Some thesis title on rail tracks

by

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CERTIFICATE

This is to certify that the thesis titled **Some thesis title on rail tracks**, submitted by **Mr. Test guy**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Doctor of Philosophy**, is a bonafide record of the research work done by him under our supervision and guidance. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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(test guy)

ABSTRACT

High-speed rail transportation requires careful design of a rail track. The design of a railway track is governed by the load-bearing capacity and maximum possible speed of transportation. The capacity of a high-speed rail tracks is generally limited by its critical speed. It is the speed at which the vibration occurs at the largest magnitude. Thus, its identification is necessary to prevent derailments and damage to the rail tracks.

संक्षेप

हाई-स्पीड रेल परिवहन के लिए रेल ट्रैक के सावधानीपूर्वक डिजाइन की आवश्यकता होती है। रेलवे का डिजाइनट्रैक भार वहन क्षमता और परिवहन की अधिकतम संभव गति से नियंत्रित होता है। हाई-स्पीड रेल पटरियों की क्षमता आम तौर पर इसकी महत्वपूर्ण गति से सीमित होती है। यह है जिस गति से कंपन सबसे बड़े परिमाण में होता है। ऐसे में इसकी पहचान है पटरी से उतरना और रेल पटरियों को नुकसान को रोकने के लिए आवश्यक है।

वर्तमान अध्ययन ने एक विशिष्ट के त्रि-आयामी परिमित तत्व विश्लेषण का प्रयास किया मूल्यांकन करने के लिए अलग-अलग गति से एक ही गतिमान पहिया भार के तहत गिट्टी रेल ट्रैक महत्वपूर्ण गति और उप-महत्वपूर्ण गति पर गतिशील प्रभाव कारकों का आकलन करने के लिए। गतिशील इम्पैक्ट फैक्टर (DIF) डायनेमिक और स्टैटिक व्हील लोड का अनुपात है। यह प्रभाव निर्धारित करता है | कई अनुभवजन्य के आधार पर एक रेल ट्रैक पर गतिशील भार (ज्यादातर सबक्रिटिकल गति के तहत)। साहित्य में दिए गए फॉर्मूलेशन। ये फॉर्मूलेशन कम गति के तहत विकसित किए गए हैं पुराने ट्रैक पर लगभग 50 किमी/घंटा की रेंज। इस प्रकार, उच्च के तहत रेल पटरियों के लिए उनकी विश्वसनीयता 200 किमी/घंटा तक की गति को सत्यापित करने की आवश्यकता है। मूविंग लोड विश्लेषण के लिए अध्ययन जारी है जियोसिंथेटिक के विभिन्न ज्यामितीय संयोजनों पर आराम करने वाली गिट्टी वाली रेल पटरी पर सुदृढीकरण के प्रभाव का विश्लेषण करने के लिए प्रबलित पृथ्वी (जीआरई) तटबंध और दीवार को बनाए रखना तटबंध खंड विन्यास पर एजेंट, उनकी अनुमानित निर्माण लागत सहित। वर्तमान अध्ययन में मूविंग लोड परिमित तत्व विश्लेषण पर प्रारंभिक कार्य भी शामिल है एम्बेडेड ट्रैक सिस्टम (ETS) मॉडल, जो एक गिट्टी रहित रेल ट्रैक सिस्टम है।

गिट्टी, सबबॉलास्ट, और ट्रैक की सबग्रेड परतों को इलास्टोप्लास्टिक सामग्री के रूप में सामग्री भिगोना और विकिरण भिगोना (अनंत परतें) के रूप में तैयार किया गया था। ट्रैक प्रतिक्रिया की गणना तनाव, विस्थापन, वेग और त्वरण प्रतिक्रियाओं के रूप में की गई थी। महत्वपूर्ण व्यवहार को खोजने के लिए उपयुक्तता के लिए विभिन्न मापदंडों का विश्लेषण किया गया था, जैसे मूविंग लोड को लागू करने की विधि, प्राथमिक लोड-ले जाने वाली परत (गिट्टी) का सामग्री मॉडल, सीमाओं का प्रभाव और आउटपुट डेटाबेस से निकाले गए ट्रैक

