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Rail Vehicle-Track Interaction in Bridge Transition Zone using Multibody-Dynamic Approach

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Abstract

Track transition zones are areas where the track changes its alignment or elevation, like switches or bridges. They are prone to wear and tear from train stress, leading to higher maintenance costs. Monitoring and upkeep are crucial for safety and longevity. This study investigates the critical issue of differential settlement within the transition zone of railway tracks. Differential settlement poses significant challenges to track stability and operational safety. In this research, settlement variation along the track length is modeled linearly and uniformly. The track and rail vehicles are comprehensively modeled using a multi-body approach, with dynamic analysis conducted utilizing the ADAMS/VI-Rail software. This research provides the variation of force in rail-to-ground connection along the track near the transition zone where differential settlement takes place after a few periods(months) of operation. This force variation will help in the design of the transition zone structure.

Keywords: multi-body modelling, transition zone, hanging sleeper, sleeper void, passenger train, freight train.

1 Introduction

Nowadays, developing countries across the globe are upgrading their railway network and increasing their average train running speed. They are dealing with recent problems, and the transition zone is heavily reviewed from the perspective of railway upkeep and safety in each of them. Transition zones are the locations in the track where vertical stiffness changes and differential settlement of the track takes place (when the foundation settles unevenly), and they amplify the dynamic forces acting on the track[1]. This amplification enhances the deterioration of the ballast and subgrade.

Differential settlement is the slow process in which the sleeper loses its connection with the ground, and such sleepers are generally called hanging sleepers, and the gap between the sleeper and ground is called sleeper void. A comprehensive study on the transition zone track settlement is done by Wang and Markine[2]. Typically, these sleepers are located in close proximity to engineering structures such as bridges, culverts, tunnels, and level crossings. When analysing the dynamic behaviour of a railway vehicle in terms of vehicle-track interaction, the most common and favoured method is to model the vehicle using a multibody system approach and treat the track as a rigid structure.

Zhang and colleagues [3] proposed a model for vehicles that conceptualizes them as multi-body systems. Their approach represents the track as a three-layered structure composed of rails, sleepers, and ballast masses. In the model, each rail is treated as a Timoshenko beam supported by distinct sleepers, allowing for the analysis of lateral, vertical, and torsional beam deformations. Shabana and Sany [4] conducted research that specifically examined the computational techniques used to predict the dynamic impacts resulting from the structural flexibility of vehicle components and rails. The study also investigated the interaction between several interconnected railway trains on tracks with varying geometries. The research also examined topics such as derailments caused by gauge widening, three-dimensional wheel/rail contact, the interactions among vehicles and tracks, and the dynamics of high-speed vehicle transit.

Sañudo et al. [5] suggest using existing infrastructure and superstructure solutions to tackle problems in transition zones. It is emphasized that the kind of platform has an impact on the necessary improvements for both components. As per the UIC 719 R criteria, the optimal platforms are built using either Q3 soil or P3 supporting layers. Sayeed and Shahin [6] conducted research investigating the distribution and transmission of deviatoric stress in the substructure layers of railway tracks. An innovative three-dimensional finite element modelling approach was used to meticulously investigate the track deflections. The research investigated several train-track-ground situations and included the application of actual moving train loads. In their study, Wang et al. [7] conducted an experimental investigation on three separate transition zones, each subjected to different situations. The primary objective of their research was to quantify the dynamic displacements of the rail at various places in the approaching zone. They used a contactless mobile device that relied on the Digital Image Correlation (DIC) approach to evaluate the displacements.
Zhai, Wang, and Cai [8] created a new model that focuses on theoretical modelling, numerical simulation, and experimental validation to assess the dynamics of vehicle-track systems. A three-dimensional model was created to depict a passenger vehicle train as a multi-body system with 35 degrees of freedom. A ballasted track consists of

sleepers and ballasts and is depicted as two parallel beams supported by a separate elastic base.

In this paper, the author studies coupled vehicle track dynamic analysis in a bridge transition zone while considering the ten hanging sleepers in the embankment of the bridge transition zone.

