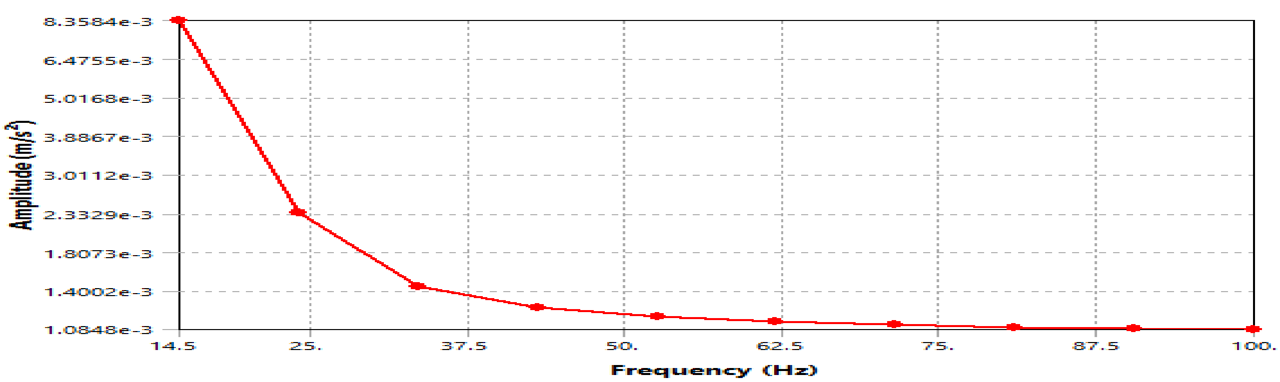

Figure 45: Acceleration v/s frequency curve for track structure

Introducing the slab mat that has the material properties in high speed railway track, excitation occurs in the track structure at frequency 14.5 Hz. It means introduction of slab mat damping property of high speed railway track is improved in such a way that maximum acceleration occurs at a 14.5 Hz frequency and its response magnitude is 2.5062×10^{-2} m/s^{-2} , 2.1904×10^{-2} m/s^{-2} and 8.3584×10^{-3} m/s^{-2} in rail, slab and track structure respectively. This acceleration response is decreased with higher frequency.

Rail track structure with slab mat: Neoprene Layer

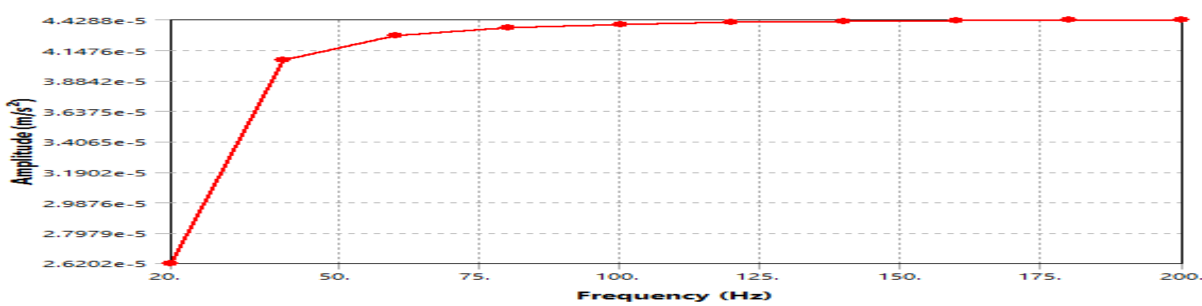

Figure 46: Acceleration v/s frequency curve for rail:

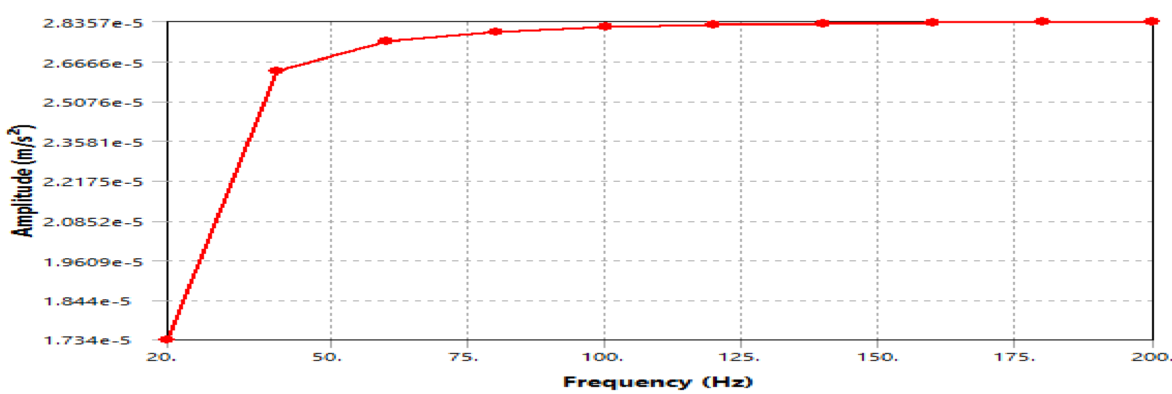

Figure 47: Acceleration v/s frequency curve for concrete slab

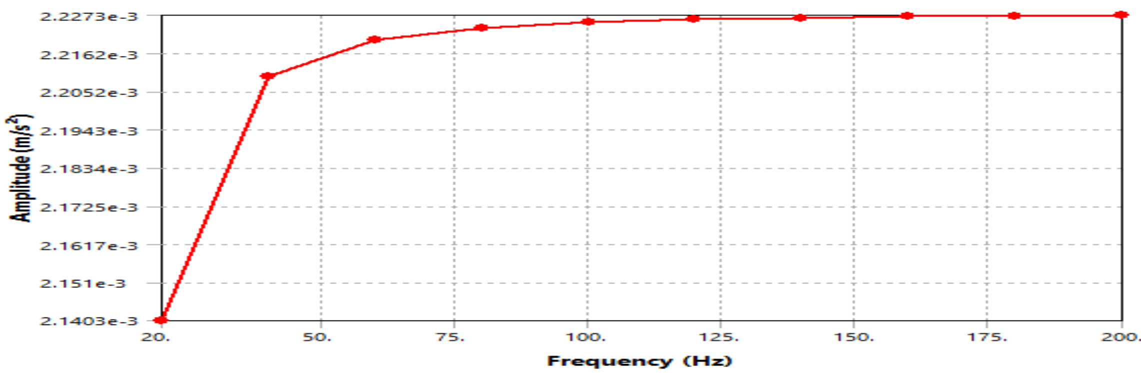

Figure 48: Acceleration v/s frequency curve for track structure

Introducing the slab mat that has the material properties as neoprene in high speed railway track, excitation occurs in the track structure at frequency 140 Hz. It means introduction of neoprene layer damping property of high speed railway track is improved in such a way that maximum acceleration occurs at a 140 Hz frequency and its response magnitude is 4.4288×10^{-5} m/s^{-2}, 2.8357×10^{-5} m/s^{-2} and 2.2273×10^{-3} m/s^{-2} in rail, slab and track structure respectively. This acceleration response is increase with higher frequency and become constant at 200 Hz.