प्रतिक्रियाएं। ट्रैक की गतिशील प्रतिक्रिया पर उनके प्रभाव को देखने के लिए ट्रैक सबस्ट्रक्चर परतों की सामग्री नमी और कठोरता पर पैरामीट्रिक अध्ययन किए गए थे। रेल ट्रैक के महत्वपूर्ण व्यवहार पर उनके प्रभाव की जांच करने के लिए सबग्रेड के अपरूपण शक्ति मापदंडों (सामंजस्य और घर्षण) के प्रभाव का भी विश्लेषण किया गया था।

गतिशील प्रभाव कारकों के आकलन के लिए, ABAQUS में VDLOAD सबरूटीन का उपयोग करके दबाव-भारित क्षेत्र पैच की गति का अनुकरण किया गया। ट्रेन की गति, ट्रैक मापांक और पहिया व्यास पर पैरामीट्रिक अध्ययन किया गया। परिमित तत्व परिणामों पर प्रतिगमन विश्लेषण किया गया था, और गति और ट्रैक मापांक के कार्य के रूप में एक डीआईएफ सूत्रीकरण विकसित किया गया था। अध्ययन से पता चलता है कि रेल ट्रैक की महत्वपूर्ण गति की पहचान करने के लिए ऊर्ध्वाधर वेग, तनाव और त्वरण प्रवृत्तियों के संयोजन का उपयोग किया जा सकता है, जो वर्तमान अध्ययन के लिए 350 किमी/घंटा के रूप में पाया गया था। यह पाया गया कि यंग के अवसंरचना ने महत्वपूर्ण गति के साथ प्रत्यक्ष आनुपातिकता नहीं दिखाई। भिगोना अनुपात का महत्वपूर्ण गति पर एक छोटा प्रभाव पड़ता है, जबकि सबग्रेड की कतरनी ताकत में वृद्धि होती है क्रांतिक गति को बढ़ाता है।

डीआईएफ आकलन के संबंध में, यह अनुमान लगाया गया था कि मौजूदा के बीच का अंतर डीआईएफ सूत्र और वर्तमान अध्ययन गति के साथ बढ़ता है। से संबंध की गणना संख्यात्मक अध्ययन ने साहित्य में मौजूदा संबंधों की तुलना में उच्च डीआईएफ का सुझाव दिया। उच्च गति (>150 किमी/घंटा) पर, रेल ट्रैक का इलास्टोप्लास्टिक व्यवहार उच्च का कारण बनता है कम गति की तुलना में कंपन (<50 किमी/घंटा) जहां गतिशील कंपन आम तौर पर होते हैं| मूविंग लोड के तहत जीआरई संरचनाओं के विश्लेषण से पता चला है कि जमीनी त्वरण 100 से 400 की गति सीमा में जियोसिंथेटिक्स और सामना करने वाली दीवारों के साथ 50% की कमी किमी/घं. यह भी अनुमान लगाया गया था कि मिट्टी के तटबंधों का विशाल द्रव्यमान इसके लिए पर्याप्त नहीं है बड़े कंपन का मुकाबला करें। गिट्टी रहित ईटीएस मॉडल पर अध्ययन ने सुझाव दिया कि कठोरता और कंक्रीट असर परत की मोटाई रेल ट्रैक की प्रतिक्रिया को सबसे अधिक प्रभावित करेगी।

Contents

List of Figures

List of Tables

List of symbols

c_d	Dilatation wave speed
C	Material damping matrix
D	Diameter of wheel
F	Force matrix
K	Stiffness matrix
L_d	Smallest mesh element size
M	Mass matrix
u(t)	Time-dependent displacement matrix
u'(t)	First derivative of time-dependent displacement matrix
u"(t)	Second derivative of time-dependent displacement matrix
U'	Vertical displacement or displacement magnitude
U	Track modulus
V'	Vertical velocity or velocity magnitude
V	Translation speed of wheel
V_R	Rayleigh wave velocity
V_s	Shear wave velocity
α	Mass proportional damping coefficients
β	Stiffness proportional damping coefficients
Δt_{min}	Minimum time increment size in an explicit integration
ξ	Damping constant of the material
ω_1	First resonant frequency of the structure
ω_2	Applied highest load frequency of the structure

Chapter 1

Introduction

1.1 General

The technological developments and the reach of accessibility have put more pressure on rail and road transportation. Specifically, rail transportation has seen a surge in passenger volumes as predicted by Ramanathan and Parikh (1999) by 2.5 folds in last two decades.

