STATIC ANALYSIS AND PARAMETRIC INVESTIGATION OF BALLASTLESS RAILWAY TRACK FOR HIGH SPEED RAIL

A DISSERTATION

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

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted By

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JUNE,2019

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I, Priti Rani, Roll No. 2K17/STE/15 of M.Tech. Structural Engineering, hereby declare that the project Dissertation titled **"Static analysis and parametric investigation of ballastless railway track for high speed rail"** 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 proper citation. This 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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CERTIFICATE

I hereby certify that the Project Dissertation titled **“Static analysis and parametric investigation of ballastless railway track for high speed rail”** by **Priti Rani**, Roll No. **2K17/STE/15**, Department of Civil Engineering, 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 or full for any Degree or Diploma to this University or elsewhere.

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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 especially **Kiran Chholak** and **Supriya Biswas** 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

Increasing population and high population density of India has put intense pressure on existing railway track. The are operating at a way more than their capacity and this has strained many rail lines which leads to derailment and other mishaps. This high population density suits High speed railway. To fight with increased traffic with regard to speed and loading, the stresses variation in various components must be known accurately to evaluate useful life of each component for its life assessment. To asses this detailed analysis is necessary to develop methodology for every track component under actual loading condition.

In this thesis a comprehensive study on the behavior of ballastless track structure for high speed train under stationary load is carried out. Finite element analysis is used for analysis.

Different track systems are considered, and the performance of track components analyzed under stationary wheel load. Deflection and stresses are the parameters which is used to analyze the performance of track system. Parametric investigation is carried out for the variation in material properties to study the effect of behavior the track under the effect of different material.

Present investigation revels increase in stiffness of rail pad and modulus of subgrade decreases the deflection in track component while increase in modulus of elasticity of concrete slab and CAM layer shows no change in terms of deflection. It is also seen that with increase in all the parameters the contact stress in the rail decreases. But in concrete slab increase in stiffness of rail pad and modulus of elasticity of concrete slab increases the equivalent stress.

CHAPTER 1

INTRODUCTION

1.1.Motivation

Train transport is known to be one of the earliest mode for locomotion. With continuous advancements, this mode of service is becoming better day by day. The arrival and development of the concept of high speed trains brought a new revolution to this mode of travelling, with the large operational ranges getting covered in such a short time span. This is taking the competition with airplanes to an all new height as more comfort and safety can be provided and that too at such a minimal cost. Though the average travelling time of airplanes is still far lesser than trains but the convenience and comfort compensates for the total time in some cases for the passengers. While calculating the time duration between the origin and the destination many factors play a vital role such as distance between infrastructure and point of starting, time taken to access the vehicle, the lines of waiting, time span needed for passengers control etc. Considering all these vital factors and considering that though airplanes take lesser time, the time of displacement for passengers is lesser in trains compared to them. Thus,this reason along with petrol price hike and ever increasing pollution has resulted in much support towards this development.

With the booming economic growth which india has undergone in the recent years the number of people and goods that are being transported in the country has also seen a sharp rise. To meet this trend, Dedicated Freight Corridors (DFC) are developed to connect Delhi to Mumbai and Kolkata. The Ministry of Railways (MOR), the Republic of India, prepared the “Indian Railways Vision 2020” in December 2009, for the construction of High-Speed Railway (HSR) on seven new routes which can create ease for the passengers travelling.

The "Indian Railways Vision 2020" was developed by MOR in India in December 2009 as a long-term vision up to 2020. The Vision has been developed to tackle four domestic objectives (JICA & MOR 2015):

(1) Inclusive Development, Geographically and Socially

(2) Strengthening National Integration

(3) Large-scale generation of productive employment

(4) Environmental sustainability

The vision sets goals to dramatically boost income, expand network and transport ability, improve safety and environmental sustainability, and reform passenger services. It also sets business development objectives in multiple areas, including standard railway passenger services, HSR and rail freight, luggage, advertising, telecommunications, and so on. The vision plans to introduce projects for at least four corridors by 2020 for HSR operating at a peak velocity of 250–350 km / h. It will also plan various paths to link the shopping malls, tourist places, pilgrim sites and so on.

1.2 High Speed Train

The International Railway Union (UIC) has described HSR by splitting it into two cases (JICA & MOR, 2015)

1. Infrastructure:

• High-speed lines specially built for speeds generally equal to or above 250 km/h.

• High-speed lines specially upgraded for speeds of 200 km / h

2. Rolling stock, high-speed sophisticated technology:

• Trains at speeds of at least 250 km / h on high-speed lines, while allowing speeds of more than 300 km / h to be achieved under suitable conditions

• Trains on current lines that have been or are specially upgraded at a velocity of 200 km / h. HSR's full-fledged era began on a fresh high-speed line in Japan in 1964. The highest operating velocity was 210 km / h when the first high-speed train was operating. As a result of the growth of multiple technical elements such as infrastructure, rolling stock and activities, this has since increased. HSR's current operating velocity has been improved to or greater than 300 kmph. Many nations have been working on the High Speed Rail network from which China has expanded its network to a big region. The nations with high speed rail, network length and UIC's highest working speed are mentioned in Table I.

India also endorsed Japan's plan for the first high-speed railway. The suggested train will operate at a top velocity of 320 km / h (200 mph) around 500 km (310 mi) between Mumbai and the western town of Ahmedabad. Operation is authoritatively concentrated to begin in 2023, but India has proclaimed expectations to attempt to activate the line a year ago. It will carry passengers from Ahmedabad to Mumbai in just 3 hours, and its ticket passage will be less costly than, for instance, aircraft such as q2500-around 3000 (JICA, MOR 2015).

Table I. List of high speed lines in the world

Country	Year of 1st operation	Maximum speed (Km/h)	Distance (Km)	Track gauge (m)
Japan	1964	320	3,041	1.435
France	1981	320	2,734	1.435
Italy	1988	300	896	1.435
Germany	1991	300	1,571	1.435
Spain	1992	300	2,852	1.435
Belgium	1997	300	209	1.435
United Kingdom	2003	300	113	1.435
South Korea	2004	300	887	1.435
Taiwan	2007	300	354	1.435
Switzerland	2007	250	144	1.435
China	2008	300(350)	31,043	1.435
Turkey	2009	250	594	1.435
Netherlands	2009	300	90	1.435
Austria	2012	250	263	1.435
Saudi Arabia	2018	300	453	1.435
Morocco	2018	320	200	1.435
USA	-	240	735	1.435

1.3 History of Indian Railway

The Great Indian Peninsular Railway Company was founded in India on 1 August 1849, layin g a 56 Kms railway track between Bombay and thane. This efficient transport system subsequ ently peaked and 24752 Kms of track was laid for traffic by the end of the 19th century.

Indian Railways have now developed into an immense Railways system spread more than 63140 course kms having more than 110,000 kms of track comprising of multi-Gauge systems i.e. Broad Gauge, Meter Gauge, and Narrow Gauge.Present track system in India is a composite structure consisting of rail, rail joints with fishplates, fishbolts, sleeper, sleeper fastenings, ballast and a part of formation as shown in Figure 1. This structure is known as conventional ballasted track structure. Today all the tracks constructed in India are ballasted track. The ballasted tracks require periodic maintenance of track to keep it in desired position. The more the track is out of its relative position, the quicker the breakdown continues.

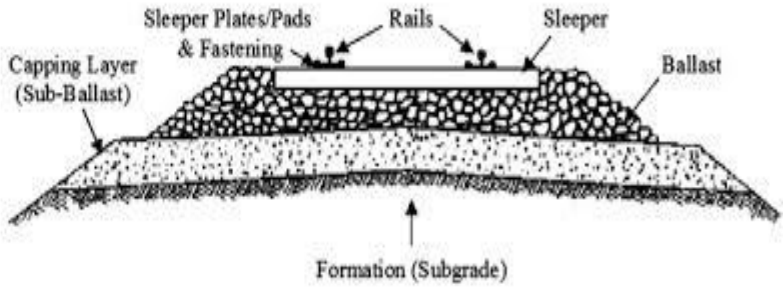


Figure 1: Ballasted Railway track

1.4 Ballastless track

The ballastless track contains a continuous concrete or asphalt surface that replaces the ballasted material. Ballastless track congregations are relied upon to give same degree of elasticity on all directions as in ballasted track. This is important to keep the static and dynamic powers inside adequate points of confinement. Ballast-less track congregations are likewise expected to play out the accompanying two capacities:

a) Distributing the approaching loads and absorbing the energy generated. This function is performed by ballast in the ballasted track. Those functions are performed by various plans in the ballastless track.
b) Damping the high recurrence vibrations of the rail. All ballast-less track assemblies have for this reason an elastomeric rail cushion under the rail. This is like the course of action with the solid sleepers in ballasted track.

1.4.1 Merits of ballastless track system

Ballastless track scheme benefits the slab track layout by considerably decreasing maintenance requirements, and providing greater stability of the structural track and greater service life.

Higher speed operation: Better High speed operation is achieved in comparison to conventional ballasted track as it offers higher degree of stability to track bed. It has been obserbed that due to high speed the fine ballast particles move out of track and deposit on the rail surface which cause severe damage when wheel passes by it.

- **Very low maintenance requirements**: Frameworks for ballastless track involve minimal maintenance of the routine. An inquiry routine is, of course, crucial, but there is no need for periodic rail realignment since the track is fixed in place. Additionally, the low maintenance prerequisite means that track workers invest less energy trackside, enhancing the well-being of specialists. There are cases of slab track facilities where for more than 25 years there has been almost no support (counting rails and pillows).

- **Shallow construction depth:** This type of track requires less construction depth as compared to ballasted track. And this proves good in construction of tunnels.
- **Reduced dead load:** The reduction in depth of construction leads to reduction in dead load.
- **Engineered noise and vibration performance:** In terms of noise and vibration, the slab track can be intended to satisfy the necessary performance criteria. The slab track system can be chosen to meet demands, e.g. booted sleepers or floating slabs will perform well for vibration delicate places. For optimizing the equilibrium between acoustic efficiency and rail stability, the resilient elements can be chosen within each generic system.
- **Long design life:** a design life estimate for traditional ballast track is approximately 15 years, (see Britpave's Life Cycle Study) After which the track needs renewal. A concrete track slab is typically built with at least 60 years of design life.
- **Increased reliability and accessibility:** Slab track systems are more reliable than ballasted track systems, requiring little maintenance routine. Therefore, for maintenance, fewer track belongings are needed, improving the accessibility of track for running trains.
- **Low overall cost:** while the capital cost of slab track systems is usually higher than the equivalent ballast track, long design life and minimal maintenance requirements for slab track systems mean that their overall life cost is lower than that of traditional ballast track systems. Slab track systems have been seen as costly in the past. While this still applies to the most advanced systems, for example, floating mass-sprung slab, for many applications the continuing innovation and optimization of slab track design now reduces capital costs to a point equal to ballasted track without compromising efficiency.
- **Sustainable solution:** the research examined the assessment of the environmental life cycle throughout the life of the track, including material source, production, design,

maintenance, decommissioning and recycling. The research discovered that it was the most sustainable choice over a 60-year and 120-year lifecycle owing to the lengthy design life and low maintenance requirements of concrete slab track.

1.4.2 Demerits of ballastless track system

- Cement concrete slab tracks are rigid bearing layers, which can break after their operational strength has been reached – this might be compared to the occurrence of rail fracture. The deterioration of the track geometry in this case occurs suddenly and unforeseeably.
- The quality of slab track has to be guaranteed by appropriate high-level quality assurance measures. This means extra cost and time for the construction works and their control. Any quality defect would remain for the entire expected life cycle (50-60 years) and can be eliminated only by applying costly measures.
- The rigid structure of the slab track allows only few improvements in the future. Adaptations to changed conditions, such as changes in track geometry, can be performed only with difficulty and at high cost.
- In case of accidents, damage is considerable. A slab track cannot be built in certain geological circumstances, such as deep cuttings in clay soils, embankments on soft peat layers, or in earthquake areas.

1.4.2 Different ballastless track system

Slab track design has two distinct methods, and these are discrete rail support and ongoing rail support. The sort of appropriate track layout relies primarily on the location's soil condition. Each slab track system has distinct flexural stiffness, which should be dependent on soil circumstances since the entire system depends only on soil bearing capacity. Figure 2 demonstrates the low diagram of the world's various kinds of plate tracks.

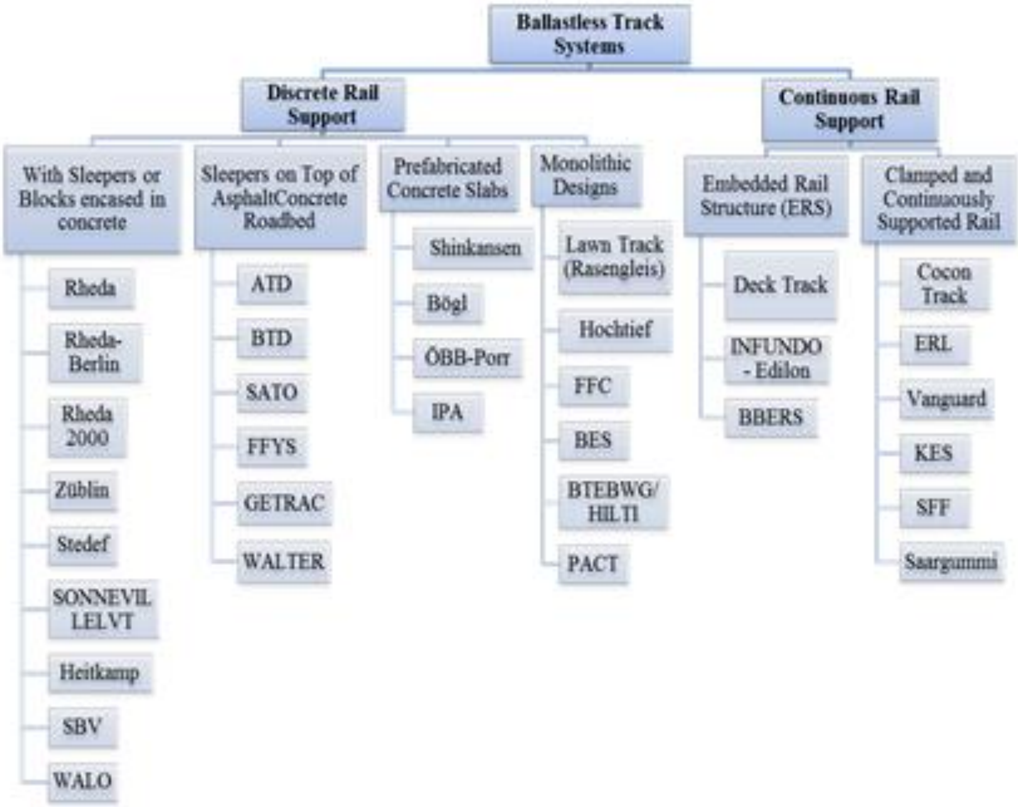


Figure 2: Different types of ballasted track

`1.4.3.1 Discrete rail support

The discrete rail support is the continuous rail supported at discrete points (mainly to sleeper with fasteners).

(i) Sleepers or Blocks encased in Concrete

- Rheda system: The name "Rheda" originates from the first ballastless track constructed in Rheda-Wiedenbruck station in 1972. The Rheda systems was developed in Germany 30 years back. At first "Rheda 1972" was designed for for loads of 225 kN/axel at 160 kmph and later Rheda 2000 was designed for loads of 225 kN/axel at 300 km/h.