Rail track structure with slab mat: Butyl Rubber Layer

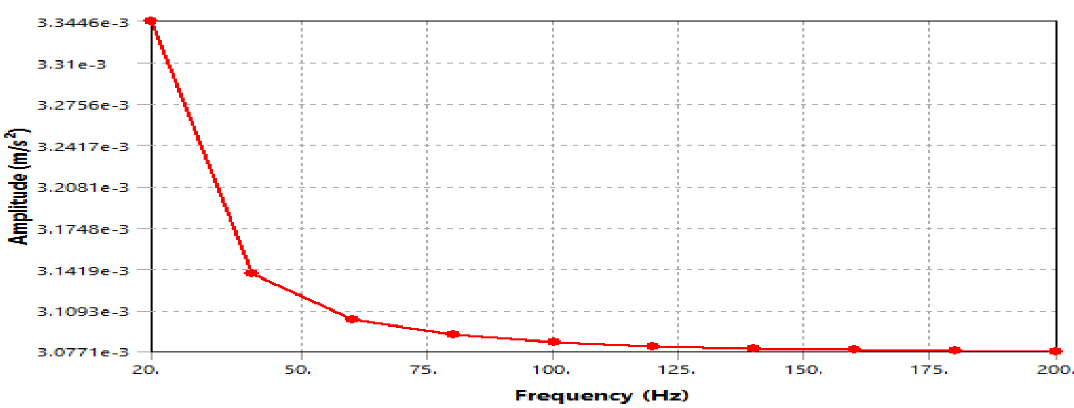

Figure 49: Acceleration v/s frequency curve for rail

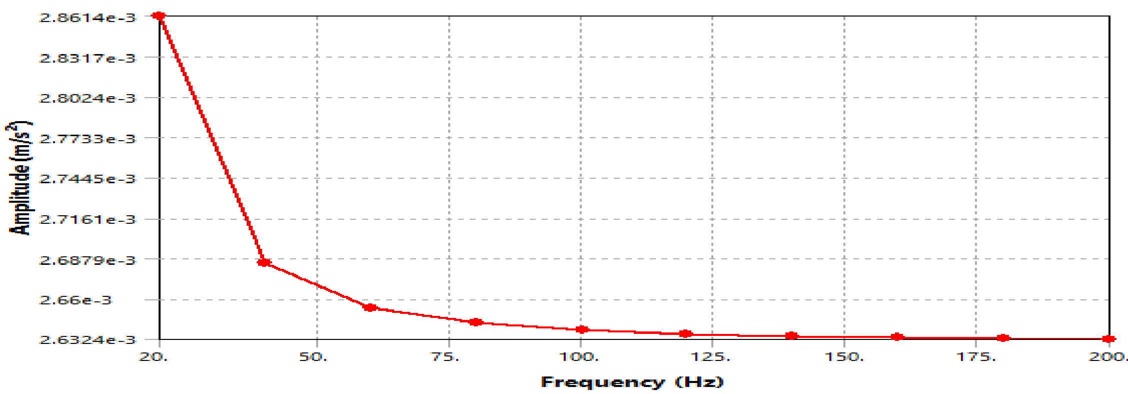

Figure 50: Acceleration v/s frequency curve for concrete slab

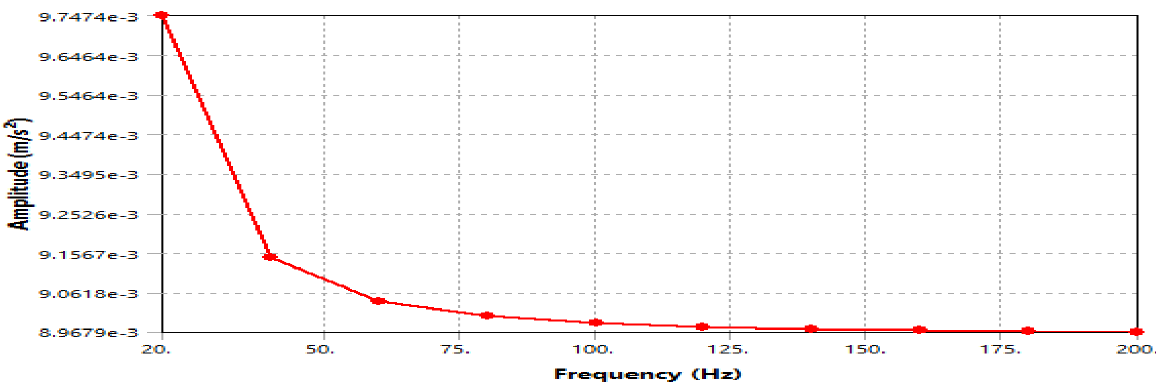

Figure 51: Acceleration v/s frequency curve for track structure

Introducing the slab mat that has the material properties as butyl rubber in high speed railway track, excitation occurs in the track structure at frequency 20 Hz. It means introduction of butyl rubber layer damping property of high speed railway track is improved in such a way that maximum acceleration occurs at a 20 Hz frequency and its response magnitude is 3.3446×10^{-3} m/s^{-2}, 2.8614×10^{-3} m/s^{-2} and 9.7474×10^{-3} m/s^{-2} in rail, slab and track structure respectively. This acceleration response decreases with higher frequency and become constant at 200 Hz.

Effect of Slab Mat Layer in Reducing Vibration Response:

Acceleration in various component likes, rails, concrete slab and complete track structure of high speed railway track structure are considered, to study the impact of reducing the vibration response. Analysis was done for two different conditions of railway track structure first analysis are done for high speed railway track structure without slab mat layer followed by high speed railway track structure with slab mat which consist of CAM layer as material.

From the fig. results are observed that the response magnitude of acceleration in all considered component of high speed railway track structure are reduce and retain approximately to $0.01 m/s^2$ as frequency increased, when slab mat layer is provided. However, results obtain when analysis was done without insertion of slab mat layer, acceleration of all component of track varies at initial frequency and become constant at high frequency. Since when acceleration in high speed railway track structure is high, the vibration response is also higher.

In terms of reducing the propagation of the vibration response from the high speed railway track structure to the adjacent area, slab mat layer must be provided in the high speed railway track str ucture.