1.2 Details of ballasted rail track

Most railway tracks in India and the world are constructed by first finishing the ground (subgrade), then laying over the subballast and ballast layers, followed by placement of the sleepers connected with the rails.

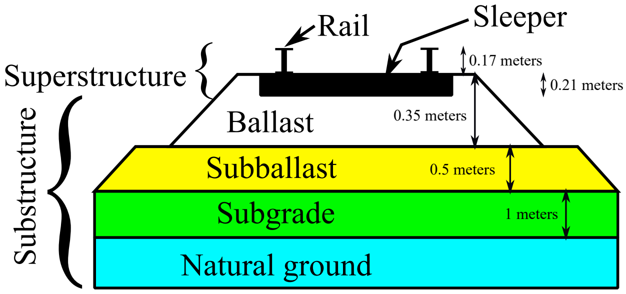

Figure 1.1: A typical ballasted rail track (Width of layers change with track gauge)

1.3 Ballastless (slab) rail track and their comparison with ballasted tracks

The life cycle cost of slab track will become lower than the traditional ballasted rail track after 25 years (Michas, 2012). A typical cross-section of a ballastless rail track based on German Rheda rail track is shown in Figure 1.2 while the differences between ballasted and ballastless railway tracks are mentioned in Table 1.1.

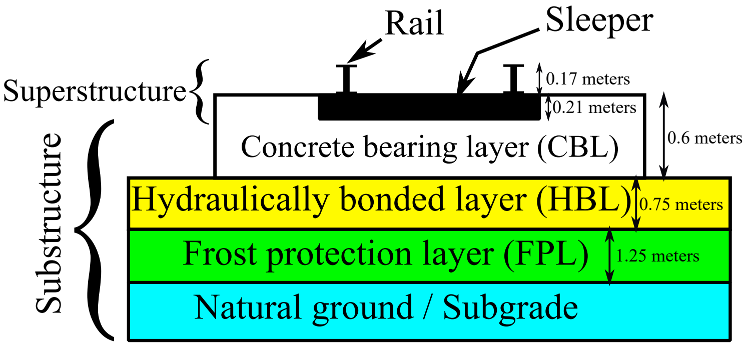

Figure 1.2: A typical ballastless rail track (Width of layers change with track gauge)

Table 1.1: Comparison between ballasted and ballastless tracks (Esveld, 2001; Michas, 2012)

S No.	**Ballasted track**	**Ballastless track**
1	Frequent maintenance	Less maintenance
2	Relatively low construction costs but higher life cycle cost	Relatively high construction cost but lower life cycle cost
3	High elasticity due to ballast	Elasticity is achieved via rubber pads and other artificial materials
4	Poor Life expectancy (15-20 yrs)	Good Life expectancy (50-60 yrs)
5	Relatively High noise	Relatively low noise and vibration nuisance

6	Ballast fouling at high speeds, causing damage to rails and wheels	No such damage to rails and wheels
7	Ballast is relatively heavy, thus increased cost on bridges and viaducts	Less cost of construction of bridges and viaducts due to lower dead weight of the ballastless track
8	Depth of ballasted track is relatively high, which require large tunnel diameters	Reduced height
9	Reduced permeability due to fouling	High impermeability
10	Release of dust from the ballast causing environmental pollution	Less environment pollution

1.4 Methods of railway track analysis

There are several methods to study the dynamic responses of railway track.

1.5 Objectives of the present study

The main purpose of present study is to perform a dynamic load analysis of rail tracks with the objectives as listed below:

1. To develop a methodology which can identify the critical behaviour of a ballasted rail track as well as ballastless rail track using a three-dimensional finite element ballasted track model under moving load.
2. To assess and scrutinize the existing dynamic impact factor formulations given in literature and suggest a new formulation based on finite element analysis.