Design principle was to replace two mass springs, by expending vibration isolation, and replacing it with a single stage system. The modifications of the Rheda 2000 consists of usage of a matched bi-block sleeper, and infill concrete together with reinforced sleeper as shown in Figure 3 (Freudenstein, 2010). Rheda 2000 can be used on all types of substructures appropriate for ballastless tracks due to its low structural height

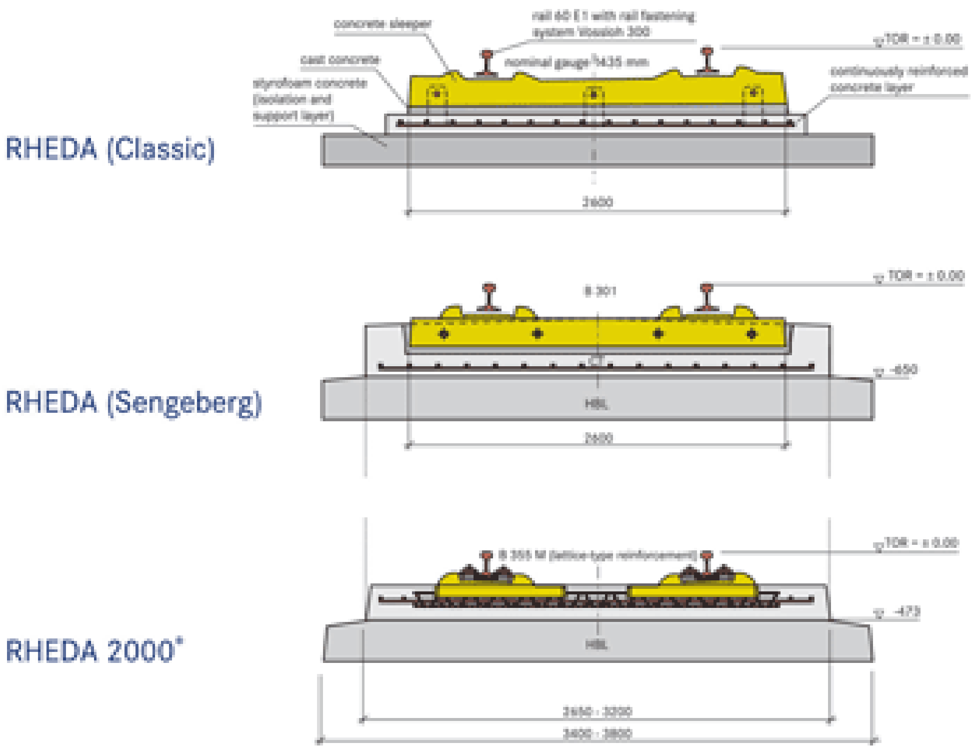


Figure 3: Rheda system

- Stedef: The Stedef system (France) consists of a resilient pad that is positioned under the sleeper and then enclosed in a highly flexible rubber boot that reassures strong noise and vibration security. This system is primarily used in tunnels and the traditionally used rail fastening is Nabla. A classic Stedef scheme is illustrated in Figure 4.

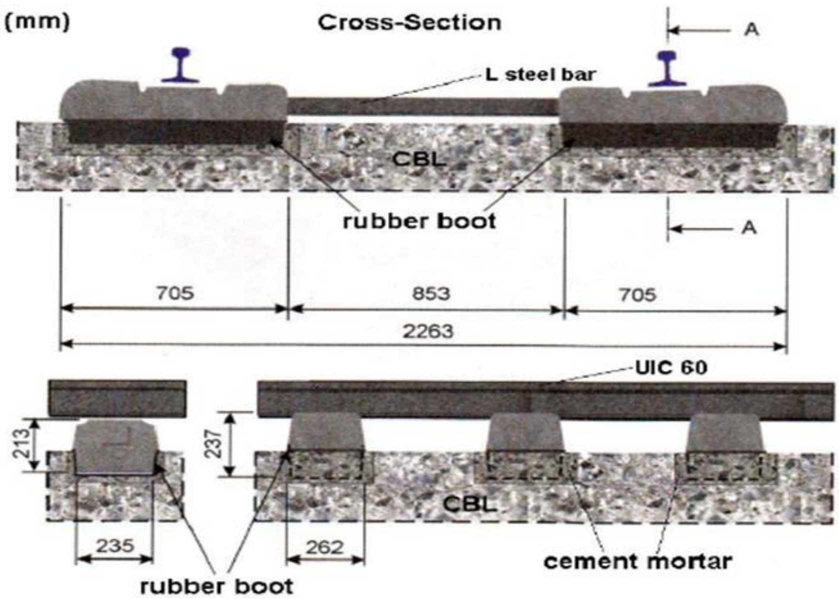


Figure 4: Stedef system

(ii) Sleepers on Top of Asphalt Concrete Roadbed

Asphalt layer provides as Table and supportive layer to track and can replace conventional ballast layer and system's performance is also improved. According to (Esveld,2001) due to visco-elastic properties of asphalt it deforms until a new equilibrium is achieved and the pressure is levelled when higher pressures occur below particular sleepers than other

- SATO: The SATO (Studiengesellschaft Asphalt-Oberbau) comprises of Y-steel sleepers that are attached to an asphalt supporting layer by welding the sleepers to a smooth steel with Nelson brackets to fasten the sleepers in both horizontal and vertical directions (Lichteberger, 2005). The flat steel strip is integrated in the asphalt bearing layer in conjunction with the tie bolts. As shown in Figure 5, the Y-steel sleepers are fixed in this costly framework in both their horizontal and vertical directions.

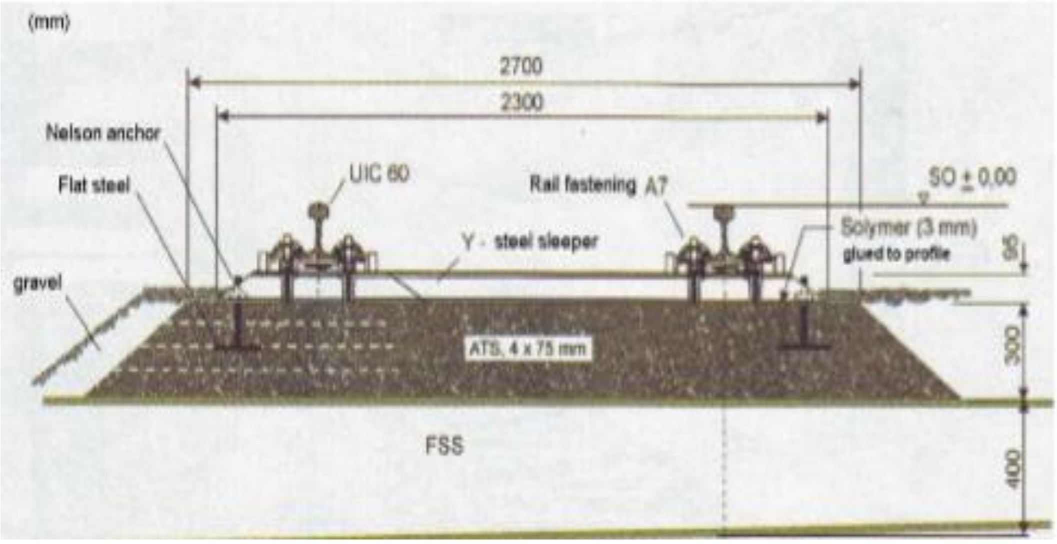


Figure 5: SATO System

(iii)Pre-made concrete slabs-

This slab track category consists of strengthened or pre-stressed concrete slabs that simultaneously preserve the tilt and gage of both rail lines constantly and securely (UIC report,2002). In many locations around the globe, prefabricated slabs can be discovered, e.g. Japan, Germany, Taiwan, Italy, China.The benefits of this scheme are:• High quality of the prefabricated parts of the slab (Esveld,2001).

- High mechanization level, therefore quick construction.
- Work-saving on-site building.

- ➢ Direct rail adjustment and fastening.
- ➢ Very small workmanship risk.
- ➢ Comfortable repair and refurbishment.

Their disadvantages are primarily its greater building cost, it can be as high as four times the ballasted track building price and greater structure.

Shinkansen system : This slab track system was first developed and applied in Japan in 1972 (Lichtberger, 2005). It consists of a cement stabilized sub-layer and 4.95 m / 2.34 m / 0.19 m installation plates(Esveld,2003). These slabs weigh about 5 tons each and are adjusted on top of a hydraulically bonded surface (HBL); a minimum 40 mm thick cement asphalt mortar is injected under the slab(Esveld,2003). The plates are held longitudinally and laterally by concrete cylinders (dowel) that are closely attached to the plates (Lichtberger, 2005).Diagram of Shinkansen system is show Figure 6

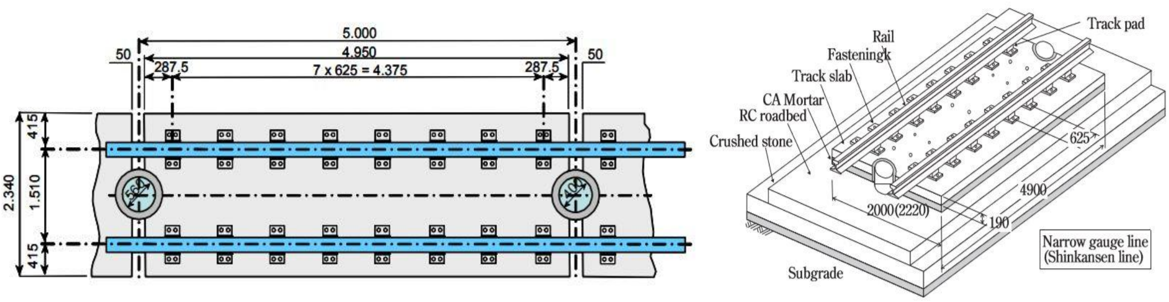


Figure 6: Shinkansen system

- ➢ The Bögl slab track scheme was created in 1977 in Germany. This prefabricated scheme is produced of a 6.45m*2.55m*0.20 m steel fiber concrete slab. The complete building depth of approximately 0.475m(Esveld,2003) as shown in Figure 7. The plates are prestressed laterally and usually strengthened with' GEWI ' bars longitudinally (Bastin, 2006). These prefabricated plates are intended to avoid random crack formation in the slab with unique breaking points organized between the supporting points (Lichtberger,2005). According to (Bastin,2006),

The primary benefits and disadvantages of this scheme are: the benefits of factory-based manufacturing reassure great performance.

- ➢ Easy to install and quick.
- ➢ Once mounted, traffic may be opened.
- ➢ Easy to replace damaged components or entire units if necessary.

Disadvantages

- Higher cost

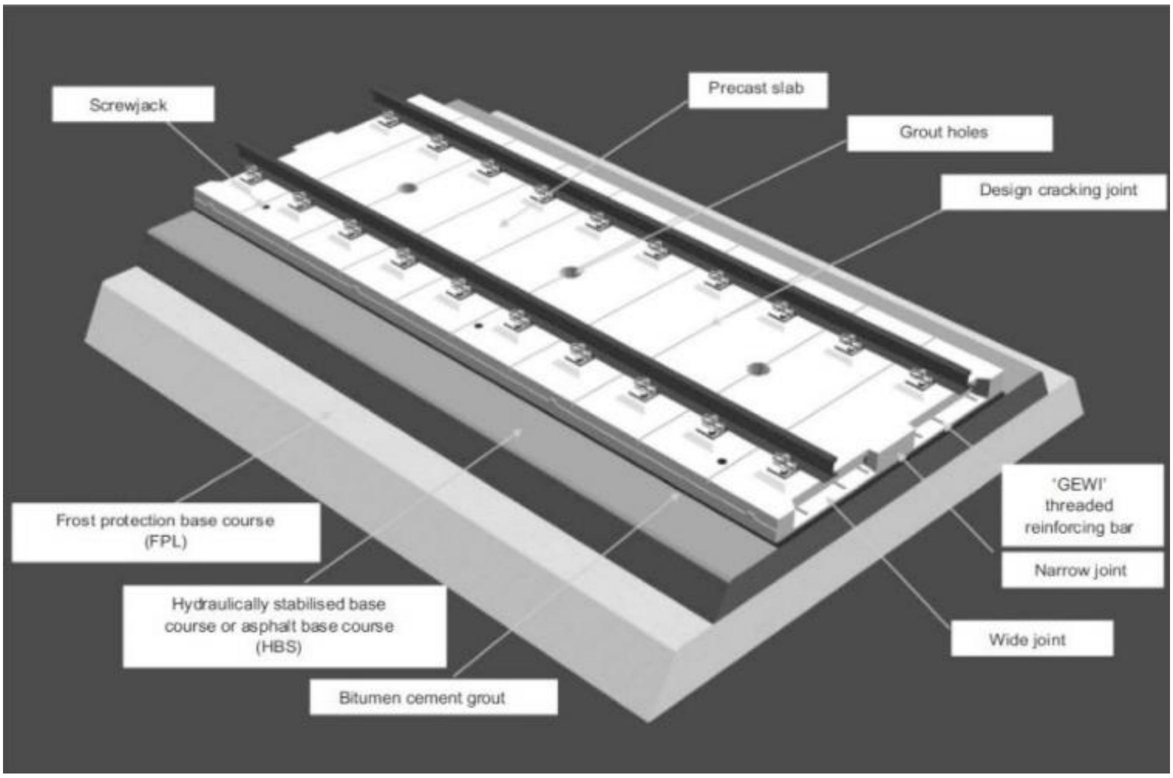
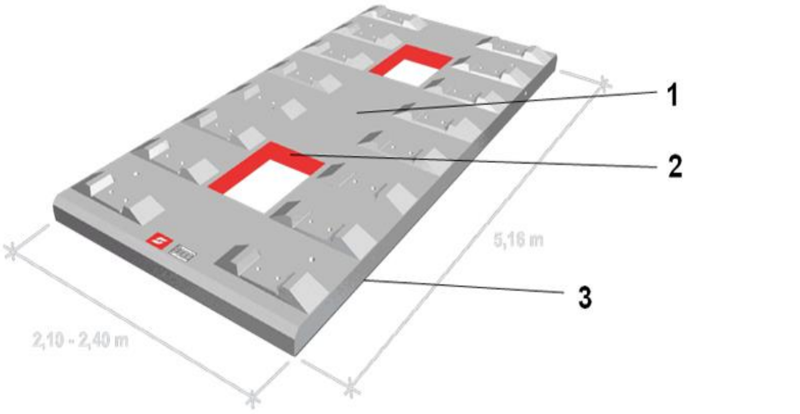


Figure 7: Bögl system

- OBB-Porr system: OBB-Porr system is a type of prefabricated track developed in Austria. The system is called system OBB-Porr is elastically supported on track base plate. The track base plate usually has the dimensions of 5.16 x 2.40 m^2 and a height of 16 cm and has eight pairs of supporting points, at 650 mm as shown in Figure 8. The vertical loads are as 250 kN for the speed of 330 km/h as per UIC Load Model 71 (UIC report,2002). An elastomer layer is incorporated in the slab to reduces the noise and prevent crack due to stress.



1. Gleistragplatte (GTP)
2. Gummigranulate 6mm (Fläche der Vergussöffnungen)
3. Gummigranulate 3mm (Unterseite der GTP)

Figure 8: OBB-Porr system

- IPA slab track system: Similar to the Shinkansen scheme, this scheme was first created in Italy in 1984 (UIC report,2002). It is made up of prefabricated concrete slabs laid on a concrete bearing layer in CAM layer. The primary distinction between the layout of IPA and Shinkansen is that the positioning post for the longitudinal and lateral fixation of the plates is component of the slabs where the recess is created in the concrete foundation. Figure 9 demonstrates the ad sizes of the structural function.

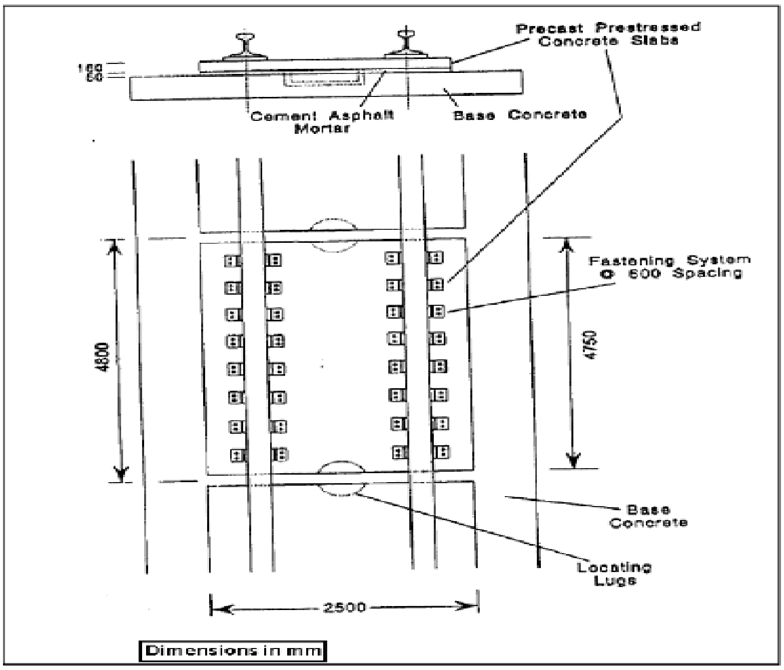


Figure 9: IPA slab track system

(iv) Monolithic Designs

Monolithic structure is a constant monolithic concrete slab with directly linked fasteners. The sleeperless designs are either created as a monolithic concrete layer made from prefabricated plates or as a linked concrete paver (Esveld,2003). The monolithic designs are stiff and rigid enough to act under traffic loading as a continuously supported elastic beam as it can be used on soft soil.