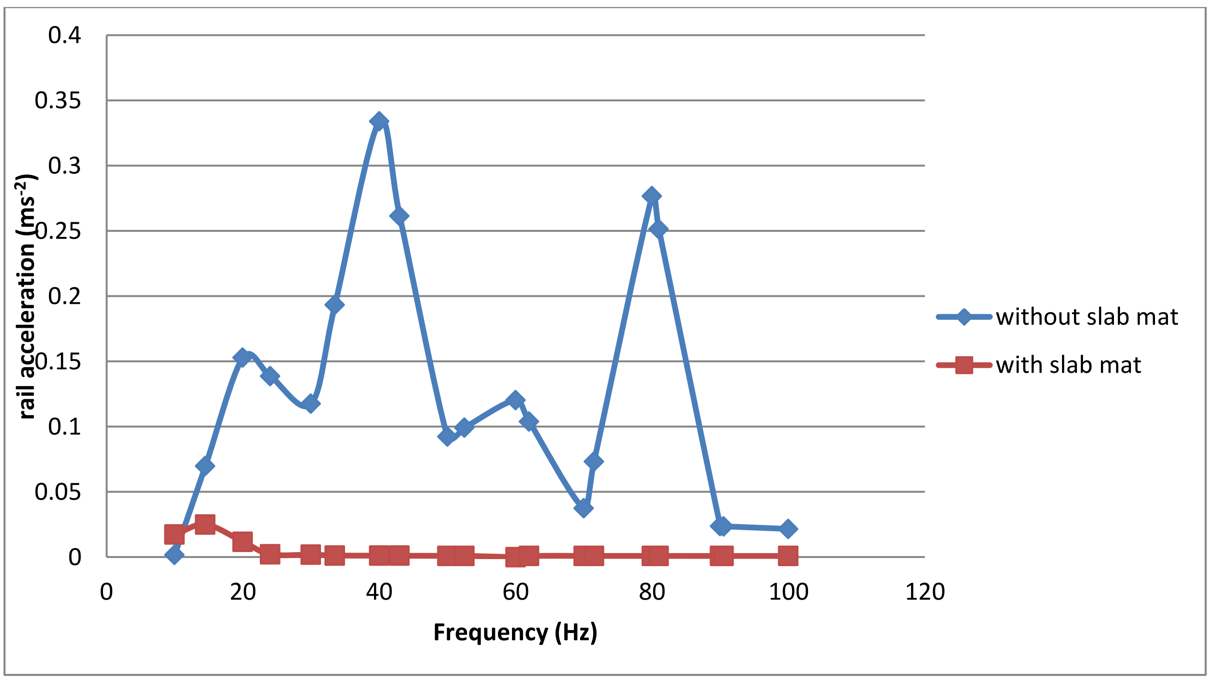

Figure 52: for Rail acceleration v/s frequency curve for non- ballast track without layer of slab mat and with layer of slab mat track