2 Methods

This section covers the modelling of the railway system, including the track and train coach. It delves into the details of key subsystems like the bogie, car body, and wagon.

2.1 Track Modeling

The bridge transition section has varying stiffness track properties. Due to this, the track's modelling is slightly different. The embankment portion is taken as flexible, and the bridge portion is rigid. The track affects the vehicle's dynamics, and it is modelled separately in the ADAMS/VI-RAIL using the Flex Track Plugin.
The Flex-track plugin in VI-Rail ADAMS is designed to simulate flexible tracks within the virtual environment. By incorporating the Flex Track plugin, users can analyze the dynamic behavior of the railway system, including interactions between the train and the flexible track. This plugin enhances the fidelity of simulations, enabling more comprehensive studies on the performance and behavior of railway vehicles under different operating conditions.

The Flexible connection is represented through lumped parameters, and the sleeper-to-ballast connection is represented using linear bushing as indicated in Figure.1

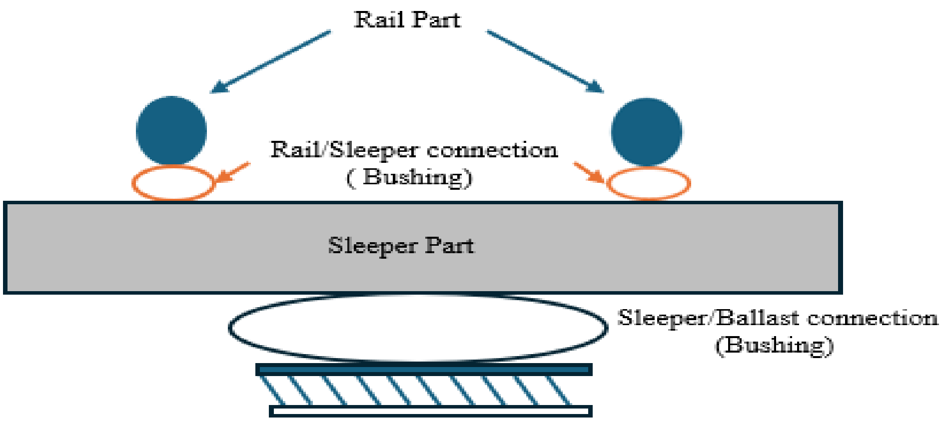


Figure 1: Details of rail to ballast Connection

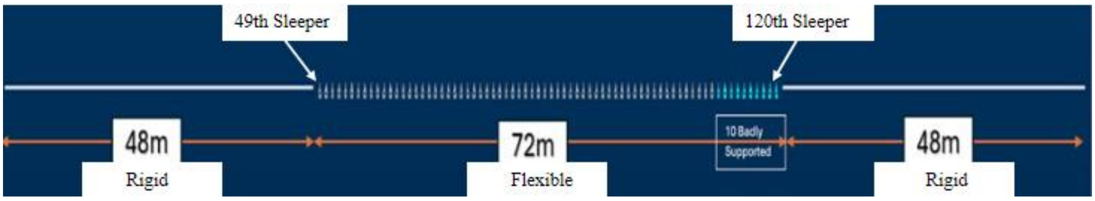


Figure 2: Track Model

The transition zone is divided into two sections: bridge to embankment (rigid to flexible) and embankment to bridge (flexible to rigid). The modelling approach is based on the methodology outlined by Wang and Markine [1], with a modification in our model that introduces a Rigid-Flexible-Rigid configuration, representing a bridge-embankment-bridge structure and differential settlement is considered in the embankment to bridge portion because it is more critical to bridge to the embankment.