- Lawn Track system : This structure comprises of a 30 cm thick permeable concrete layer with trapezoidal cross-section and longitudinally strengthened. This is linked to CBL ensuring the stability of the track (Lichtberger,2005). The rail attachments are attached to the longitudinal concrete beams cast in pre-drilled holes by rail clamps. A substratum covered by oligotrophic grass (low vegetation) (Lichtberger,2005) as shown in Figure 10 fills the room between the concrete beams and their outer regions.

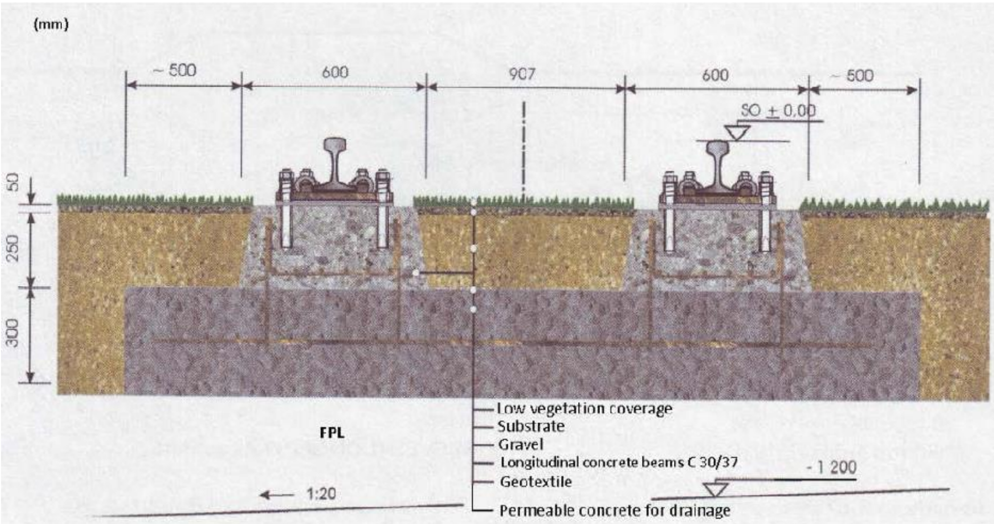


Figure 10: Lawn Track system

- BTE slab track system: A two-level machine platform scheme is used in the BTE scheme to obtain the desirable geometry of the concrete slab layer (CBL) (UIC report,2002). It comprises of a concrete layer of bearing (CBL) over a hydraulic layer (HBL). These tacks use Ioarg 336 and ERL (BWG) as a fastening scheme. At the place where fasteners and rails are situated, the additional resistance is given to concrete. Figure 11 shows the BTE slab track scheme.

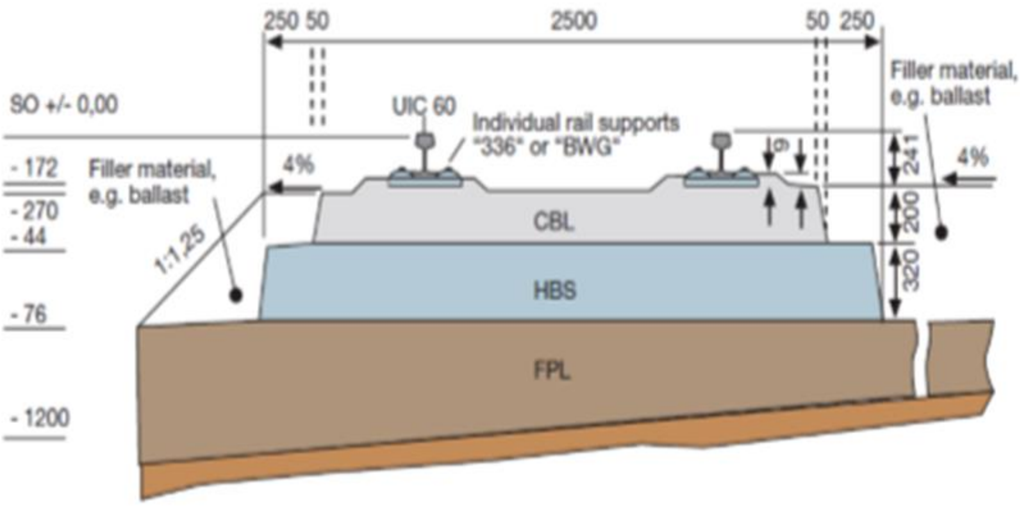


Figure 11: BTE slab track system

1.4.3.2 Continuous Rail Support system: -

Continuous rail support is one in which the concrete bearing layer (CBL) supports the rail ela stically. Rails are either built in or linked to CBL.

(i) Embedded Rail Structures

Embedded rail structure (ERS) is a continual elastically supported rail using a compound like cork and polyurethane (Esveld,2001). There is no extra element to secure the track ga uge. It involves high-speed to light rail tracks.

- Deck-Track design: As stated by (Esveld,2001) the Deck-Track is an arrangement of elevated flexural Deck-Track design: It is expressed by (Esveld,2001) the Deck-Track is an arrangement of high flexural stiffness stiffness that can be attached in sensitive soils. It was created in the Netherlands and a test track of 200 m was developed in Rotterdam. It consists of an unceasing in-situ or pre-fabricated strong layer set in the floor as shown in Figure 12. The rails can either be integrated or fixed straight on the solid surface. Deck-Track is a hollow tube of comparable evacuated soil load. Its elevated bending and torsional stiffness lead in reduced vibrations. This assistance to preserve a strategic distance from differential colonies, providing a constant basis for tracking even on fragile soils.

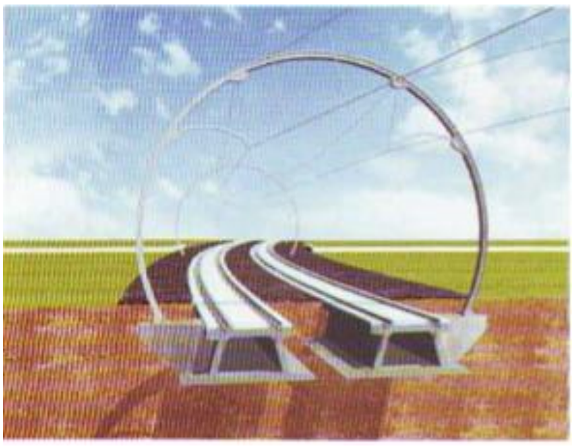


Figure 12: Deck-Track design

(ii) Clamped and continuously supported rail

These frameworks provide continuous rail support by clamping the rail's web.

- SFF: The SFF structure consists of profiled trough integrated longitudinal sleepers in the concrete bearing layer (CBL) as shown in Figure 13. Rubber pack provides continuous support which encompasses the rail. The rail is bolstered by the versatile mixes underneath the rail head and hangs unreservedly over the trough base taking into consideration huge vertical diversions (engrossing vibrations). The elastic used to keep the rail set up falsehoods firmly against the rail and solid surface going about as a seal. Any water that infiltrates under the rail foot is collected and driven through sidelong gaps. This framework is restricted to burrows and urban rail frameworks (Lichtberger,2005).

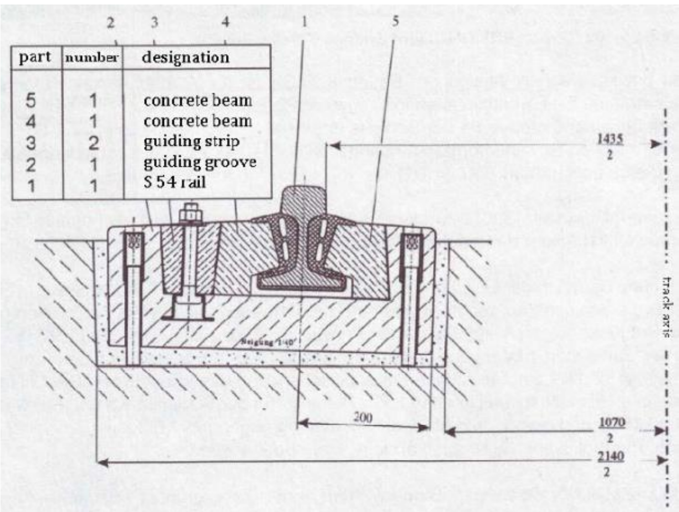


Figure 13: SFF slab track

- Saargummi: The SAARGUMMI setup utilizes longitudinal sleepers in a trough without profile. Whether the longitudinal sleepers are placed on or integrated in the Concrete bearing layer (CBL) is up to the client. The rails are constantly bolstered by elastomeric parts covering the rail flange and adjusted using profiled clamping bodies with adjustable threaded bolts as shown in Figure 14. In longitudinal sleeper, the height and horizontal location, track gage and rail gradient are adapted.

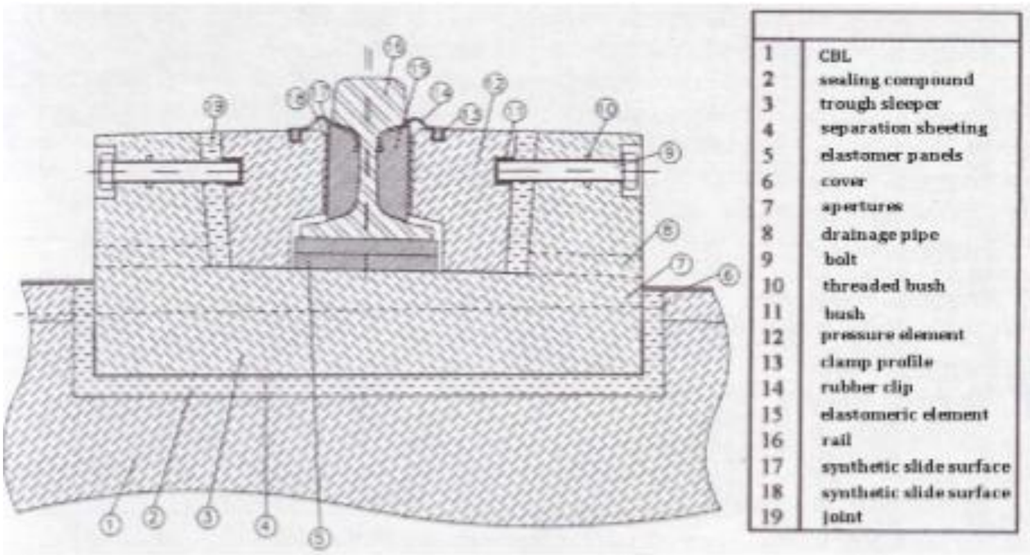


Figure 14: Saargummi system

1.4.4 Components of Ballastless track

Rail: - Rail provide hard and unyielding surface to wheel and transmit load to bottom layer. Different rails are not required for different speed so UIC 60 (Figure15) is recommended for high speed trains. However, it is suggested that attention should be given to assembly, acceptance, surface defect etc. It is considered that length of individual rail should not be close to 36m to avoid running on some point due to welding having critical wavelength. Average length in Japan is 25 m. the inclination for High speed is recommended as 1 in 40.

Generally, 60 kg/m rail track is considered accepTable all over the world for high speed corridor. Thus, it is proposed to have 60 kg 90 UTS FF UIC new rails with CWR/LWR (IRICEN, 2015) over the entire stretch as per the provision of permanent way manual for Indian High-Speed Corridor. The equivalent conicity should be further reduced as the speed is increased and the wear profiles should also be monitored.

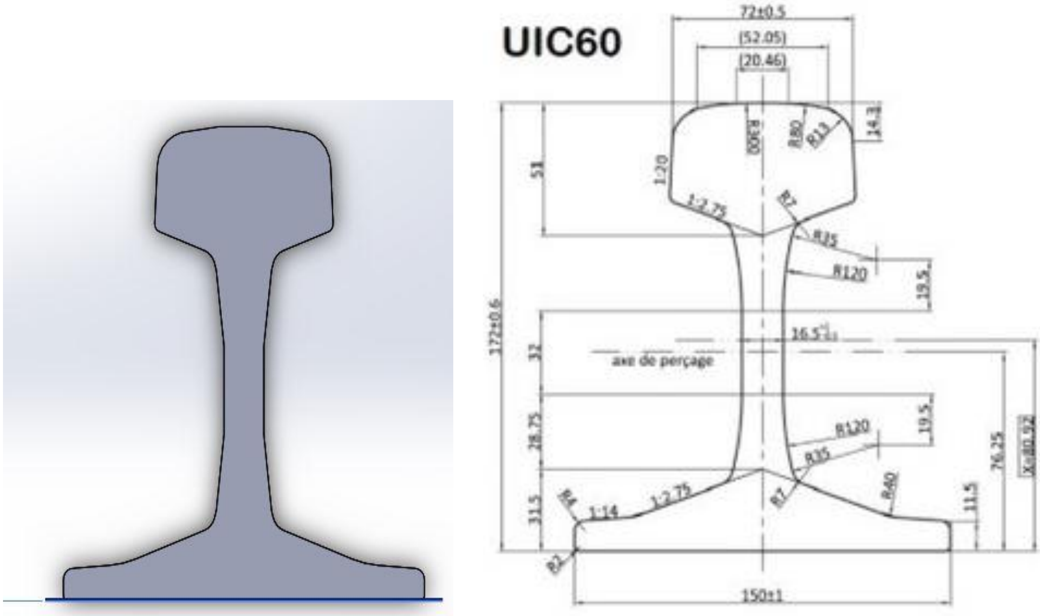


Figure 15: model and sketch of UIC 60

Rail pad and fastening system: - Rail pads are used to reduce the vertical dynamic forces rails and wheels. Rubber pads are cushioned between rail and slab fastened by wire spring/ leaf spring/TGV Nabla or any other system for damping the vibration and distributing vertical load. The main characteristics of rail pad is its vertical stiffness and it is formed with rubber or elastomer. The optimum value stiffness of the track (as an assembly) is found to be 50KN/mm for 200 kmph and 78KN/mm (IRICEN, 2015) for 300 kmph. To assess the ability of the track to carry trains running at speeds of more than 300 km/h, with a minimum maintenance cost it is necessary to try to establish a reference value both for the vertical stiffness of the track and for its damping capacity. It is the tendency to opt the overall vertical stiffness of 100kN/mm. The shape of railpad is shown in Figure 16.

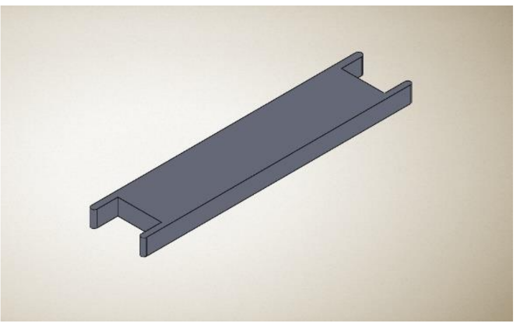


Figure 16: Rail pad

Concrete Bearing Layer: - The required profile resilience on the CBL surface is+ 2 mm. The cement content in the rock is in the range of 350 and 3370 kg / m somewhere. The percentage of reinforcement to stop crack growth must be somewhere within the range of 0.8 and 0.9 percent (IRICEN, 2015) of the concrete cross-area. This is to gurantee that the crack width remains superficially below 0.5 mm and that the height remains 200 mm. The surface is cut at intervals of about 2 m due to plans without sleepers to achieve regulated crack growth. After concrete is set, the concrete bearing layer can be loaded and a base pressure protection of more than 12N / mm is achieved. An increasing CBL thickness prompts greater bending load. A base thickness of 180 mm should be observed.