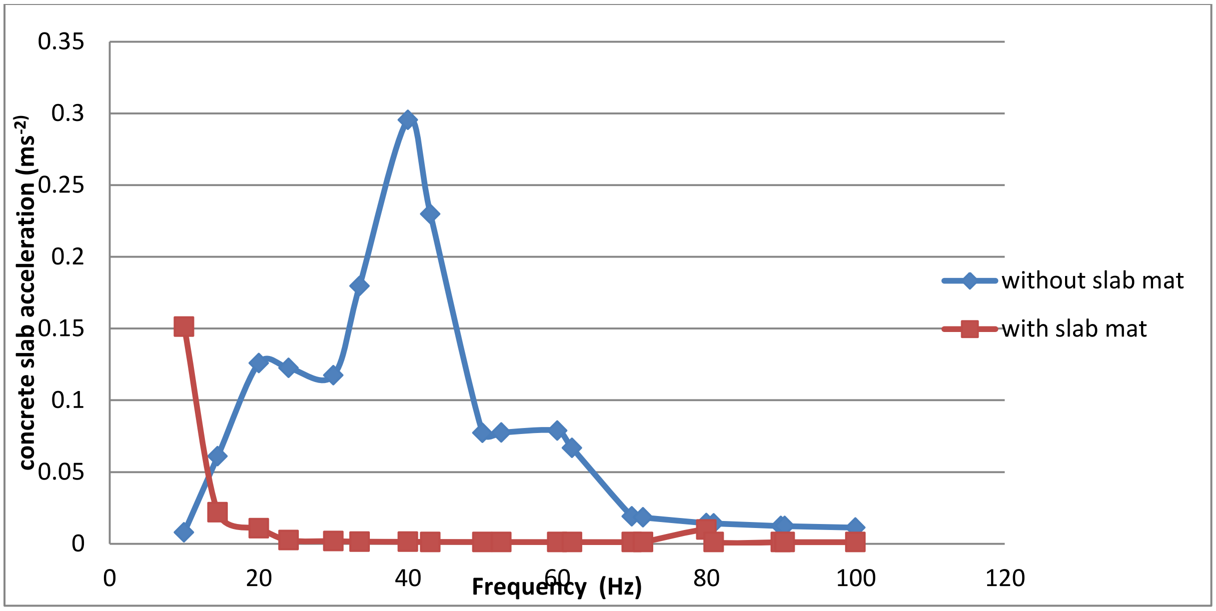

Figure 53: Concrete slab acceleration v/s frequency curve for non- ballast track for without layer of slab mat and with layer of slab mat track

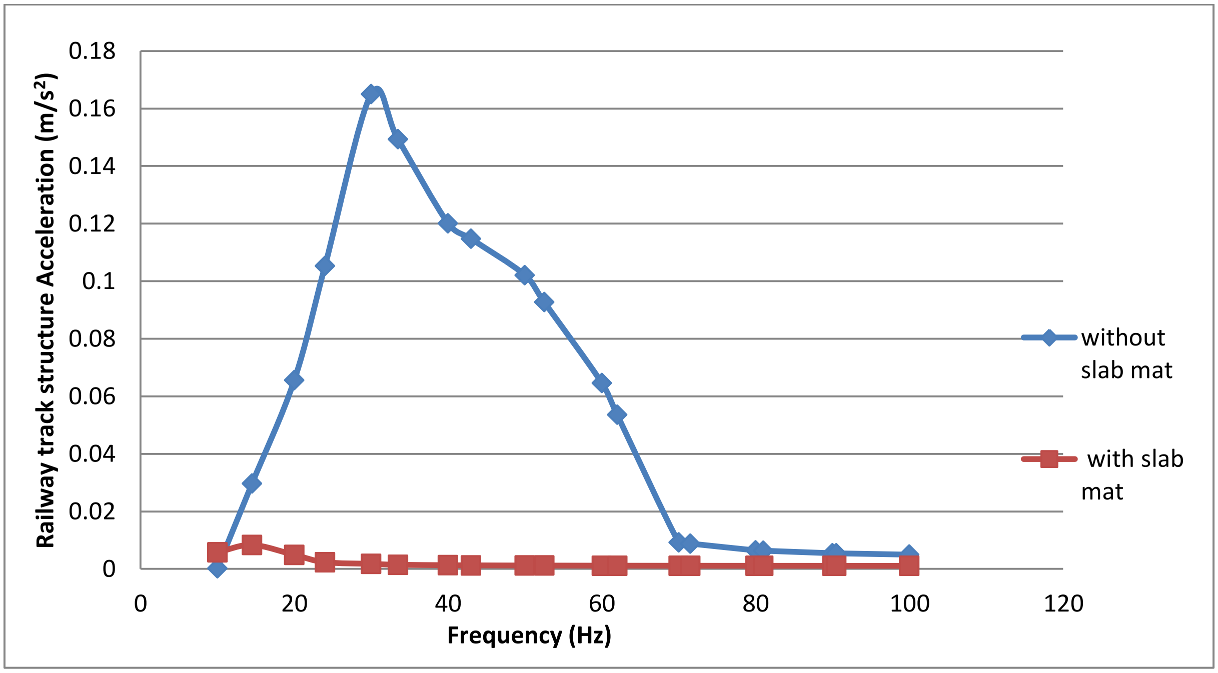

Figure 54: Railway track structure acceleration v/s frequency curve for non- ballast track for without layer of slab mat and with layer of slab mat track

Effect of Mat Layer of Slab Stiffness in Reducing Vibration Response:

Stiffness effect of elastic material to reducing vibration response in high speed railway track structure are done by introducing butyl rubber and neoprene as elastic material in slab mat layer. Butyl rubber and neoprene with an elastic module of 1.0MPa and 0.7MPa act as an elastomer to absorb vibration response. According to research a relation between elastic modulus and stiffness of material was exist such as $k = \frac{AE}{l}$, stiffness varies directly proportional to modulus of elasticity of material it means higher elastic modulus material having higher stiffness properties.