The rail profile taken is UIC60, Young's modulus of the rail is 210 GPa, and the broad gauge is taken 1676 mm

Table 1: Properties of track

Base Busing Properties		Rail Bushing
Parameter	Value	Value
Lateral stiffness	3.7×10^7 N/m	4.3×10^7 N/m
Lateral damping	2.4×10^5 Ns/m	2.4×10^5 Ns/m
Vertical stiffness	1.0×10^9 N/m	5.0×10^7 N/m
Vertical damping	1.0×10^6 Ns/m	2.0×10^5 Ns/m
Rolling stiffness	1.0×10^6 N/m	1.0×10^7 N/m
Rolling damping	1.0×10^4 Ns/m	1.0×10^4 Ns/m
Torsional stiffness Y	1.0×10^7 Nm/rad	1.0×10^7 Nm/rad
Torsional stiffness Z	1.0×10^7 Nm/rad	1.0×10^7 Nm/rad
Torsional damping Y	1.0×10^4 Nms/rad	1.0×10^4 Nms/rad
Torsional damping Z	1.0×10^4 Nms/rad	1.0×10^4 Nms/rad

Figure 2: illustrates the track model, indicating that the transition from bridge to embankment begins at 48m and the transition from embankment to bridge starts at 120m. In the zone from the embankment to the bridge, there are ten poorly supported sleepers.

2.2 Multibody Model of Coach

A rail coach consists of a car body and bogies, all of which are modelled using a multibody approach. For simplicity, the author has excluded the braking and electrical systems from the models. These models are detailed in the following sub-section.

2.2.1 Train 18 (Vande Bharat)

Train 18, often referred to as Vande Bharat Express, is India's first domestically-produced semi-high-speed train. Produced by the Integral Coach Factory (ICF) located in Chennai. It represents a significant advancement in Indian Railways' modernization efforts. Train 18 is designed for efficiency and speed, with a maximum operating speed of 160 km/h. The train's design is aerodynamic, and it offers a smooth and quiet journey for passengers.

Modelling of Bogie

The bogie model encompasses various essential components, including the wheelset, bogie frame, dampers, and suspension, as shown in Figure 3. To maintain simplicity, the author omits the traction motor and gear system from our considerations. We gather geometric and technical parameters from the RDSO[7], Vande Bharat Maintenance manual[8], and established literature in the field.