Asphalt layer: - Asphalt bearing layers are applied in 4 layers with a total standard thickness of 300mm (IRICEN, 2015). The needed building tolerance on the surface is+ 2 mm greater than that required for highway construction. Moving of train on the asphalt bearing layer is allowed, only when temperature of the asphalt is below 50^{o}C. Asphalt must be covered by gravel, stone chips or other such materials as it is sensitive to UV-rays.

Hydraulically bonded bearing layer: - HBL having thickness 300mm is inserted below the asphalt or concrete bearing layer. It is a mixture of well graded coarse aggregate of nominal size 32mm, compacted by a hydraulic bonding agent. OPC is used as bonding agent in portion 110kg/m (IRICEN, 2015). The minimum width for HBL is 3.8m and the total bearing capacity of track is increased with increase in stiffness of HBL from top to bottom. Hydraulically bearing layer is designed in such a way that it achieves modulus of deformation E > 120 N/mm on the upper unbounded surface.

Sub soil: - Unlike ballasted track ballastless track require a subsoil which is free from settlement so that it can perform adequately. This is the reason such tracks are best suited for tunnels and bridge constructions. The acclimations to the track geometry after development are restricted, henceforth uncommon readiness of the subsoil before development is fundamental.

Using suitable customized, quality-assured earthwork materials, the ballastless track must normally be prepared at a depth of at least 2.5 m below the slab. The frost protective layer of slab track should not be less than 70 cm (IRICEN, 2015).

For embankments, the lower bearing layer of at least 1.8 m thickness consists of the top layer of the filling, for cuttings–the soil below, or the soil must be replaced if the bearing capacity of the current soil is inadequate.

Differences in settlement for a narrow range, between +26mm and - 4mm, may be compensated by the rail pads of different thickness (rail fasteners).

The subsoil must be durable and have a suiTable bearing capacity combined with small settlement behaviour in time. Subgrade treatment or replacement of soft and cohesive should be done to avoid its effect on subsoil. The presence of soft soil leads to uncontrolled settlement depending on dewatering capacity and water ratio.

1.5 Loading system

The track structure is subjected to three different type of loading system:

(1) Vertical loading

(2) Lateral loading

(3) Longitudinal loading

These are sub divided in to two categories, Stationary and moving load. The main source of loading in the vertical direction is the wheel loads of the vehicle. The factor which influence the vertical loading are

(1) Magnitude of wheel loads

(2) number and spacing of axles

(3) Train speed (moving load)

(4) Frequency of wheel load application

The lateral loading of track structure can occur due to

(1) Lateral wheel loads on rail tangent sections

(2) Sunkinking temperature change effects

(3) Run in effect as trains enter sharp curve or steep grades

(4) Jackknifing of cars or locomotive due to severe braking.

The longitudinal loading of the track is generated due to

(1) Sunkinking

(2) severe braking effect.

The vertical loading of the track structure is predominant, so the present study is confined to this loading system in stationary and moving state.

1.6 Ansys

The ANSYS Workbench is an instinctive finite element assessment tool used for design modelers and CAD frameworks. ANSYS Workbench is a structural, thermal and electromagnetic analysis software. The class centres around the development and optimization of geometry, attaching current geometry, setting up the model of finite elements, solving and reviewing outcomes. The class will describe how to use the code as fundamental ideas of finite element simulation and interpretation of outcomes.

ANSYS Workbench combines the strength of core simulation tools with the tools required to manage the projects. The main project workspace of ANSYS is called Project tab. Projects are represented as flowchart known as Project schematic. To perform analysis required blocks can be added to project schematic. Each project schematics consists of one or more cell which represents the steps for specific analysis. Links can be used to transfer data from one system to other. Parameters specified by ANSYS are material properties, geometry, and boundary conditions. Analysis is performed from top to bottom cells of the system. Any part of the analysis can be modified, and project is automatically updated for simulation results. Modelling can be done in Design modular of Ansys Workbench or it can import data from different modelling software like SOLIDWORKS, AutoCAD, CATIA, Solid Edge, SketchUp etc.

In this project Static structural analysis system in ANSYS Workbench is used.

Structural analysis

ANSYS is a structural analysis software which enables users to make better designs and help them in taking faster decisions by solving complex structural engineering problems. To analyze multiple design scenarios, users can customize, automate solutions and even parameterize them using the finite element analysis (FEA) tools available in the suite. Connections to other physics analysis tools can impart better accuracy for the system. ANSYS structural analysis software allows technicians throughout the design sector to optimize their products and therefore also helps to reduce physical testing costs.

Static structural

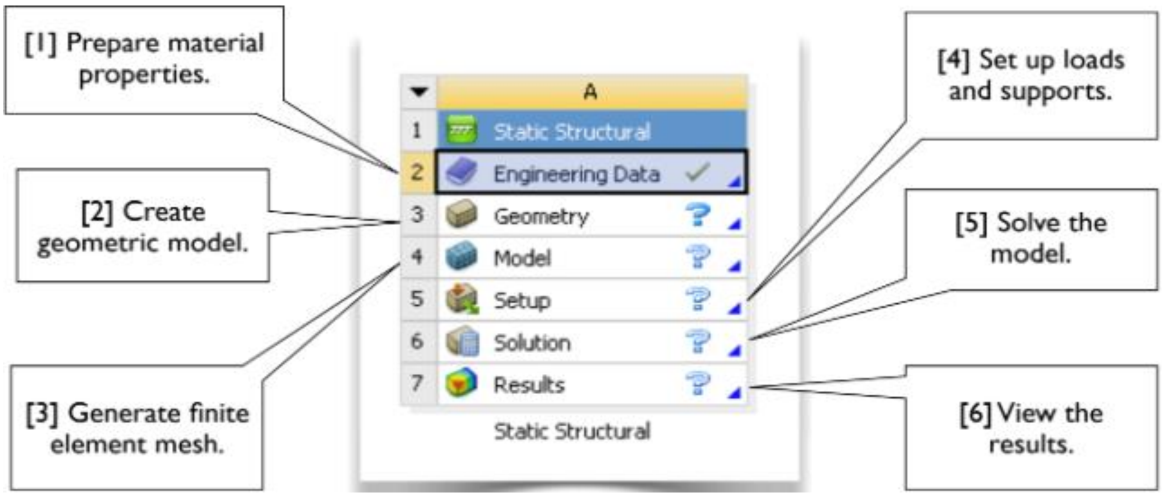


Figure 17: Tools of static structural

Different tools present in the static structural which are required to perform analysis is shown in Figure 17. A static structural analysis evaluates the forces, stresses, displacements and strains in structures or components caused by loads that do not include damping effect. The loading and reaction is presumed to be constant, i.e. it differs slowly with time. The types of loading which can be applied in static analysis are:

- Applied load and pressure
- Imposed displacement
- Temperature
- Steady state inertial force.

An applied force F creates a deformation x according to

$$F = [K]x$$

where the shape of the geometry and the material's Young's Modulus E define the stiffness matrix [K].

ANSYS solves this equation for the unknown values of x. Once deformations are known, strains can be calculated. Once strains are calculated, stress is calculated using

$$Stress = E * Strain.$$

So, solving the Static Structural model makes available deformation, strain and stress all at once. The governing equations are usually partial differential equations, and Finite element method is used to determine solutions of such equations. The pattern and relative positioning of the nodes also affect the solution, the computational efficiency & time. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure.

Nonlinear Static analysis in Ansys Workbench uses Newton-Raphson Iterative method to find the solution. There are different variation methods can be adopted (full, initial stiffness, etc) or simply it can be left as programme controlled. This method is based on series linear solutions. Each solution is evaluated with stiffness calculated in previous step.

1.7 SOLIDWORKS

The SOLIDWORKS CAD software is a design software which allows the designer to sketch its ideas, play with dimensions and features and generate models and drawings. Basic building block of SOLIDWORKS software is Parts. Assemblies are formed by combining parts and other sub-assemblies. A SOLIDWORKS model comprise of 3 dimensional geometry which defines its surface, faces and edges. SOLIDWORKS model are defined by 3D design and is based on its components. This software helps in designing the models quickly and precisely.

SOLIDWORKS is a 3-dimensional design approach in which a part is designed from initial sketch to final 3D model. With this model 2 dimensional drawings or 3D assemblies can be created with mate component on parts or subassemblies. The SOLIDWORKS design provides the exact view of model as it looks after manufacturing.

CHAPTER 2

LITERATURE REVIEW

The basis of analysis of the track structure was to provide and prove a system which would predict the stresses, elastic deflections and settlements which occur in the different components of track structure under stationary vertical wheel loads.

The function of rail track models is to interrelate each component in the 0track structure in order to simulate the integrated properties in determining the reactions of the moving train load. Rail track models which include all the track components enable us to predict the track performance more effectively and precisely. As an important track component, rail is used to support and guide the vehicle by providing smooth running surfaces. The forces of a train on the top of the rail are distributed over concrete slab. Lateral loading, from train wheels, uniformly distributed on rails, and longitudinal loading, which is generated by braking and acceleration, are also passed on to the track structure (Gao, Y. 2013)

In simulation, the rails are usually simplified as two mathematical models: Euler-Bernoulli Beam (E-B beam) and Rayleigh-Timoshenko Beam (R-T beam). E-B beam only considers bending behaviour of rails. R-T beam theory includes not only bending, but also shear deformation of the beam.

Euler Bernoulli Beam Model

Euler – Bernoulli beam theory, shear deformations are neglected, and plane sections remain plane and normal to the longitudinal axis. In the Euler - Bernoulli beam the deformation at a section, dvo/dx, is just the rotation due to bending only, since the plane section remains normal to the longitudinal axis as shown in Figure 18. Euler - Bernoulli Beam elements give good results for normal stress, because they are capable of capturing bending dominated deformation fields. Classical beams are very good for thin beam applications (Goerguelue U., 2009)

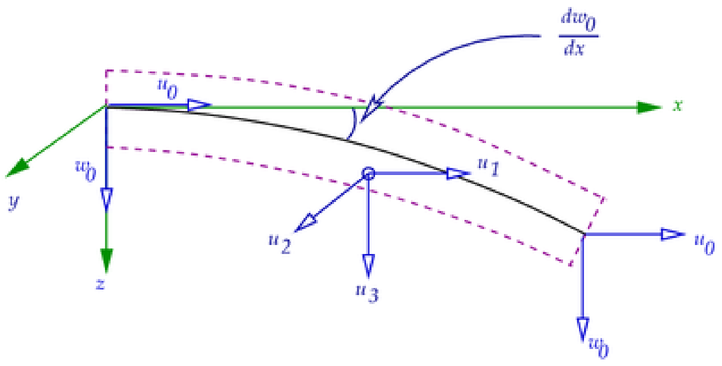


Figure 18: Euler Bernoulli Beam Model

Rayleigh- Timoshenko Beam Model

Timoshenko beam theory, plane sections remain plane but are no longer normal to the longitudinal axis. The difference between the normal to the longitudinal axis and the plane section rotation is the shear deformation in the Timoshenko beam the section deformation is the sum of two contributions: one is due to bending, dwb/dx, and the other is the shear deformation, dws/dx. By considering an infinitesimal length of the beam, it is seen that the shear deformation in Timoshenko beam theory, dws/dx, is the same as the shear strain related to pure shear (Goerguelue U., 2009) as shown in Figure 19. Timoshenko beams transverse shear stresses are considered. Timoshenko beams initially cross section in normal to the neutral axis but does not remain normal after bending. If a beam is not slender and it goes into bending dominated deformation, then Timoshenko elements are weak to capture normal stress and classical beam elements are weak to capture shear deformation. I think the superiority of classical elements to Timoshenko beam elements comes from cubic Hermitian shape functions. Timoshenko beams for good for thick beams.

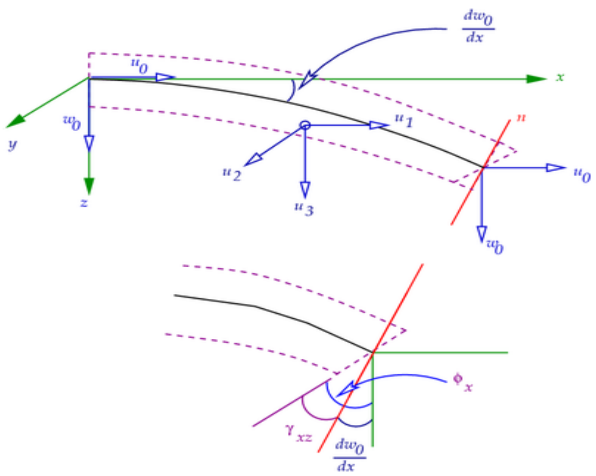


Figure 19: Rayleigh- Timoshenko Beam Model

Setu G. et al. (2015) presents analytical formulation of rail track system. A change in track model brings in wide change in receptance and track decay rate in frequency domain. The complexity of track model is varied from Euler beam on continuous elastic support to a Timoshenko beam on single layer and two-layer continuous supports The effect of different model on receptance and decay rate in frequency domain is investigated.

Earlier these problems were solved using classical elastic analysis methods, but these methods were not so useful because of their several drawbacks. Finite Element Methods (FEM) is found to useful for many engineering problems. It enables loading and geometric condition to be more truly represent and soil can be given elasto-plastic property.

Many computational techniques have been developed using finite element methods that can be applied to the track structure problem. For this analysis, the track is considered as a beam on elastic foundation of Winkler type. The Winkler type foundation is presented here in two ways: Continuous and discrete support form (Mohanta M. et al.,2015).

1. Beam on elastic foundation model on discrete support

   ASSUMPTIONS

   - Castiglione’s theorem is restricted to small displacement.
   - Every plane cross-section of each member of a structure before deformation remains plane after deformation.

In this model the supports could either be discrete spring-damper systems or spring-mass spring systems for modelling rail pad, concrete asphalt mortar (CAM) layer. In a three-dimensional model, the rail (a beam element) is placed on a spring and damper in parallel. This spring-damper system models the rail pad. Below this another beam element, modelling the slab is placed. The slab rests on an elastic CAM layer i.e. another spring –damper system which is attached to ground as shown in Figure 20 (Mohanta M. et al.,2015).

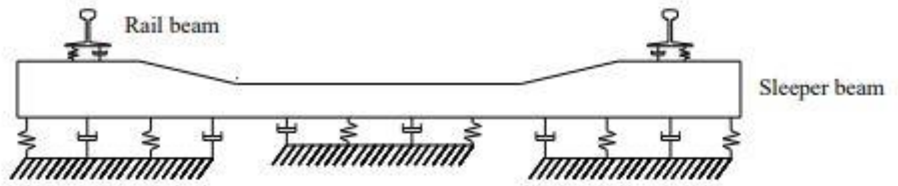


Figure 20: Beam on elastic foundation model on discrete support

1. Beam on Continuous Elastic Support

   ASSUMPTIONS

   a) The foundation has enough strength to prevent its own failure.
   b) The foundation resists the load transmitted by the beam in a linearly elastic manner.

   These assumptions are accurate for small deflections (Mohanta M. et al.,2015).

   In this model, the rail pads and ballast are represented by distributed elastic layers with no mass, separated by a distributed mass layer representing the sleepers. he supports layers are characterized by two stiffness per unit length, ' kb for the ballast layer and ' kp for the rail pad layer, with each layer incorporating a damping loss factor ηb and ηp respectively. The sleeper mass per unit length in the x direction is ' ms as shown in Figure 21. The sleeper layer has no bending stiffness in this model (Setu G. et al. 2015).