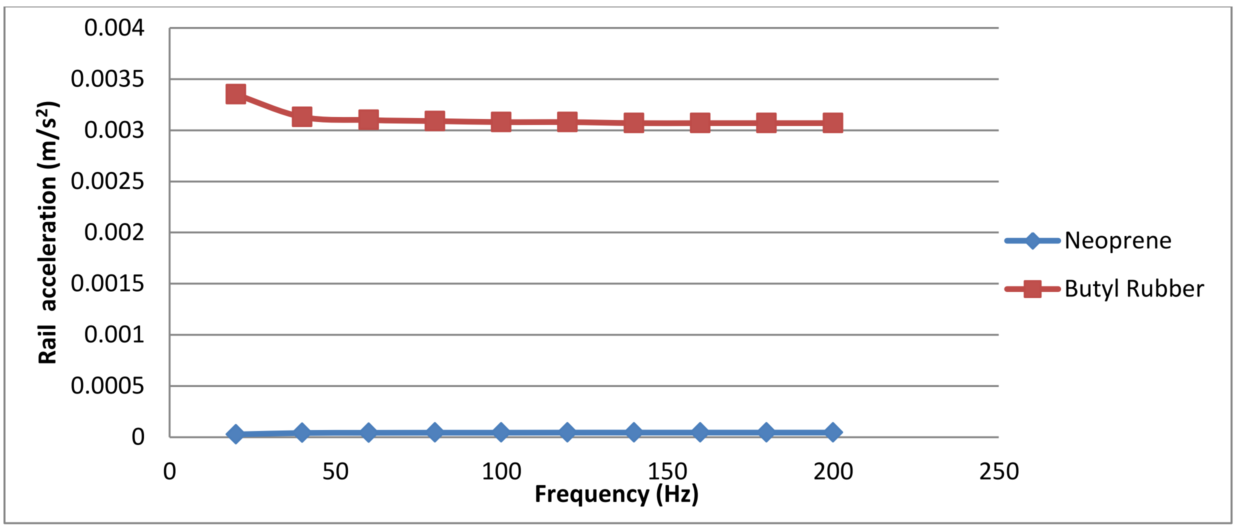

Figure 55: Rail acceleration v/s frequency curve for non-ballast track using two separate forms of Elastic material for layer of slab mat

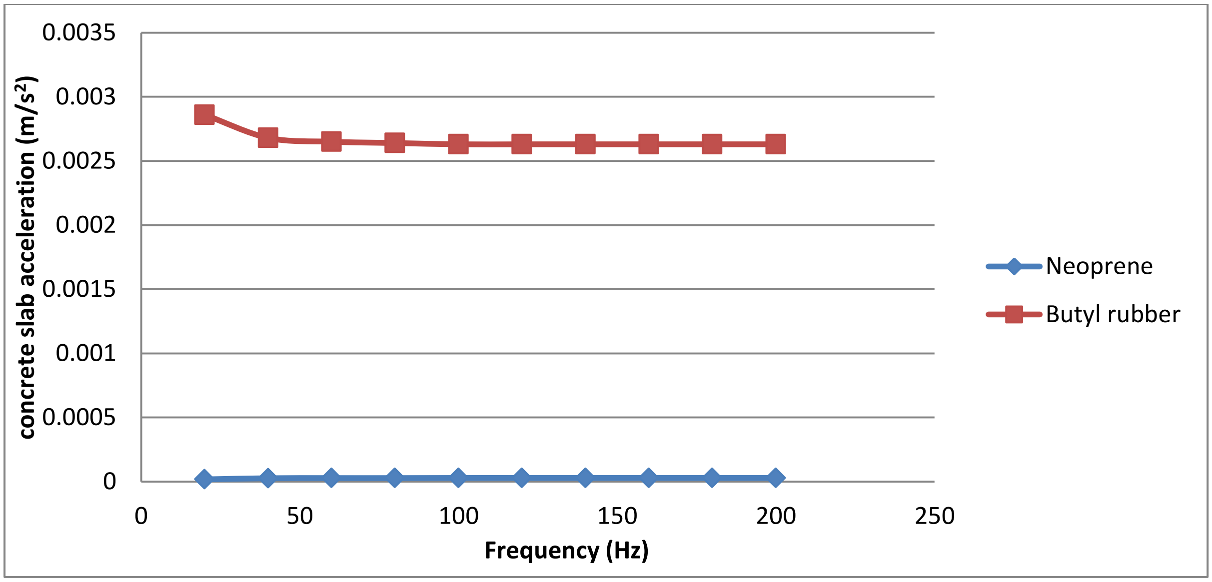

Figure 56: concrete slab acceleration v/s frequency curve for non- ballast track using two separate forms of Elastic material for layer of slab mat