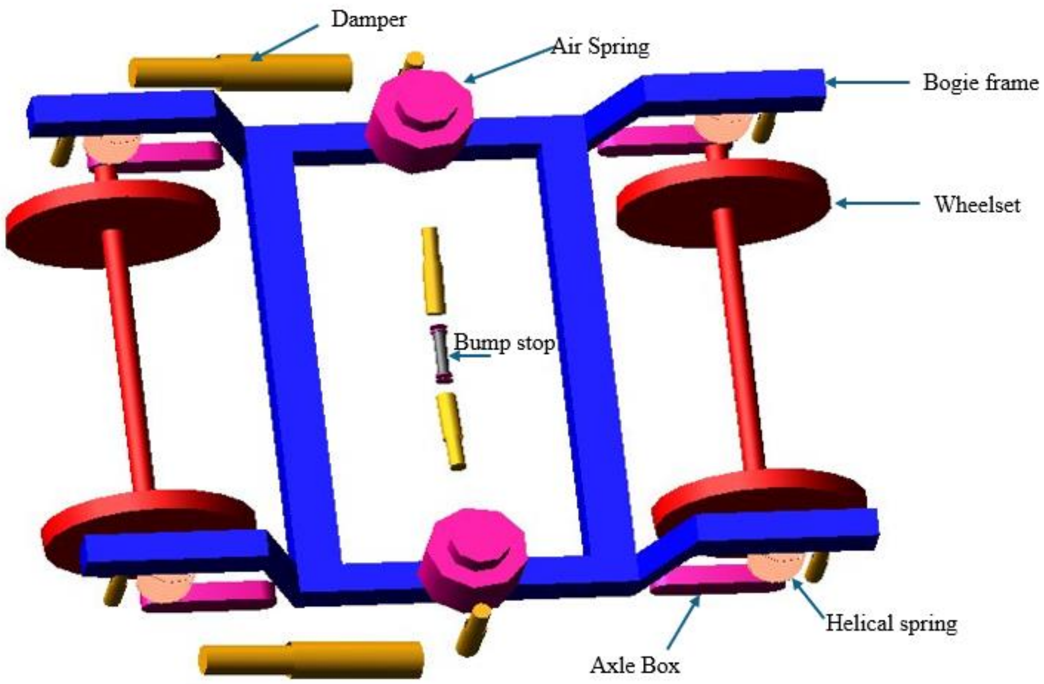


Figure 3: Multibody Modle of Train 18 Bogie

Modelling of the car body

The car body significantly influences the dynamics of rail vehicles due to the variations in load it experiences. Simplifying the system, we typically model it in two scenarios: tare load and gross load. In the case of tare load, the car body carries only its weight. However, with gross load, it must accommodate the sum of the passenger's luggage, weight of freight and tare load. This distinction allows for a more comprehensive understanding of the vehicle's behavior under different loading conditions. The car body's dimensions are 24 m in length, 3.24 m in width, and 4.14 m in height. Additionally, it has a mass of 30.45 tons.

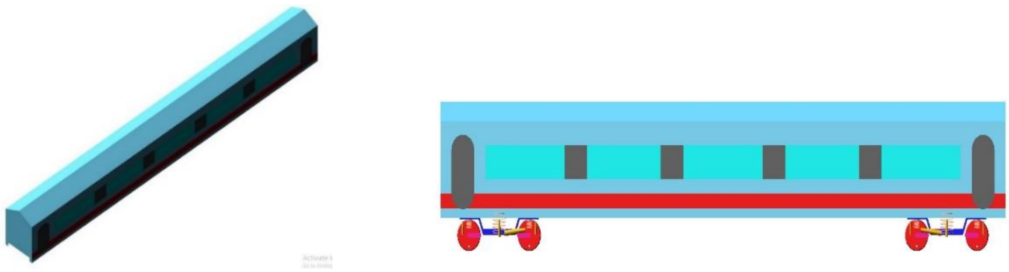


Figure 4 : (a) Car Body (b) Train 18 Coach

Similarly, the Linke Hofmann Busch (LHB) coach multibody model is built in the ADAMS/Vi-rail by using their respective data.

2.2.2 BOXN Wagon

The BOXN wagon, or Bogie Open Box Wagon, is a freight wagon type utilized by Indian Railways for transporting bulk materials. It features a pneumatic brake system and is mounted on two cast steel high-speed bogies(Casnub Bogie) with four 22.91-ton axle load wheel sets.

Modelling of Casnub Bogie

The bogie model encompasses various essential components, including the wheelset, side frame, bolster, friction wadge, axle box, centre plate, and suspension. To maintain simplicity, the author has omitted the braking system from our considerations. The author has to gather geometric and technical parameters from reliable sources such as the RDSO, Casnub bogie maintenance manual, and established literature.

Figure 5: Casnub Bogie Source Indian Railway

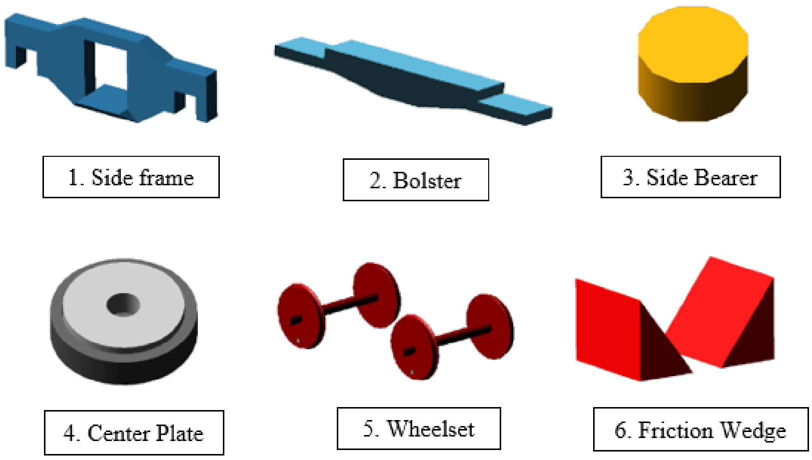
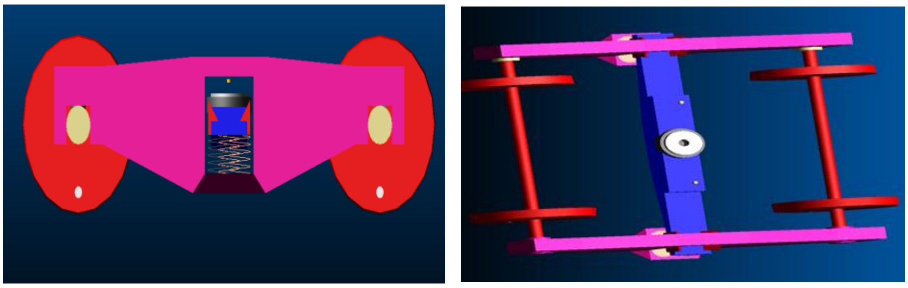