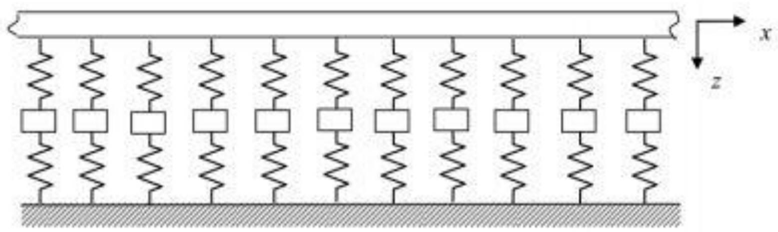


Figure 21: Beam on Continuous Elastic Support

Static analysis is 1st step for performing any dynamic and vibration response analysis. Beam on continuous elastic foundation is often used in various engineering problems and has applications in rail track engineering for foundation design and analysis.

Mallick et al., 2006 states that It is generally modelled as beam on Winkler or Pasternak type foundations but the effect of difference in modelling is insignificant. The steady-state response of a uniform beam placed on an elastic foundation and subjected to a concentrated load moving with a constant speed has been investigated. The foundation is modelled by using one and two parameters. The mathematical form of the solution is justified by Fourier transform. It is observed that the steady state is not attained at supercritical speed of the load in the ideal undamped case. Numerical results are presented for maximum settlement, uplift and bending moment in the beam.

Linand Trethewey, 1990 explained a complex foundation model may lead to unmanageable equations, which are difficult to solve analytically. The ratio of the vehicle weight and the support beam weight is large, so the system can be simplified as single degree of freedom system having weights on a mass less beam.

In most cases, elastic foundation is replaced by spring element and analysis of beam on spring element is assumed as simplified model. The railway track can also be assumed as an infinite beam on equally spaced spring element which represents the model as beam on discrete elastic support. (Biot, 1937). Hetenyi (Hetenyi, 1961) presented a closed form solution for an infinitely long beam on an elastic foundation under static loads and series solutions for the cases of finite beam.

Li and Berggren (Li and Berggren, 2010) investigates the effect of vertical track stiffness, and its variations along the track, on track performance with focus on dynamic responses of the track due to parametric excitations. Two approaches for calculating global track stiffness, a static one based on Zimmermann's theory and a dynamic one based on the track model used in the dynamic vehicle–track interaction program. This article presents a statistical analysis of the collected results and provides information of track stiffness and its variation on typical Swedish tracks. It showed that rail displacement should be in the range of 0.5-1 mm for a wheel load of 100 kN.

Kerr (Kerr,2000) using Kerr method determined the rail support modulus for static load condition and opined that static test gives better result than dynamic test for determining track modulus. To include the dynamic effects of the moving trains by multiplying the static wheel load by a `speed-effect coefficient'. This coefficient is obtained from field measurements of rail strains, caused by actual trains (passenger and freight) moving in the speed range of 10±150 mph. In this approach, the rail support modulus k is determined from a static field test.

Baykasoglu et al.,2012 in his paper explained Railway vehicle structures generally consist of shells, plates and beams, and behaviour of these members directly affects static and dynamic structural behaviours of these vehicles. In this study, numerical results on stress, vibration and crash analyses of railway passenger and freight car structures made of steel members are presented. Finite element (FE) method is used to assess the static and dynamic structural behaviour of railway vehicles. Full length detailed railway vehicle models are used in all FE analyses. FE models should be validated against experimental measurements; most common-base references that are considered are UIC CODE OR 577 and ERRI B12/RP17. As a result of relevant simulations, static and dynamic structural characteristics and structural weaknesses of designs are determined. Suggestions for improving dynamic, static and crashworthiness characteristics of rail car structures can be proposed.

Setu, G. et al, 2015 presents governing differential equation and finite element formulation of the beam on elastic foundation of Winkler type is taken into the account. The results from two loading pattern: single point load of 98 kN (Srivastava et al., 2014) corresponding to a single wheel and two pair of wheel of same magnitude at each of the contact point is provided for track displacement, bending moment and shear force variation in an around the contact region by considering different boundary conditions. The results for track displacement are simultaneously compared with those obtainable from Euler-Bernoulli beam theory and Timoshenko beam theory. The difference in track displacement for both the foundation model is compared using finite element analysis software (ANSYS 15). The solution of governing differential equation become complex to solve for multiple loading, so the complexity is reduced by transforming into Dirac-delta function.

CHAPTER -3

METHODOLOGY

In this thesis following process (Figure 22) is followed for modelling, simulation and analysis of railway track.

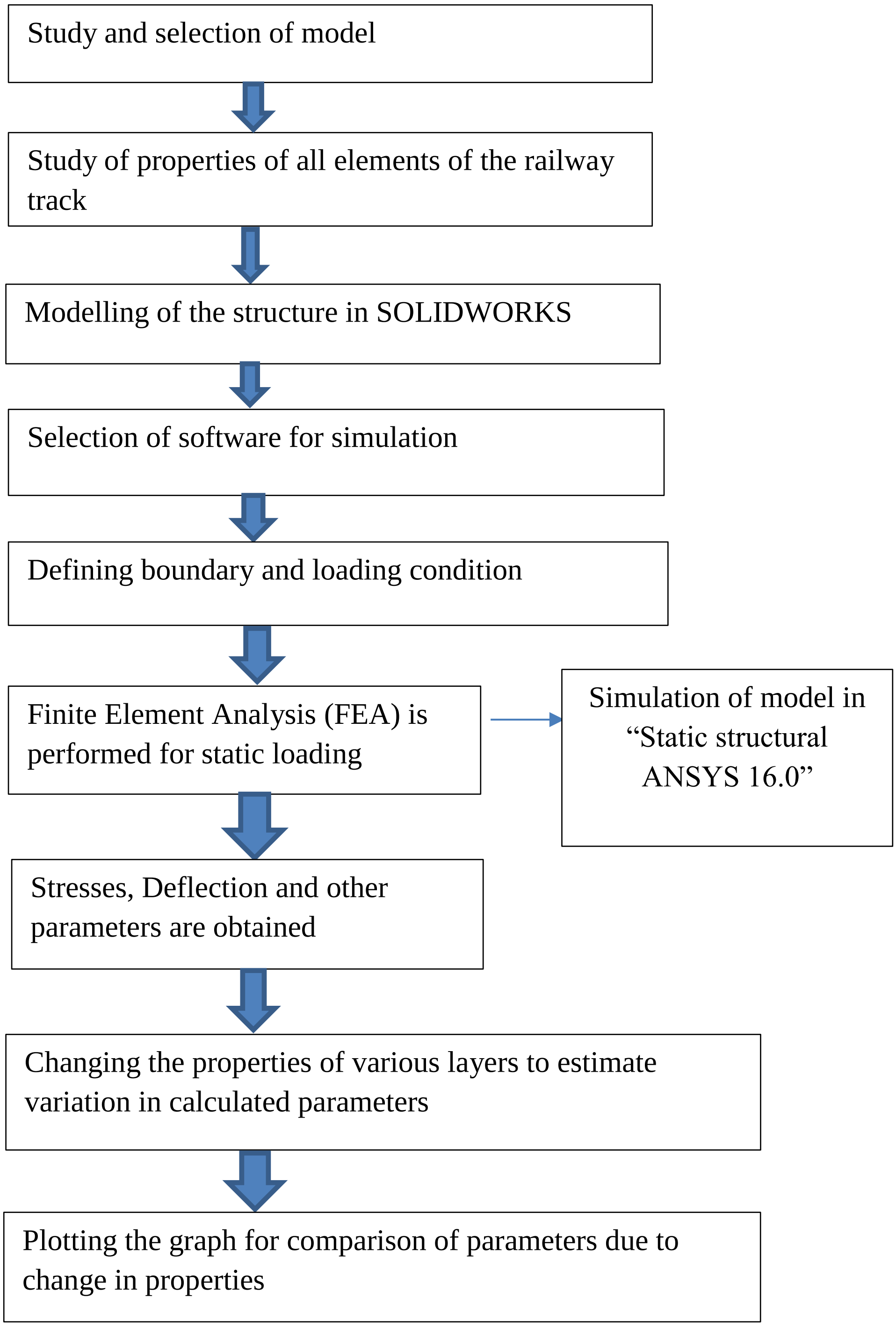


Figure 22: Flowchart of Methodology of static analysis

3.1. Modelling and Analysis

3.1.1. Model 1: Model without Railpad and CAM layer

This model is a simple slab track model consist of rail, concrete slab, hydraulic bearing layer (HBL) and foundation. The geometry adopted for this model is that rail with I type cross-section. The I section is such that its flange width and highest moment of inertia is same as of UIC60. The HBL layer is modelled as trapezoidal section and rest other are rectangular section. Material properties of different components of the above track structure is metioned in Table 2 and geometrical parameters of the components are same as mentioned in Table 4.

Table 2: Track model properties without railpad and CAM layer

	Youngs modulus (MPa)	Poisson's ratio (υ)	Density(kg/m^3)
Rail	205800	0.3	7872
Slab	38000	0.2	2400
Hydraulic bearing layer	23000	0.25	2400
Subgrade	100	0.3	1800

3.1.2. Model 2: Model with Railpad:

This model consists of railpad in addition to the Model 1.Railpad provide stiffness to the structure. The material properties are represented in Table3 and geometrical parameters is taken from Table 4 and model of components is hown in Figure 23.

Table 3: Track model properties with railpad

	Youngs modulus (MPa)	Poisson's ratio (υ)	Density(kg/m^3)
Rail	205800	0.3	7872
Rail Pad	1100	0.42	950
Slab	38000	0.2	2400
Hydraulic bearing layer	23000	0.25	2400
Subgrade	100	0.3	1800

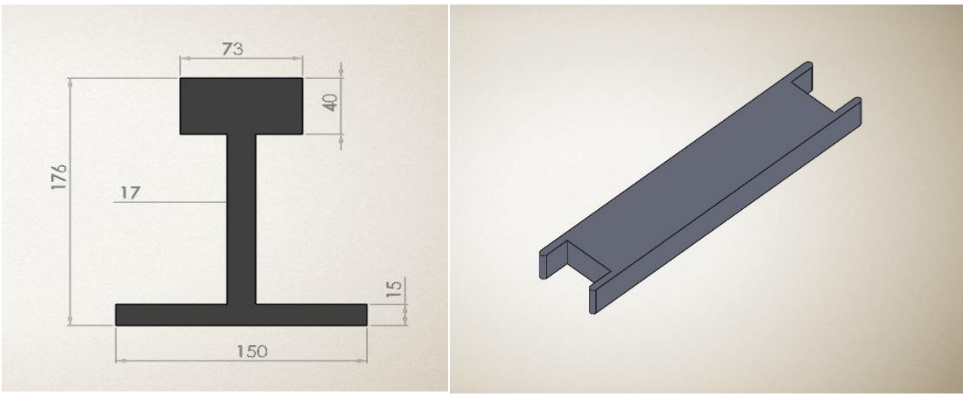


Figure 23: Components of rail track (a) Rail Section (b) rail pad

3.1.3. Model 3: Model with CAM Layer and RAILPAD

This model represents the similar model in the field with simplified geometry of track components. Front view, Top view, Side view, Isometric view and all the dimensions are shown in Figure 24.

Table 4: Track model properties of track with railpad and CAM layer

	Dimension	Youngs modulus (MPa)	Poisson's ratio (υ)	Density(kg/m^3)
Rail	I section	205800	0.3	7872
Rail Pad	stiffness=70kN/mm Thickness= 9mm	1100	0.42	950
Slab	Length= 6.45m Width= 2550mm Thickness= 300mm	38000	0.2	2400
Concrete Asphalt Mortar Layer	Length= 6.45m Width= 2550mm Thickness= 40mm	8000	0.25	1800
Hydraulic bearing layer	Length= 6.45m Width=2950mm Thickness=200mm	23000	0.25	2400
Subgrade	Length= 6.45m Width= 7.5m Thickness= 4m	100	0.3	1800

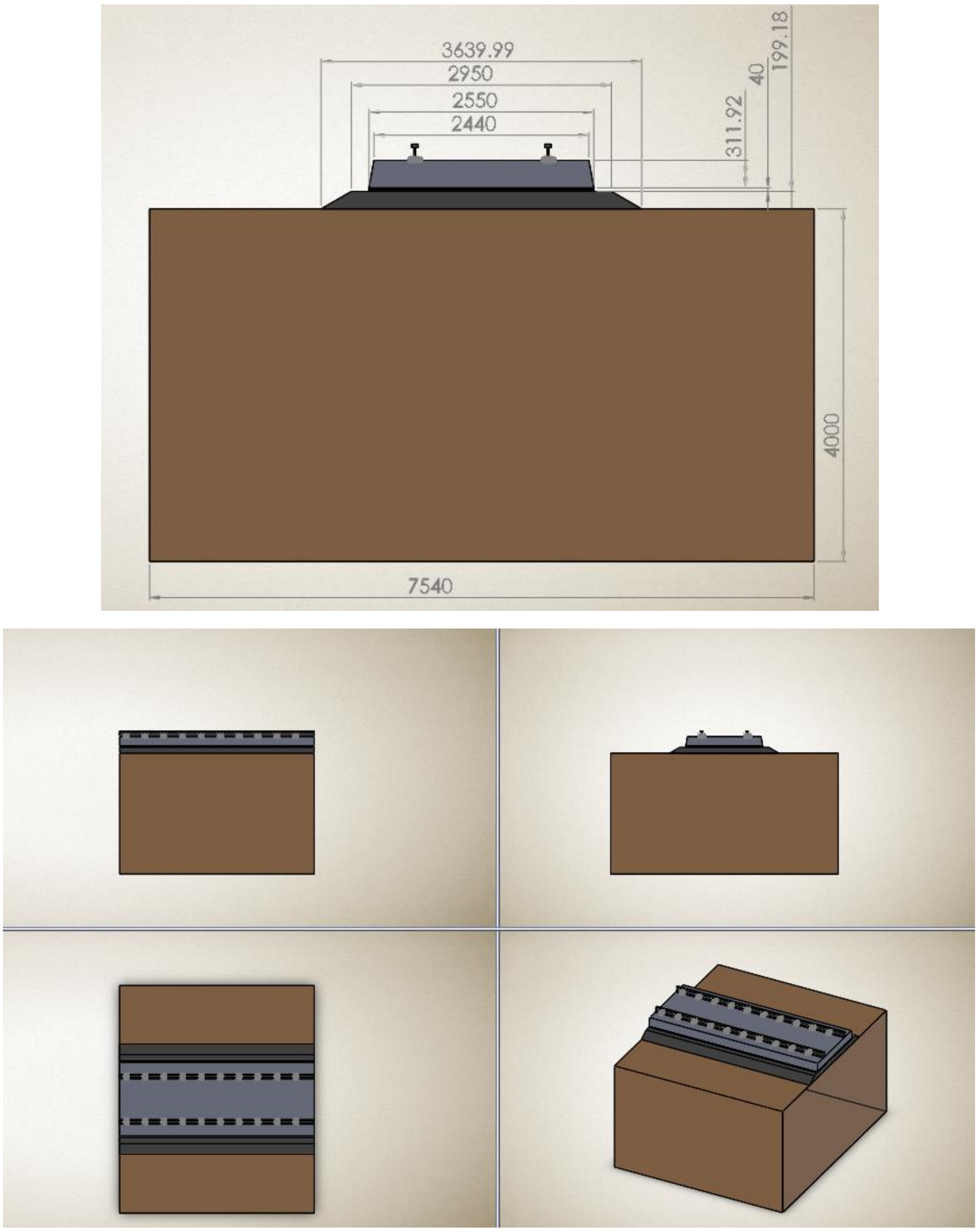


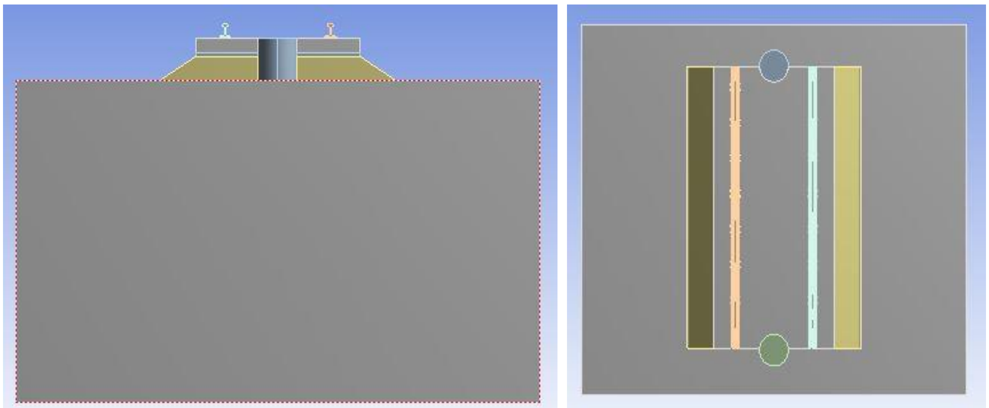
Figure 24: Model of track structure

3.1.4. Model 4: Shinkansen Model:

The Shinkansen slab track consists of a sublayer stabilized using cement, reinforced prestressed concrete slabs measuring 4.95 m x 2.34 m x 0.19 m and bituminous cement mortar injected under and between the slabs. It also consists of a cylindrical "stopper" which prevents lateral and longitudinal movement of tack and provide stability to it. Geometrical and material properties of different track components are shown in Table5. The SOLIDWORKS model of shinkansen track is shown in Figure 25.