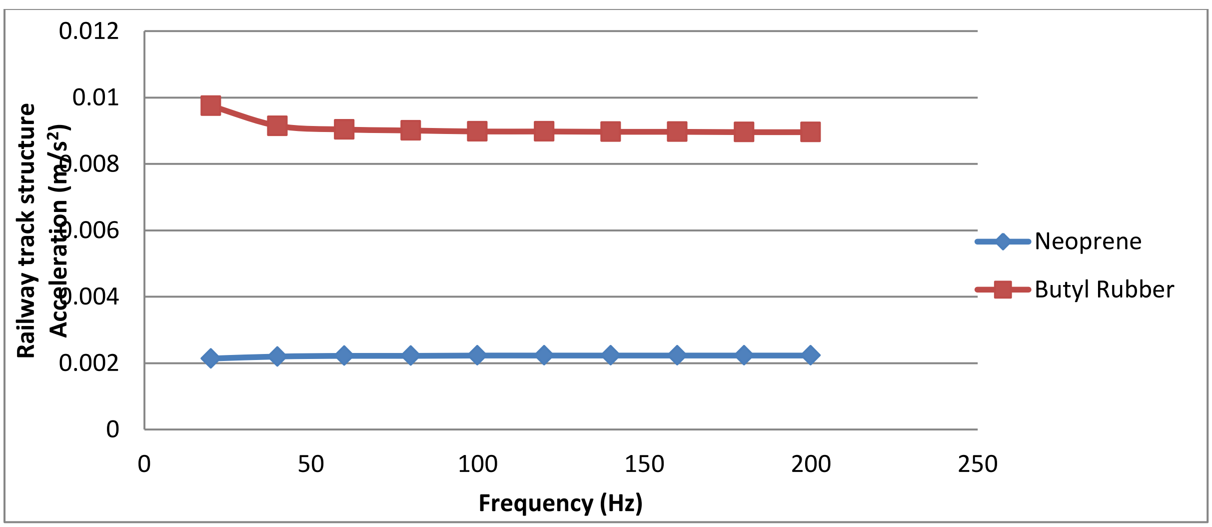

Figure 57: Railway track structure acceleration v/s frequency curve for non- ballast track using two separate forms of Elastic material for layer of slab mat

When the frequency of the highspeed railway track is less than 50 Hz, the vibration response is reduced.Vibration response can be minimized by using neoprene because neoprene has a lower elastic module (stiffness) compared to butyl rubber slab mat. Therefore, the reduced stiffness sla b mat is preferable for minimized vibration response (acceleration).

Effect of slab mat damping ratio on vibration response:

Vibration response of high speed railway track structure can also be reduced by changing the damping ratio of slab mat material. Mechanical energy transformed to heat due to the damping characteristics of the material, according to studies. Thus, mechanical energy decreases when it passes through slab mat material.

Butyl rubber and neoprene slab mat are considered for analysis of high speed railway track structure with higher constant damping ratio. Damping ratio varies from 1% up to 10 %. As per the studies, due to damping there is no effect on frequency only amplitude of dynamic response effected. Vibration response of high speed railway track structure that is acceleration decreases as the constant damping increase in both damping material that is butyl rubber and neoprene. The decreasing response of vibration in track structure is not visible because variation of constant damping ratio in butyl rubber and neoprene are not significant.