1.6 Thesis organisation

The thesis is organized as follows:

1. Chapter 1: This chapter initiates the thesis by discussing about the increasing demand of high-speed railways and articulating the emerging transportation systems.
2. Chapter 2: This chapter deals with the literature studied based on different objectives.
3. Chapter 3: This chapter explains the finite element analysis adopted for the determination of critical speed of a ballasted rail track.
4. Chapter 4: This chapter deals with the analysis of geosynthetic reinforced earth (GRE) embankments supporting railway track subjected to moving load.
5. Chapter 5: This chapter explains the moving load finite element analysis on ballastless railway track, specifically, on embedded track system placed over cohesive subgrade.
6. Chapter 6: This chapter outlines the major conclusions drawn from the present study.

Chapter 2

Literature review

The literature survey conducted in the present study covers detailed mechanisms for analysing the dynamic responses of a rail track system. The literature survey chapter is divided into sections based on the objectives stated in Chapter 1. The sections were further divided based on the type of procedures adopted, i.e., mathematical modelling; simulation of rail track geometry using a numerical method (FEM, DEM, FDM); laboratory prototype testing; and field testing.

2.1 Literature on determination of critical speed of railway tracks

The critical speed, similar to the resonant frequency for a structure, causes the highest vibrations in a railway track structure.

2.1.1 Laboratory models and field observations of railway tracks

Quinn et al. (2010) reported the results of an investigation into the mechanical and aerodynamic forces acting on ballast particles that are generated during the passage of a high-speed train and addresses the question whether these might offer a possible explanation for the initiation of ballast flight.

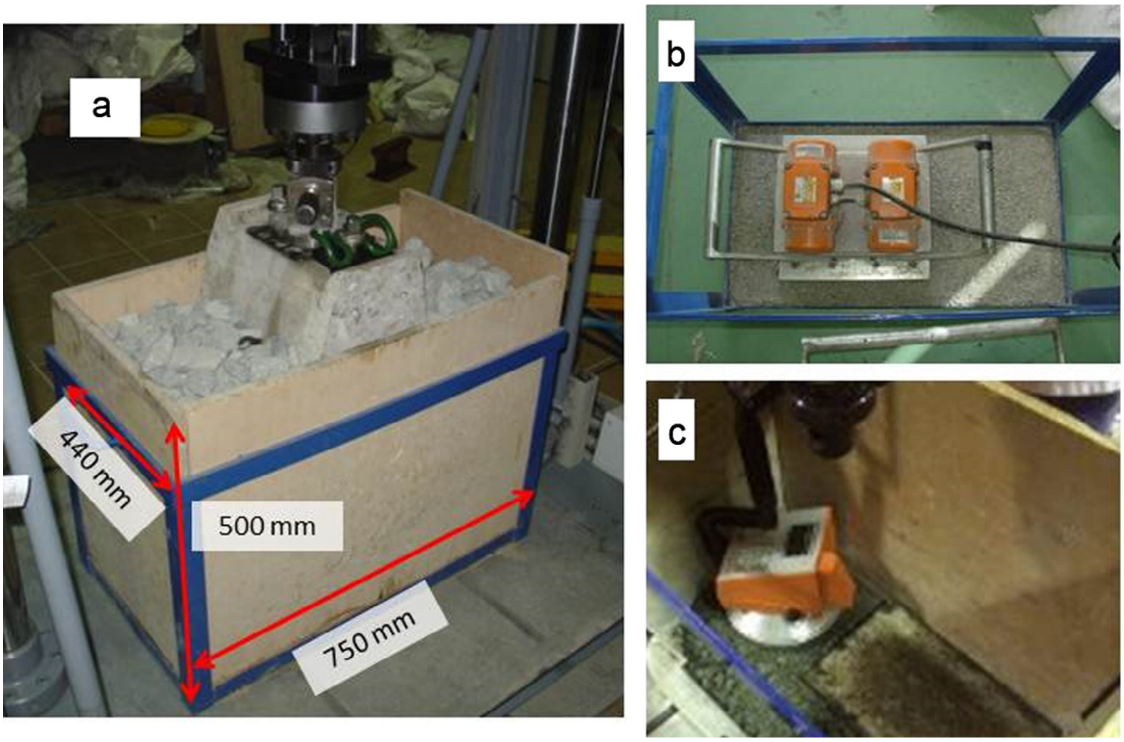

Figure 2.1: Images from Sol-Sánchez et al. (2016) (a) the box used for the study, (b) the compaction of a sandy layer to simulate the subgrade, (c) and a control of the compaction of granular layers.