Table 5: Shinkansen track properties

	Dimension	Youngs modulus (MPa)	Poisson's ratio (υ)	Density(kg/m^3)
Rail	UIC 60	205800	0.3	7872
Rail Pad	stiffness=70kN/mm Thickness= 9mm	1100	0.42	950
Slab	Length= 4.95m Width= 2340mm Thickness= 190mm	38000	0.2	2400
Concrete Asphalt Mortar Layer	Length= 4.95m Width= 2340mm Thickness= 40mm	8000	0.25	1800
Hydraulic Bearing Layer	Length= 4.95m Width=2950mm Thickness=200mm	23000	0.25	2400
Subgrade	Length= 5.5m Width= 7.5m Thickness= 4m	100	0.3	1800



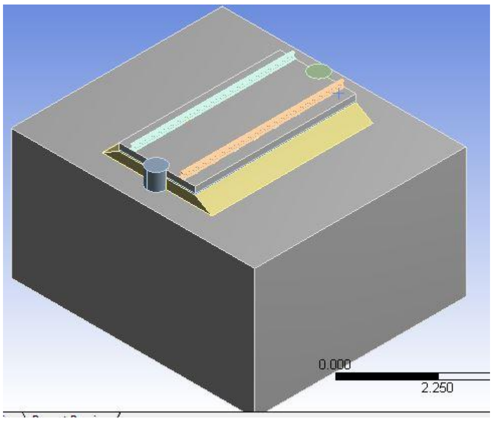


Figure 25: Shinkansen model

3.2 Simulation

Flow chart in Figure 26 shows the three consecutive step in simulation of the model.

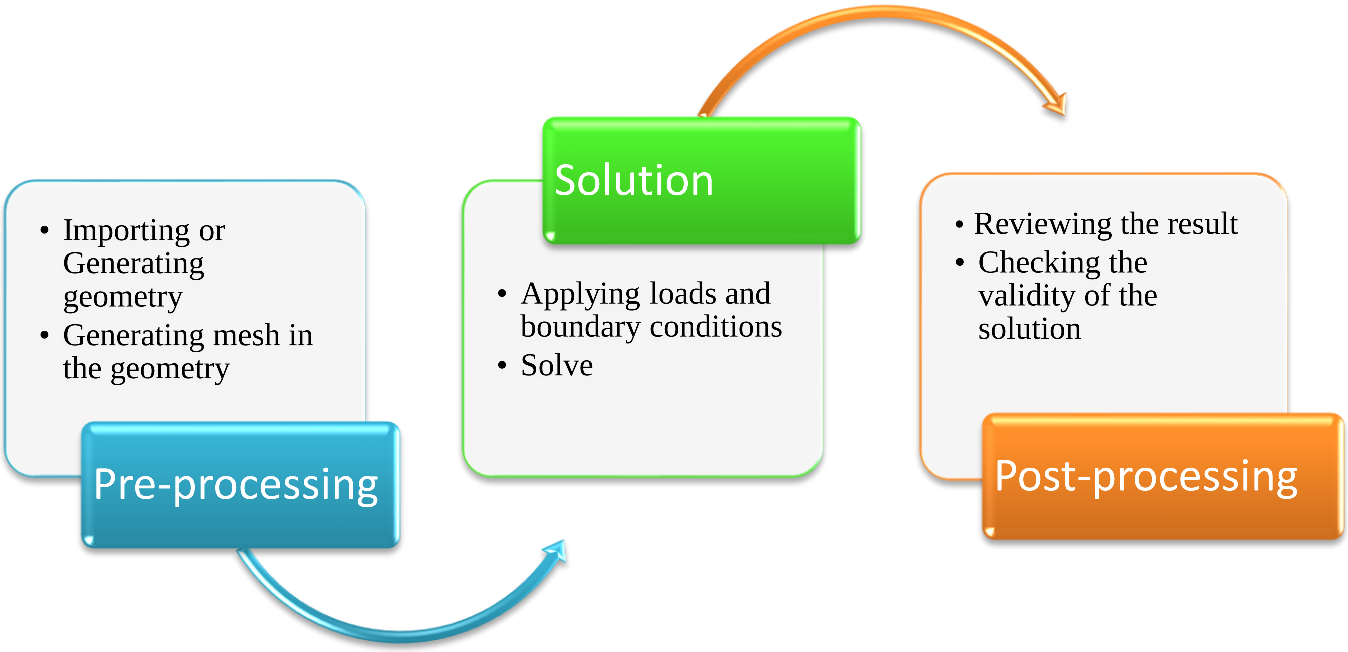


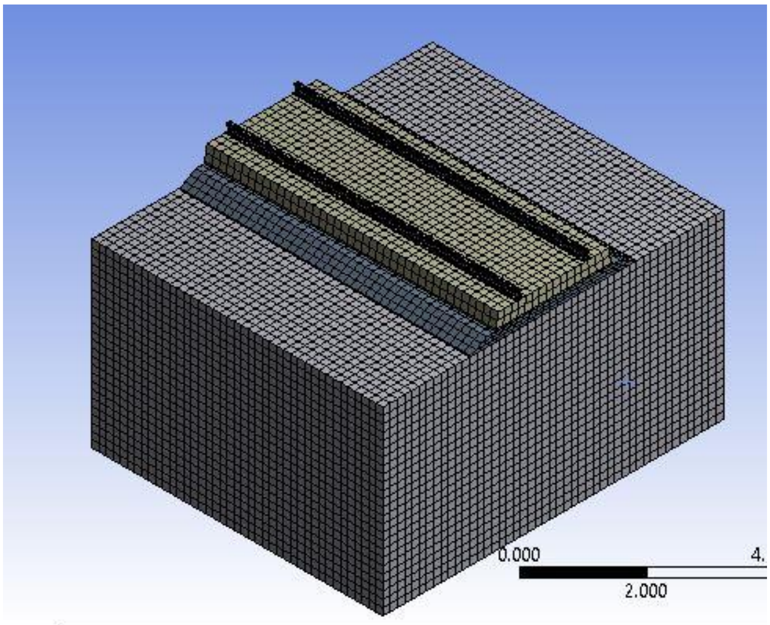
Figure26: Flow chart of process of analysis in ANSYS Workbench

i. **Pre-processing**: - Pre-processing mainly involves providing input to the programme and its main purpose is to generate finite element model. This step consists

- Importing or generating geometry: - The SOLIDWORKS model is attached to the Geometry of ANSYS16.0. The material properties of different layers of track are assigned in Engineering Data.
- Generating mesh in the geometry: - Meshing is the most important part in any of the computer simulations. In this solid element is filled with elements and nodes i.e. Finite element model is created. Too many mesh i.e. smaller mesh size leads to longer

time for simulations and fewer mesh i.e. large size mesh leads to inaccurate result. Various parameters which controls meshing are mesh size, mesh shape, element type etc. The nature of the mesh directly affects the rate of convergence, the execution extracted from the numerical model and the total computational time required for the simulation to be performed. The results are calculated by solving the relevant governing equations numerically at each of the nodes of the mesh.

In Ansys Workbench Meshing is done by selecting the templet i.e. STATIC Structural. Meshing function is accessed by right click on model and choose EDIT. This launch the mechanical application and then highlight the object in the tree as needed. Click on MESH object to access meshing application function and apply mesh control. For the present analysis a small mesh size to provide accuracy to the result as shown in figure 27.



Mesh size	Fine
Mesh type	Quadrilateral
Edge length	0.00216 m
No. of Elements	60394

Figure 27: Meshing Diagram and values of Track

ii. **Solution**: - Solution step is one in which loads, and support conditions are applied, and solver calculates the Finite element solution

- Applying loads and boundary conditions: - Boundary conditions have high impact on our analysis and results. For any model structural support is crucial so it should be provided efficiently. In present analysis boundary conditions used are assuming hard strata below subgrade i.e. no deformation is allowed for this the bottom most surface is fixed. And other is clamping the railpad between rail and concrete slab.

For the loading conditions stationary multiple vertical wheel loads are considered for the present study. Research Designs and Standards Organisation (RDSO) has defined several wheel load configurations for coaches, locomotives and wagons. For present study maximum axle load defined by RDSO to considered for high speed railway track is considered. India has moved to

Maxima Axle load = 22 tons

This load is provided in the form of uniformly distributed load acting on an elliptical patch on the rail. This elliptical patch (Figure 28) represents the contact area between wheel and rail. Two patches on each rail are made at a distance of 2800 mm showing the distance between wheels of boggie as defined by RDSOas shown in Figure 28.

Area of elliptical patch = $8.905 * 10^{-4}$ m^2

Load per wheel = 22/2 = 11 tons

= 11*9.81 = 107.91 kN

Therefore, Applied pressure force = 121184556.3 Pa

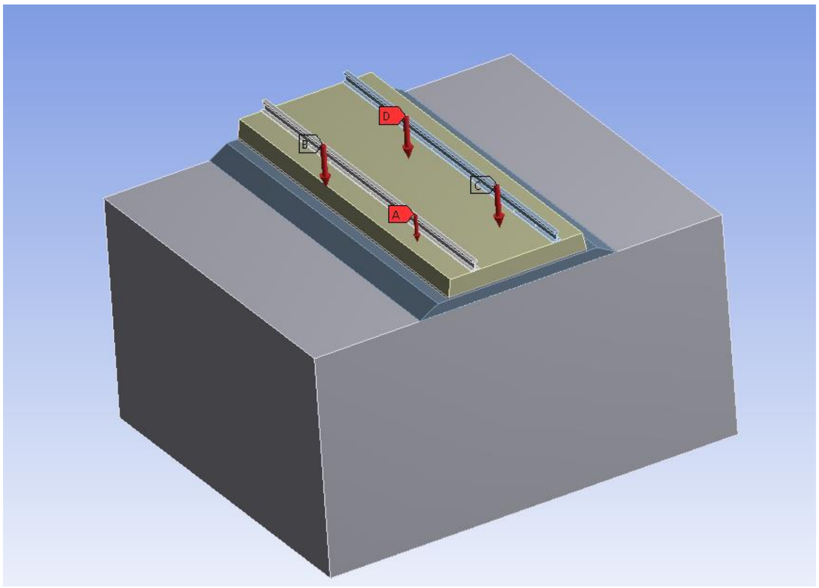


Figure 28(a) Load application in Ansys Workbench

- Solve: - After applying loads and boundary condition the desired parameters are calculated by adding them in solutions and then the model is analysed using SOLVE command.

An applied force F creates a deformation x according to

$$F = [K]x$$

where the shape of the geometry and the material's Young's Modulus E define the stiffness matrix [K].

ANSYS solves this equation for the unknown values of x. Once deformations are known, strains can be calculated. Once strains are calculated, stress is calculated using stress = E * strain.

This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure.

iii. **Post processing**: - This step involves

- Reviewing the result
- Checking the validity of the solution.

3.3 Parametric study

The influence of various parameters on the behaviour of ballastless track structure under stationary wheel load (22t/axle) condition are investigated as under. The track with rail, railpad, Concrete slab, Cement Asphalt Layer, Concrete treated Hydraulic bounded layer and subgrade is considered for analysis. Variations in the parameters were made and comparison is done based on deformations and stresses produced in the rail and the concrete slab.

Railpad stiffness: The simple section with all the components railpad and CAM layer is analysed for varying stiffness. Stiffness is directly proportional to modulus of elasticity, so the stiffness is induced using this relation by changing the modulus of elasticity. The other properties of track structure are taken same as before for analysis. The variation is shown in Table 6 and computed maximum vertical deflection and equivalent stress are shown in Figure 25 and Figure 29.

CAM Layer: The track structure is analysed for varying modulus of elasticity of CAM layer. This layer is of relatively inexpensive material which helps in reducing vibration and induce elasticity behaviour in track. The variation is shown in Table 6. Figure 26 and Figure 30 represents the maximum vertical deflection and equivalent stress in the track and Concrete slab.

Concrete Slab: The modulus of elasticity of the Concrete Bearing Layer (CBL) is varied to analyse its effect of the maximum vertical deflection and maximum equivalent stress. This is shown in Figure 27 and Figure 31.

Subgrade: Different types of subgrade having different modulus of elasticity are considered to study the effect of this parameter on the static behaviour of track structure. The computed maximum displacement and maximum equivalent static stress are shown in Figure 28 and Figure 32.

Table 6: Variation in values of parameters used in the analysis

Stiffness of rail pad (kN/mm)	50	60	70	80	90	100
Modulus of CAM layer (MPa)	4000	6000	7000	8000	9000	10000
Modulus of CBL (MPa)	25000	30000	34000	38000	40000	42000
Modulus of subgrade (MPa)	50	70	100	120	150	200

CHAPTER -4

4. RESULTS AND DISCUSSION

4.1 Static response of track structure

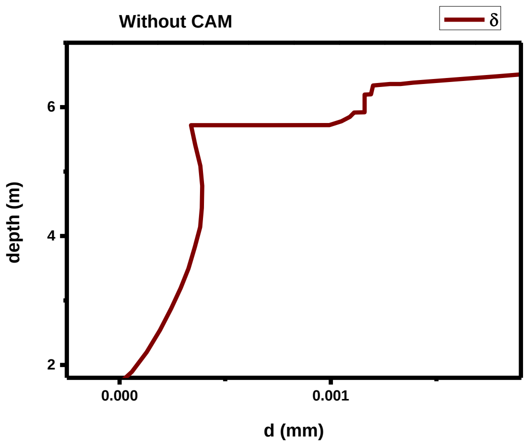
The wheel load of 22tons/ axle is applied on the rail to evaluate the displacement and stresses in rail section and concrete slab. The vertical displacement and equivalent stress distribution varying with depth in all the four models (without Railpad and CAM, with railpad, with railpad and CAM, Shinkansen model) are shown in Figure 29 and Figure 30 respectively. The maximum stress and maximum vertical deflection occur at the contact area patch formed where the load is applied.

Displacement: Figure 29 gives the variation of maximum vertical displacement occurring at different depth. With increase in depth the vertical displacement decreases. All the Graphs shows same trend of decrease in deflection with depth. It is observed from the graphs that maximum displacement is occurred in the model-1 without railpad and CAM layer shows a very high deflection of 5.96 mm (Figure 29(a)). To mitigate the rider's discomfort due to high deflection railpad was provided in model-2 causes considerable decrease in deflection. Further introduction of interface CAM layer along with railpad (model 3) also cause more reduction in the track. The result of displacement in Shinkansen Model is shown in Figure 29(c) which is less than previous results because of additional stability due to stopper.

The comparison between the results taken from design model to that of reported model taken from Matias, S. (2015) shown in Figure 29 and 30 respectively. Model with railpad and CAM represents the result in accordance with VSB track structure in Matias, S. (2015) model. The slight variation in the result is due to the conditions applied and software simulation criteria.

Stress: The variation in stresses in the track structure at different depths are shown in Figure 31. The maximum stress occurs in the track structure is at contact path where wheel load is applied. This has been proved by Herz Theory that maximum stress in the track is at contact surface of rail and wheel. In the analysis an elliptical patch is formed on the rail representing contact area between rail and wheel (Ashofteh, R.S., 2013). Model 3 and Shinkansen model has high stiffness due to presence of rail pad and CAM layer. This shows the rapid mitigation of stress for the subgrade part.