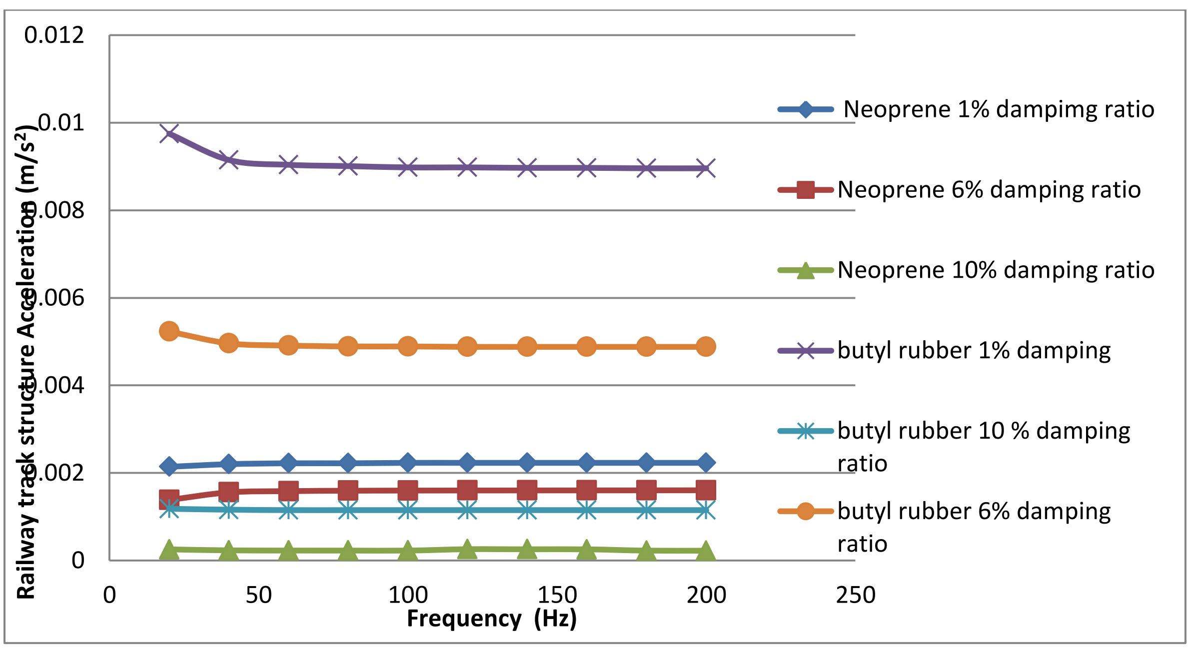

Figure 58: Railway track structure acceleration v/s frequency curve for non- ballast track using of two separate forms of Elastic material for layer of slab mat with varying damping ratio.

Vibration response of high speed railway track structure decreases as constant damping ratio increase in neoprene with 10 % constant damping ratio.

CHAPTER 5

CONCLUSION & FUTURE SCOPE

The aim of this dissertation is to assess the vibration of the high speed railway track. High-speed railway track analysis, modeling of different track modal is carried out in SOLIDWORKS 18 and simulation in ANSYS18.1.

To study the vibration of high speed railway track, two type of railway track modal considered for simulation, track structure non-slab mat and slab mat layer.

Various modal parameters of the mat layer of slab such as stiffness, material and damping ratio a re examined to show the effects acceleration response reduction of high speed railway track struc ture. Modal analysis and harmonic response analysis are needed in ANSYS 18.1 for simulation.

Modal analysis is performed to determine the natural frequency and corresponding mode prior to the harmonic response analysis.

Results are obtained after the completion of simulation in the form of vibration response i.e acceleration v/s frequency curves from harmonic response analysis. The acceleration of high speed railway track is reduced when slab mat layer introduced between CAM layer and HBL layer in railway track modal. Slab mat layer have the ability to absorb the effect of vibration response.

In computational modeling the vibration response of high speed railway track structure has been simulated with altering the slab mat layer parameters. Results indicate that neoprene with lower stiffness property works better for the same damping ratio then butyl rubber.

In addition, when constant damping ratio of neoprene layer is raised beginning 1 percent to 10 percent the (acceleration) response of vibration of high speed railway track structure reduces, which indicate a positive impact on reducing the vibration response.

The vibration result from the present railway track research was correlated with the response for comparable research reported by Ren C.J (2018). The variation in vibration response has been obtained in current study with the Ren C.J (2018) study indicates considerably favorable acceptance, which ensures the correctness of the study.

FUTURE SCOPE:

In this study vibration analysis of high speed railway track has been done considering the dynamic impact of static load by using dynamic load amplification factor for non-slab mat and slab mat layer track modal by using ANSYS 18.1.

- ✓ Vibration response of high speed railway track has been analyzed considering moving train effect at different speed.
- ✓ To reducing the vibration response of high speed railway track has been analyzed considering the varying slab mat thickness.
- ✓ Vibrations due to the passage of a railway vehicle on straight and curved tracks
- ✓ Vibration response of high speed railway track has been analyzed considering irregularities like wheel flat, rail corrugation, rail weld. Limited research has been available which consider the effect of gauge irregularity, track alignment irregularities, profile irregularities and cross level irregularities on vibration response of high speed railway track.

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