In addition, Sol-Sánchez et al. (2016) performed a lab experiment (Figure 2.1) on distinct sections of track for evaluating the impact of different types of elastic components having diverse properties, different kinds of subballast, and varied ballast layer thicknesses. The results of the study showed that lowering the track's stiffness by adjusting the elastic elements above the ballast surface enhances the efficiency of the track to attenuate energy and lower the settlement.

2.1.2 Beam on elastic foundation approach of railway tracks analysis

The most widely used method for railway track analysis in the literature is the beam on elastic foundation (BOEF) mechanism. The primary approach is to simplify the railway track as the BOEF (the Euler-Bernoulli or Timoshenko beam equation) to calculate its critical speed. There are different mathematical approaches based on BOEF model, which can be represented by Eq. 2.1 (Kumawat et al., 2019). Eq. 2.1 represents the effect of wheel load on a beam (rail) placed on the elastic foundation (ballast, subballast, and subgrade) (Mallik et al., 2006).

$$p(x,t) = E_S I_S \frac{\partial^4 w}{\partial x^4} + q(x,t) + \rho_S \frac{\partial^2 w}{\partial t^2} + c_S \frac{\partial w}{\partial t} \tag{2.1}$$

Where w (x,t) is the beam's transverse deflection (m); x is the space coordinate assessed along the beam length (m); t denotes the time (s); I_S represents the rotational inertia about the neutral axis of the beam cross-section (m^4); E_S is the modulus of elasticity material (N/m2); q (x,t) represents reaction through ballast to the beam (N/m); ρ_S is the mass/unit beam length (kg/m); p (x,t) is the common time-dependent distributed vertical load (N/m) that acts on the beam; and c_S denotes the viscous damping coefficient per/unit beam length ($N.s/m^2$).

2.1.3 Dispersion spectrum analysis of railway tracks

Sheng et al. (2003) compared the theoretical ground vibration model (Figure 2.2) utilizing the ThompsonHaskell method as an effective method for soil dispersion graph computation with measured data at three locations. The model included both quasi-static and dynamic excitation mechanisms. A semi-analytical approach to a 3D layered ground is coupled to the dynamics of various vehicles traveling at a constant speed on an infinite track.

Zhai et al. (2015) measured ground vibration in the field on the Beijing to Shanghai high-speed railway line in China. The obtained measurements of vertical ground accelerations