Figure 6: Main Components of Casnub Bogie



(a) (b)

Figure 7 : (a) Side view (b) Top view of Casnub Bogie

Referring to Figure 6, the bogie frame supports the entire bogie assembly and connects it to the railcar, while wheelsets(5) with axles and wheels support and propel the train. The bogie bolster(2) supports the weight of the railcar and distributes it to the wheelsets. Side frames(1) provide lateral stability and connect the wheelsets.

Primary suspension, often made of elastomeric pads, absorbs impact and vibrations between the bogie frame and wheelsets. Secondary suspension, consisting of springs (inner, outer, and snubber), improves ride quality, stability, and weight distribution. Friction wedges(6) are key for adjusting springs and maintaining smooth, stable operation, reducing wear and tear. The centre plate(4) provides a pivotal connection between the bogie and railcar body, distributing weight evenly and absorbing operational forces for stability and durability. Side bearers(3), a clearance type, utilize rollers with each bogie, sharing load only during motion on curved tracks. Load transfers primarily through the centre pivot during straight motion.

Modelling of Car body

The car body significantly influences the dynamics of rail vehicles due to the variations in load it experiences. Simplifying the system, we typically model it in two scenarios: tare load and gross load. In the case of tare load, the car body carries only its weight. However, with gross load, it must accommodate the sum of the weight of freight in addition to the tare load. This distinction allows for a more comprehensive understanding of the vehicle's behavior under different loading conditions. The car body's dimensions are 9.784 m in length, 3.111 m in width, and 2.3 m in height. Additionally, it has a mass of 1920kg. We use the same track for both the BOXNS Wagon and Train 18 analysis.

3 Results

In this section, the author has discussed the variation of force in rail and its connection for different sets of Railway vehicles.

3.1 Train 18 (Vande Bharat)

Two coach Train 18 (Vande Bharat) passenger train is simulated at 220 km/hour with tare load, and the results are shown below.