When designed model is compared with reported model Matias, S. (2015), the graph of equivalent stresses with depth in Figure 31 shows the similar trend of graph of vertical stresses as of Matias, S. (2015) model shown in figure 32.



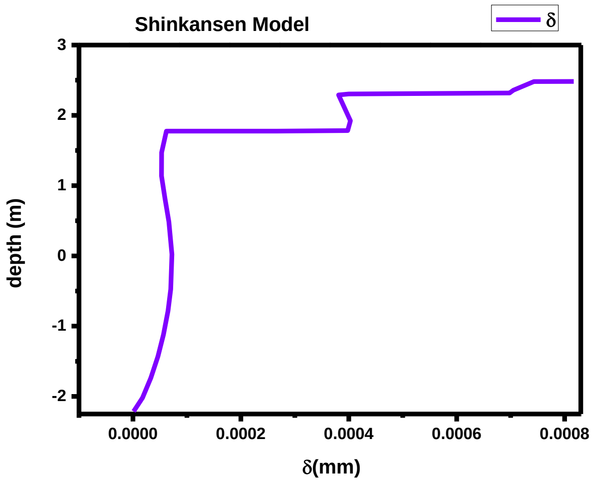


Figure 29: Vertical displacement in depth for a) without CAM layer model, b) Shinkansen Model

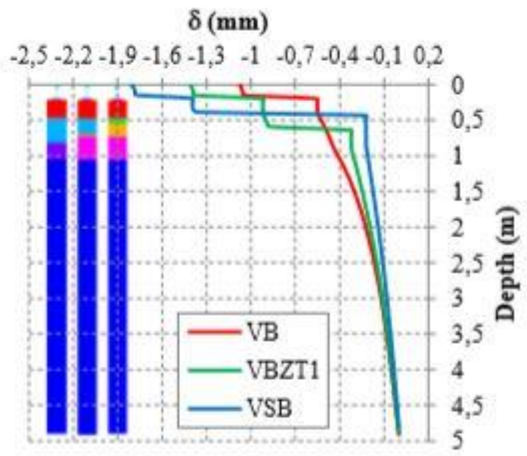


Figure 30: Vertical displacements in depth for VB, VBZT1 and VSB (Matias, S. (2015))

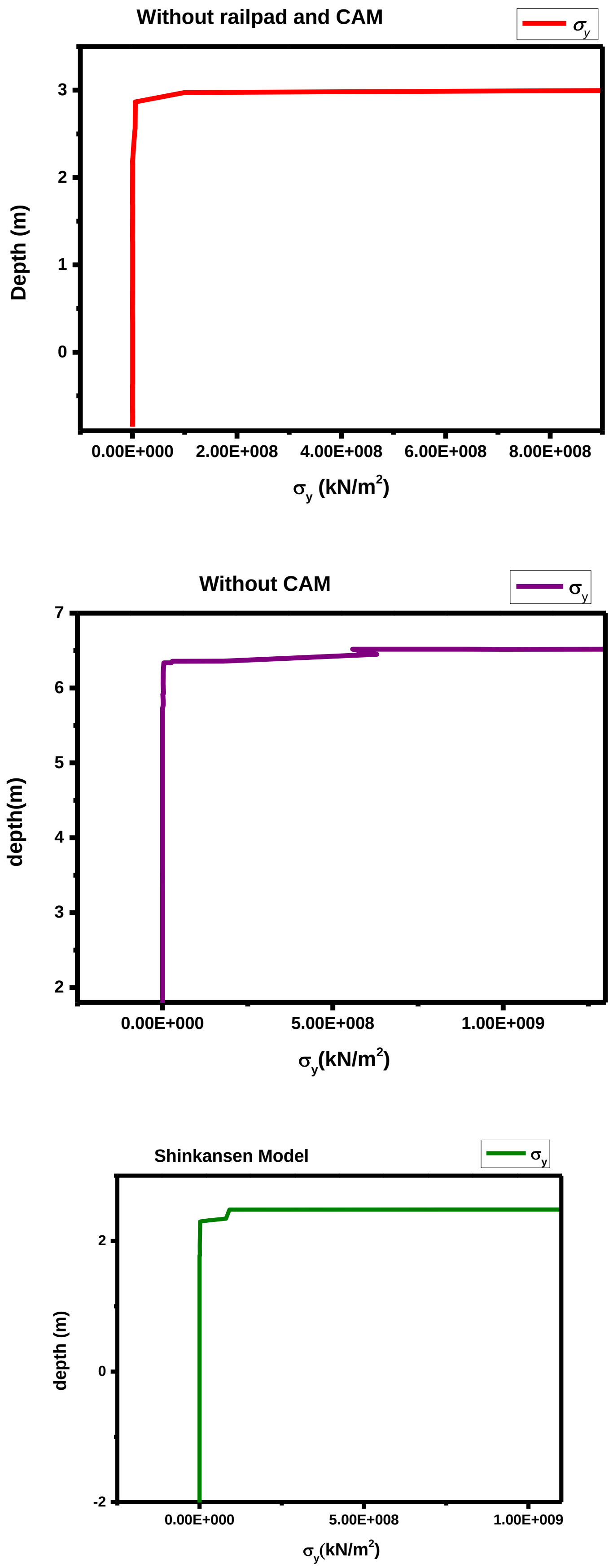


Figure 31: Equivalent Stresses in depth for a) without CAM layer model, b) without CAM layer c) Shinkansen Model

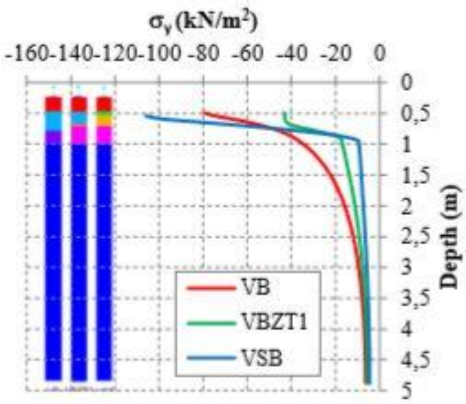


Figure 32: Vertical stress in depth for VB, VBZT1 and VSB (Matias, S. (2015))

4.2 Parametric study

The results of defection and stress due to variation in track components parameters as shown in Table 6 is presented in Figure 33-36

4.2.1 Deflection: -

i) Railpad:

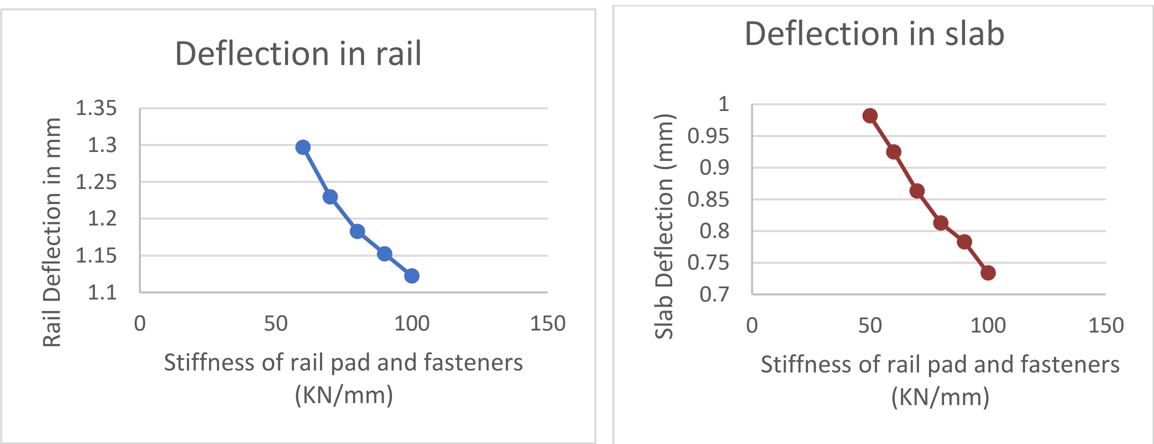
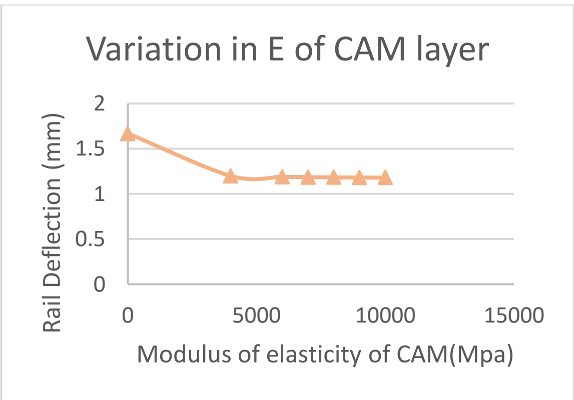


Figure 33: (a) Deflection in rail due to variation in stiffness of railpad. (b) Deflection in concrete slab due to variation in stiffness of railpad.

ii) CAM layer:



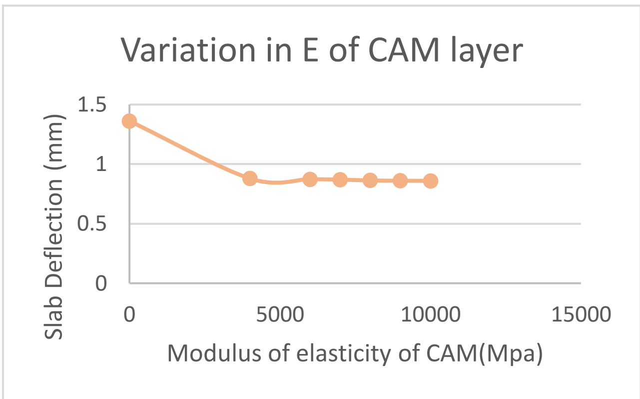


Figure 34: (a) Deflection in rail due to variation in modulus of elasticity of CAM layer. (b) Deflection in concrete slab due to variation in modulus of elasticity of CAM layer.

iii) Concrete slab:

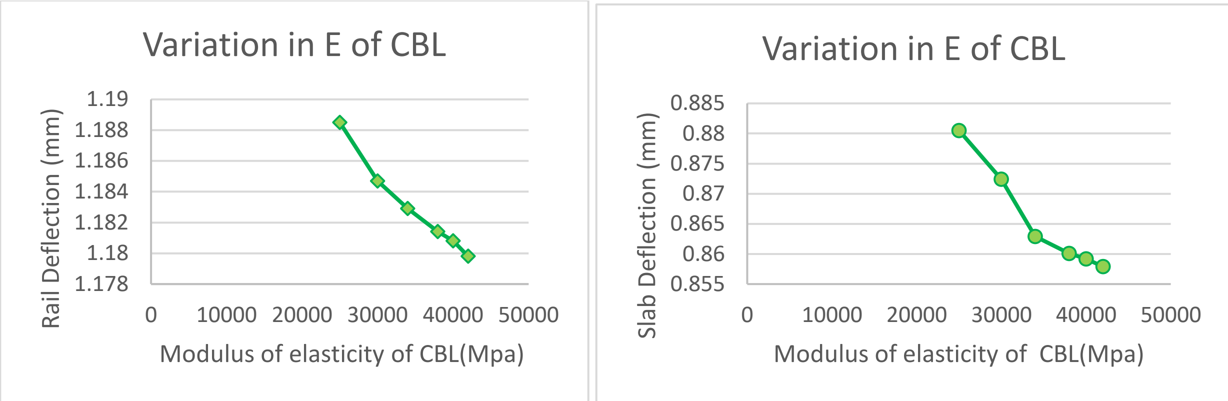


Figure 35: (a) Deflection in rail due to variation in modulus of elasticity of concrete slab. (b) Deflection in concrete slab due to variation in modulus of elasticity of concrete slab.

iv) Subgrade:

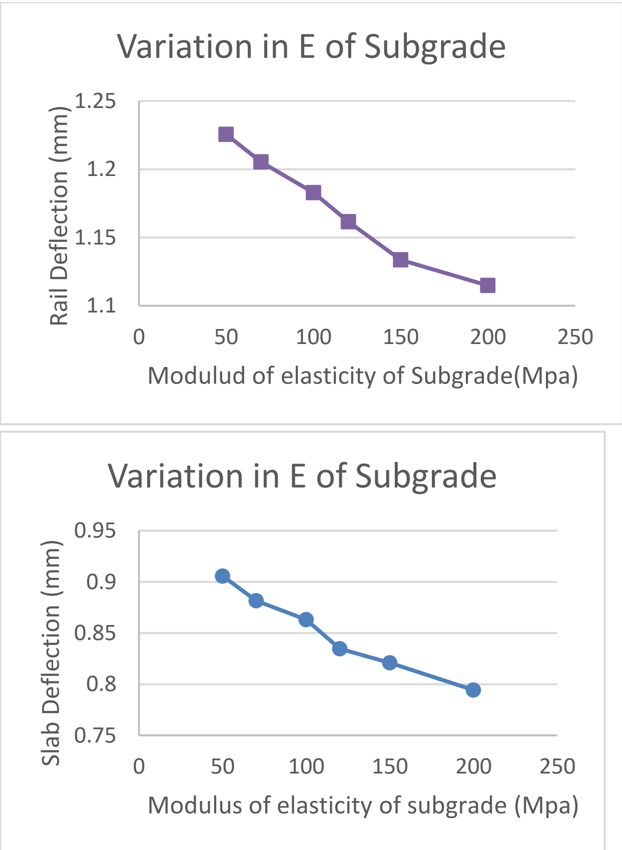
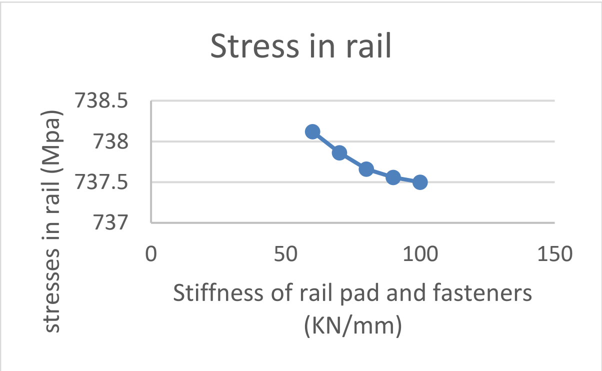


Figure 36: (a) Deflection in rail due to variation in modulus of elasticity of subgrade. (b) Deflection in concrete slab due to variation in modulus of elasticity of subgrade.

Parametric study is carried out and deflection in rail and concrete slab is computed. In Figure 33 (a, b) the increase in stiffness of railpad from 50KN/mm to 100 KN/mm decreases the deflection from 1.29 mm to 1.05 mm in rail and 0.98 mm to 0.73 mm in slab. On varying the elastic modulus of CAM layer from 0 to 10000 MPa, decrease in deflection occurred in rail and slab is around 40-50% whereas the displacement shows a trend of constant value when elasticity in Figure 34(a, b). In case of CBL also the variation of modulus of elasticity shows negligible change in deflection.