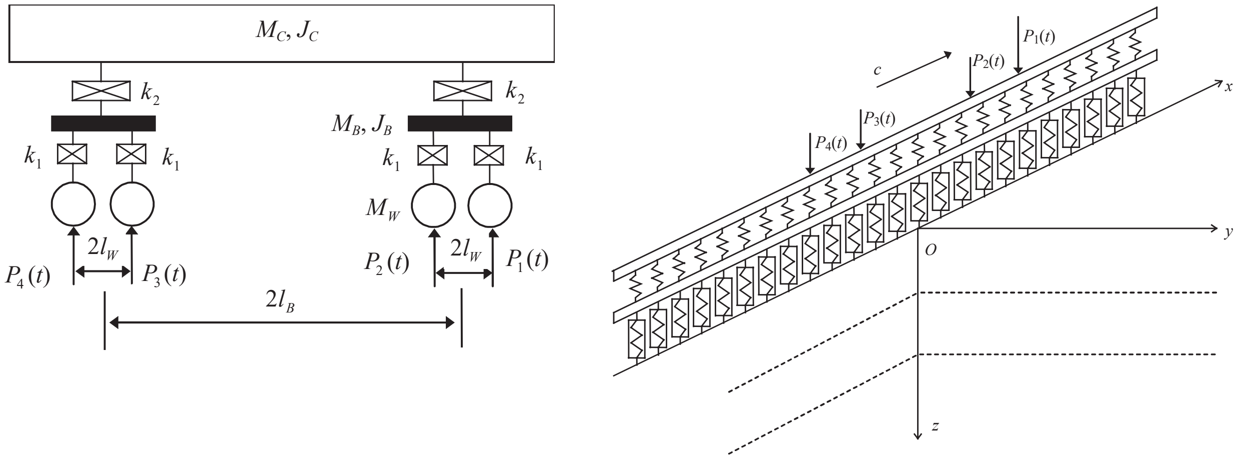

Figure 2.2: Models of vehicle (left) and track-ground system (right) from Sheng et al. (2003)

generated due to very high-speed trains traveling at speeds ranging from 300-410 km/h on a ballastless track over an embankment are noted and thoroughly analysed. The test data is used to examine the attributes of ground accelerations in both the frequency and time domains.

2.1.4 Finite element simulation models of ballasted railway tracks

The inclusion of plasticity and three-dimensional geometry is possible with finite element modelling, thus, it will be a better method to estimate the critical speed. Most modern researchers employ the finite element method (FEM) with dynamic loading to estimate critical speed. Literature shows two-dimensional (Nsabimana and Jung, 2015) as well as three-dimensional (Hall, 2003; Banimahd et al., 2013; Chen and Zhou, 2018; Li et al., 2018) rail track models for dynamic loading. The two-dimensional rail track models can not represent limited width layers (e.g., sleepers, ballast, and subballast). Based on the objectives, FEM studies use purely elastic material models for track structure Feng (2011); Bian et al. (2016); Tang et al. (2019) or elastoplastic material (Chen and Zhou, 2018; Li et al., 2018). The elastic material models are generally adopted for ballastless (slab) tracks as the deformations occur mostly in the elastic range. The elastoplastic materials are best to represent the granular materials in ballasted tracks.

2.2 Literature on dynamic impact factors of railway tracks

Railway tracks due to a movable load encounter a dynamic influence that can be expressed in terms of dynamic impact factor (DIF), one of the most important design parameters for railway tracks. The DIF summarises the dynamic impacts of moving load, wheel-rail interaction, and track irregularities altogether. The dynamic or quasi-static load (F_{dyn}) at a specified speed is divided by the static or stationary wheel load (F_{sta}) to get the DIF as shown in Eq. 2.2.

$$DIF = \frac{F_{dyn}}{F_{sta}} \tag{2.2}$$

To assess DIF, numerous railway organizations and codes suggest empirical correlations (Van Dyk et al., 2017; Doyle, 1980), as shown in Table 2.1.

The evaluation and verification of DIF formulas utilising field measurements and mathematical modelling by Gu et al. (2008) and Gu and Franklin (2010) were done at low-speed ranges of about 40-50 km/h. Thus, its scrutiny at higher speeds is the need of the hour. In the literature, the simulation-based methodology to DIF evaluation is almost non-existent.

Table 2.1: DIF formulations from literature

Source	DIF
Indian Railways (Srinivasan, 1969)	$1 + \frac{V}{58.14\sqrt{U}}$
South African Railways (Doyle, 1980)	$1 + \frac{4.92V}{D}$
Clarke (Doyle, 1980)	$1 + \frac{19.65V}{D\sqrt{U}}$
AREA (Hay, 1982)	$1 + \frac{5.21V}{D}$
German Railways (Schramm, 1961)	$1 + \frac{V^2}{3\times10^4}$
WMATA (Prause et al., 1974)	$(1 + 0.00003862V^2)^{\frac{2}{3}}$
Eisenmann (Esveld, 2001)	$1 + \delta\eta' t$

Note: V is speed (km/h), D is wheel diameter (mm), U is track modulus (MPa), δ is coefficient related to track maintenance parameter, η' is speed-dependent coefficient and t is a statistical parameter

Chapter 3

Conclusions and suggestions for future research

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1. Name Surname, Naem Surnm, and Nme Surnm. Paper on rail transportation. Structures, 12:732-743, 2022. doi:10.1016/j.istruc.2023.08.005. (Impact Factor = 4.01).

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