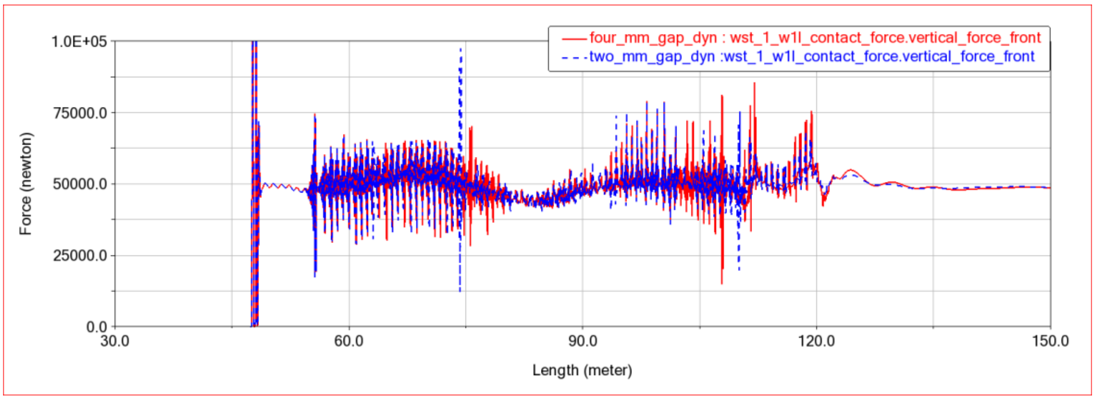


Figure 8: Wheel Rail Contact Force along the track

Figure 8 illustrates the changes in wheel-rail contact force along the track. The plot begins with a significant variation in force due to the need to overcome the vehicle's inertia. The plot superimposes track conditions with 2mm and 4mm poorly supported tracks. In areas with good sleeper conditions (zero sleeper void), the blue and red curves nearly overlap, indicating similar force values. However, in zones with hanging sleepers, the wheel-rail force values are higher with a 4mm sleeper void, supporting the findings of Wang et al. [1].

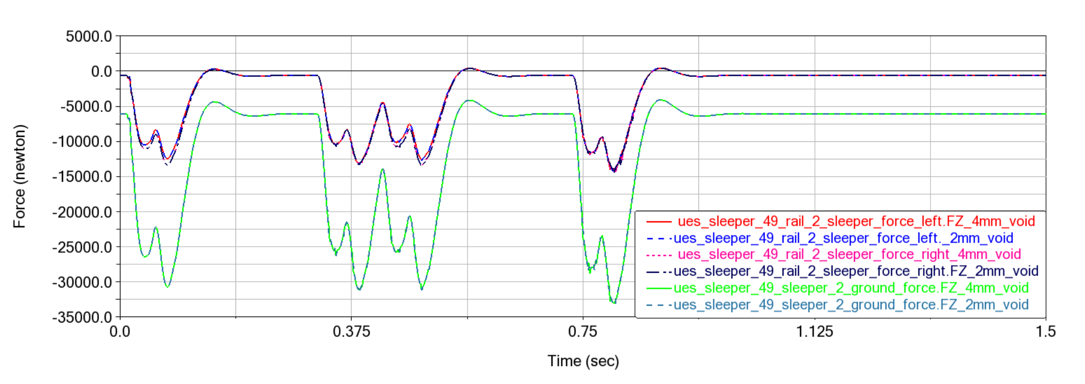


Figure 9: Contact force at 49th sleeper

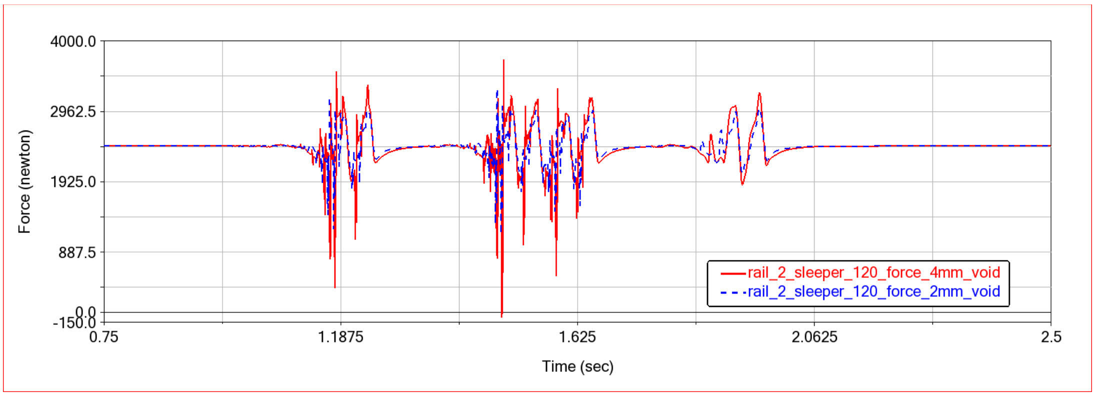


Figure 10: Contact force at 120th sleeper (badly supported)