4.2.2 Stress:

i) Railpad:



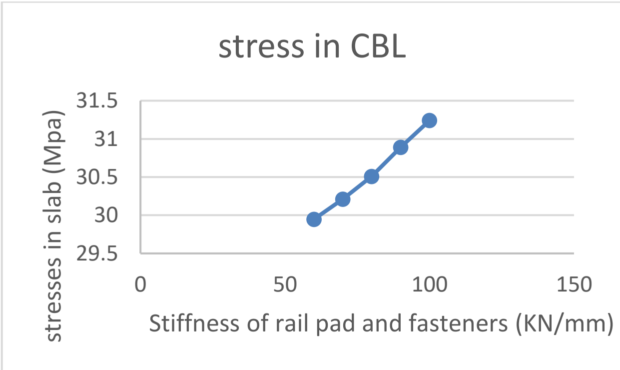
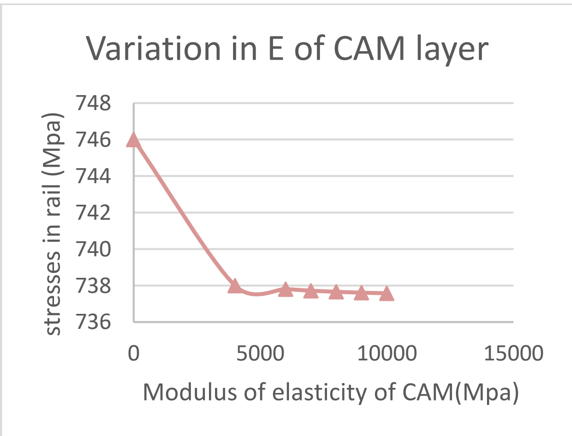


Figure 37: (a) Stresses in rail due to variation in stiffness of railpad. (b) Stresses in concrete slab due to variation in stiffness of railpad.

ii) CAM layer:



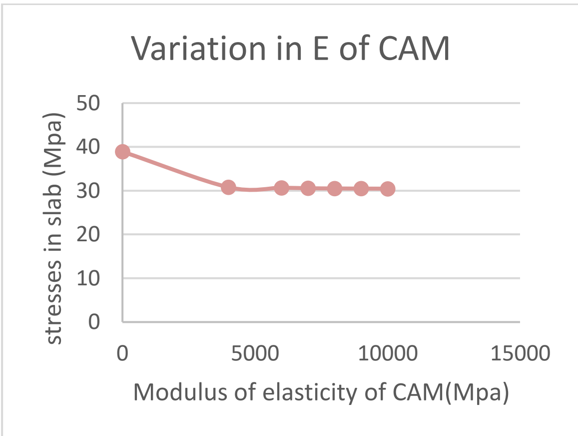
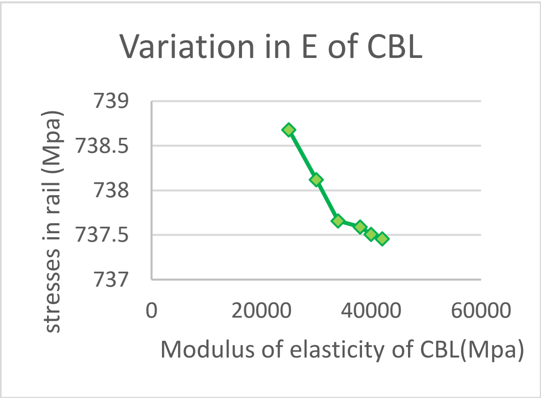


Figure 38: (a) Stresses in rail due to variation in modulus of elasticity of CAM layer. (b) Stresses in concrete slab due to variation in modulus of elasticity of CAM layer.

iii Concrete slab:



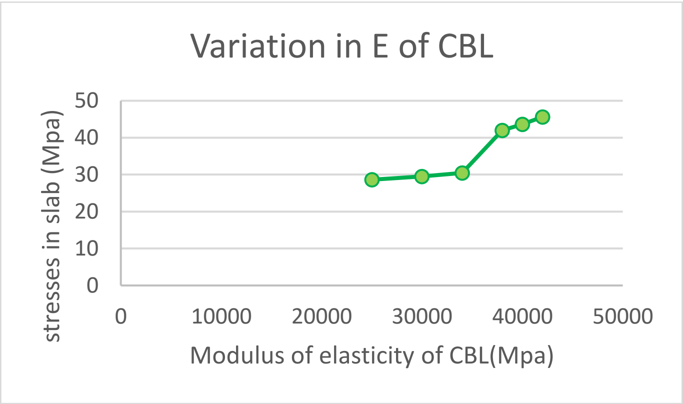
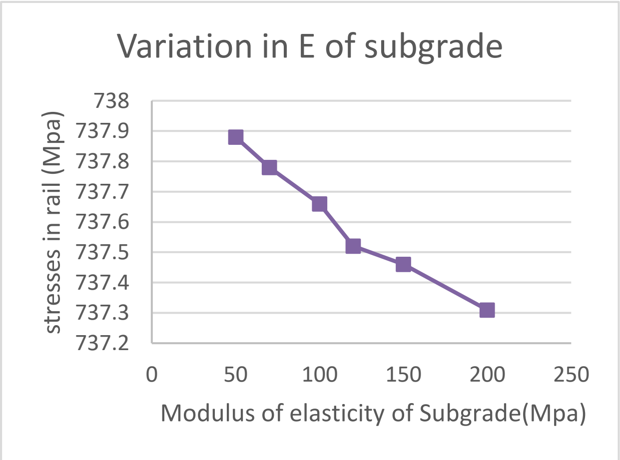


Figure 39: (a) Stresses in rail due to variation in modulus of elasticity of concrete slab. (b) Stresses in concrete slab due to variation in modulus of elasticity of concrete slab.

iii)Subgrade:



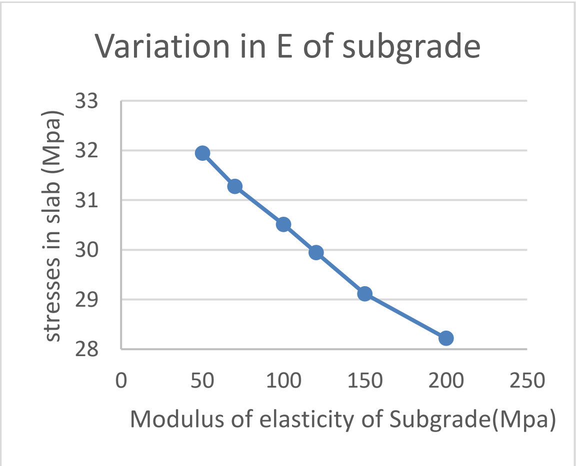


Figure 40 : (a) Stresses in rail due to variation in modulus of elasticity of subgrade. (b) Stresses in concrete slab due to variation in modulus of elasticity of subgrade.

Figure 37-40 shows the stresses in rail and concrete slab by varying the properties of different components. With increase in all the parameters the contact stress in the rail decreases. But in concrete slab increase in stiffness of rail pad and modulus of elasticity of concrete slab increases the equivalent stress.

4.2.3 Comparative Study: -

Table 7: % variation of parameters from benchmark value

Stiffness of rail pad (kN/mm)	50	60	70	80	90	100
% Variation	-28.57	-14.28	0	14.28	28.57	42.58
Modulus of CAM layer (MPa)	4000	6000	7000	8000	9000	10000
% Variation	-50	-25	-12.5	0	12.5	25
Modulus of CBL (MPa)	25000	30000	34000	38000	40000	42000
% Variation	-26.47	-11.76	0	11.76	17.65	23.53
Modulus of subgrade (MPa)	50	70	100	120	150	200
% Variation	-50	-30	0	20	50	100

i) Deflection: -

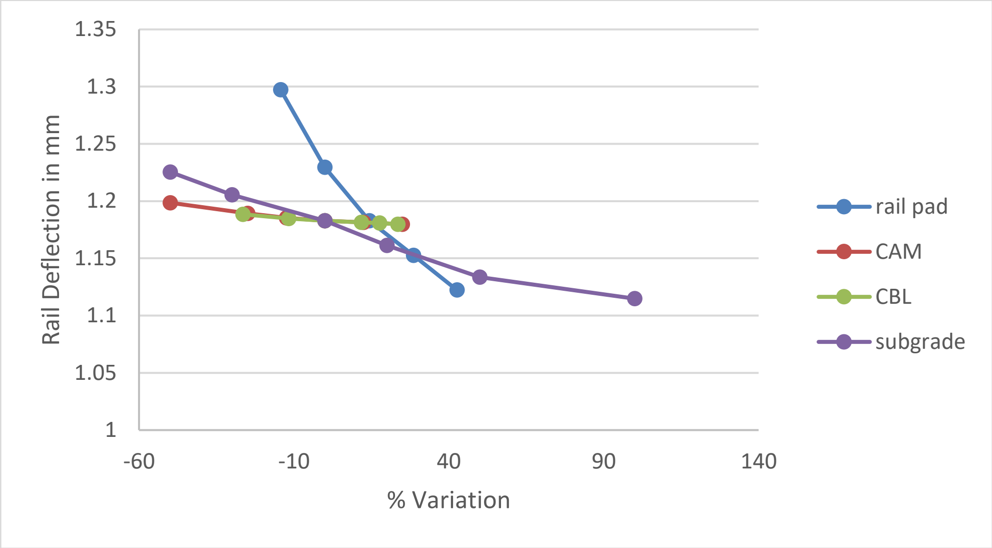


Figure 41: Effect of design parameters on deflection of rail

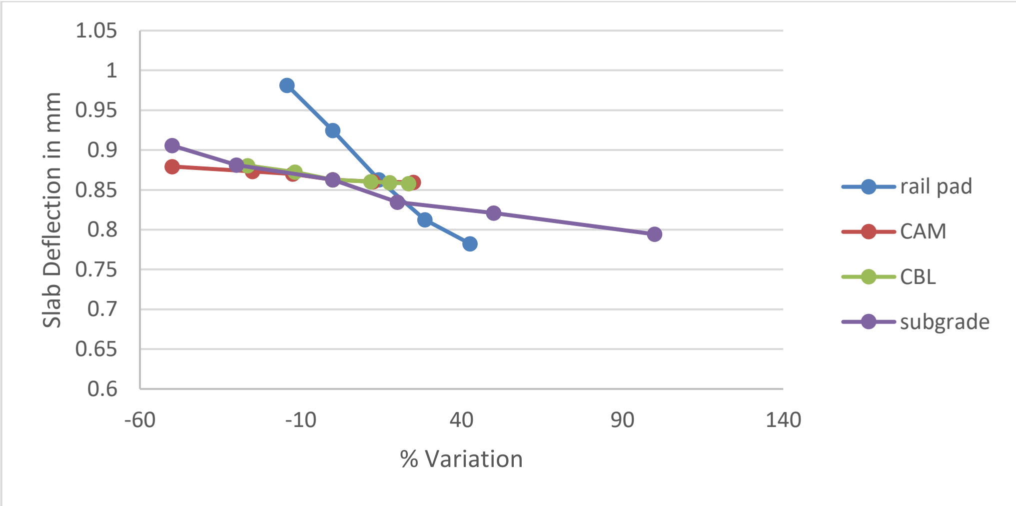


Figure 42: Effect of design parameters on deflection of slab

Table 7 represents the variation of different parameters from benchmark value and data is analysed for deflection. Figure 41 and Figure 42 is plotted to understand the effect of design parameters on the deflection of the track system. The Figure 41 shows that deflection in rail has sown negligible change by changing the modulus of elasticity of CAM Layer and Concrete slab. But the change in stiffness of the railpad has greatly impacted the deformation. It is observed that around 42% increase in stiffness railpad fastening system decreases the deflection of rail by 18%. Also, variation in modulus of elasticity of subgrade shows minor change in the deflection of rail. Increase in modulus of elasticity of subgrade by 50% decrease the deflection in rail by 4%. Figure 33 also represents the similar trend as above. The change in stiffness of raipad greatly affects the deflection in concrete slab also while variation in other parameters shows negligible effect.

The comparison between the results obtained from the designed model to that of the reported model taken from Sun L. et al. (2013) model are shown in figure 41 and figure 43 respectively. The design model and Sun L. et al. (2013) model shows similar variation in the results due to change in parameters.

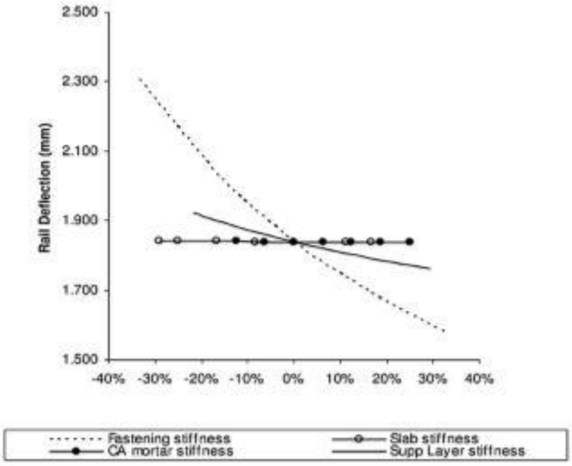


Figure 43: Effect of design parameter in CRTS II (Sun L. et al.,2013)

Stress:

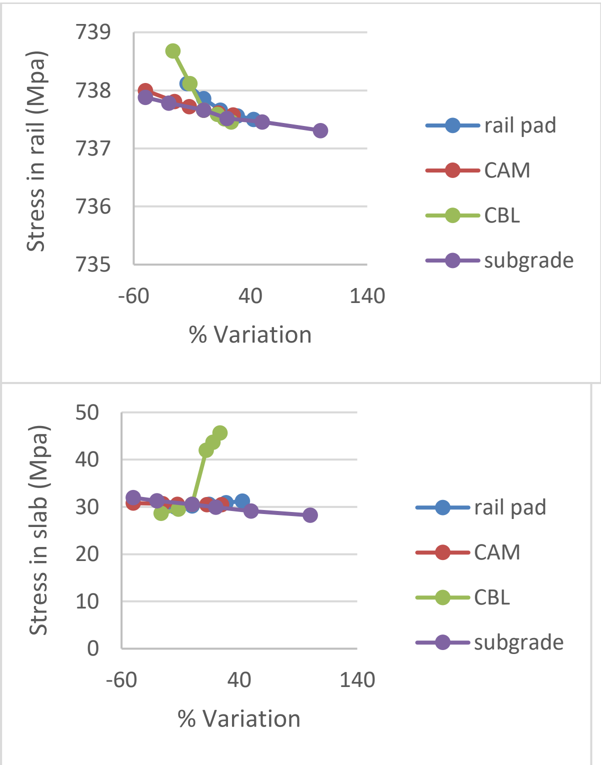


Figure 44: (a)Effect of design parameters on equivalent stress in rail (b) Effect of design parameters on equivalent stress in slab

Effect of variation of design parameters on equivalent stress induced in rail and concrete slab is shown in Figure 44 (a) and (b) respectively.

CHAPTER 5
CONCLUSION

This thesis presents the static structural analysis of ballastless track structure using 3-Dimensional Finite Element models. It is carried out by developing model in SOLIDWORKS. Simulation is carried out in finite element assessment tool ANSYS Workbench 16.0. The four different structure were analysed under multiple wheel load condition and their results in terms of stresses and deflection were analysed to understand the role of every component of track.

It is evident from the results that using railpad under rail and CAM layer between concrete slab and HBL reduced the total vertical deflection to very large extent. The total deflection is reduced to 50% by using only rail pads, further provision of CAM layer decreases the deflection to 30-40%. Shinkansen model is more stable than any other model due to presence of cylindrical stopper and this results in minimum deflection of all other model.

The graph plotted for deflection and equivalent stresses shows that load is effectively distributed by different layers thus very low stress and minimum deflection occurs at subgrade level. The contact stress at contact patches on the rail is found to be very much high with respect to surrounding areas also and this is well explained by Hertz theory. The value of contact pressure was in accordance to the value of contact pressure in Ashofteh, R.S., (2013) model and this shows the correctness of the model.

Parametric investigation is carried out and it is concluded that increase in stiffness of rail pad decreases the maximum vertical deflection which occurred in rail and decreases the deflection in concrete slab also. The variation in modulus of elasticity of CAM layer and Modulus of elasticity of concrete slab shows no change in the vertical deflection. At the same time increase in modulus of elasticity of subgrade produces slight increase in deflection. The result of the deflection by varying material parameter obtained from design model was obtained from design model was compared with reported model by Sun L. et al. (2013) for similar studies. The graph of deflection obtained in the current model and Sun L. et al. (2013) model shows similar pattern which emphasises the correctness of the model. It is seen that with increase in all the parameters the contact stress in the rail decreases. But in concrete slab increase in stiffness of rail pad and modulus of elasticity of concrete slab increases the equivalent stress.

Future Scope of research:

Advancement in computational analysis has encouraged us to perform more complex analysis in the field of research. Some of the recommendations for future work on the study of track structure are:

- Dynamic analysis can be performed to study the acceleration and dynamic behaviour of the track structure may be studied for very high speeds.
- Lateral and longitudinal loading may be considered for the analysis of track structure under both static and dynamic state.
- 3-Dimensional analysis of dynamic interaction of wheel rail contact may be carried out.
- Parametric study showing the geometrical variation in different track components for static and dynamic analysis may be carried out.

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