Figures 9 and 10 show the transfer of force from the rail to the ground. In between, there is a sleeper when the train passes at a speed of 220km/hour. The nature of forces in the sleeper are different because in the 120th sleeper, we have given the sleeper void 4mm and 2mm. In Figure 9, the force variation in the sleepers follows a W-shaped pattern, attributable to the superimposed forces from the first bogie wheelsets. The proximity of the intermediate W-shaped forces can be explained by the closeness between the rear bogie of the first coach and the front bogie of the second coach, which is closer in comparison to the distance between the front and rear bogie of each coach. There is a vertical shift in the force transfer from the rail to the sleeper and from the sleeper to the ground, primarily due to the sleeper's self-weight.Figure 10 shows the variation of rail-to-sleep force at the 120th sleeper. The variation of a sleeper of ground at 120th sleeper is zero, and it is also justified because there is a gap between sleep and ground.

3.2 LHB Coach

A coach LHB passenger train is simulated at 160 km/hour with an axle load of 16.25 Ton, and the results are shown below.

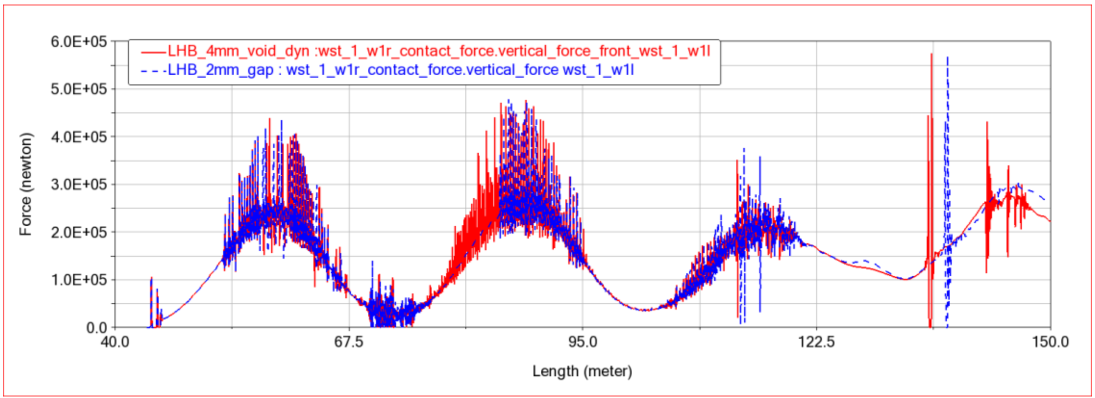


Figure 11: Wheel Rail Contact Force along the track

Figure 11 displays the variation of wheel-rail contact force along the rail track. The force variation follows a sine wave pattern, which is attributed to the assumption that the centre of mass of the car body remains consistent under both tare load and gross load conditions.

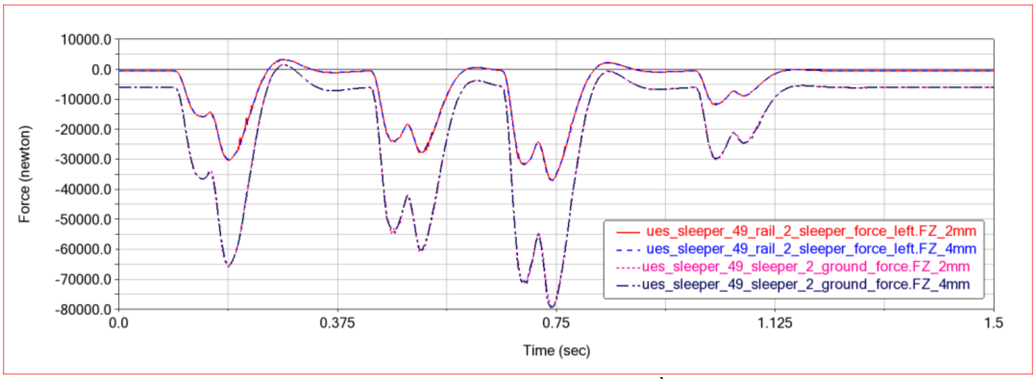


Figure 12: Contact force at 49th sleeper

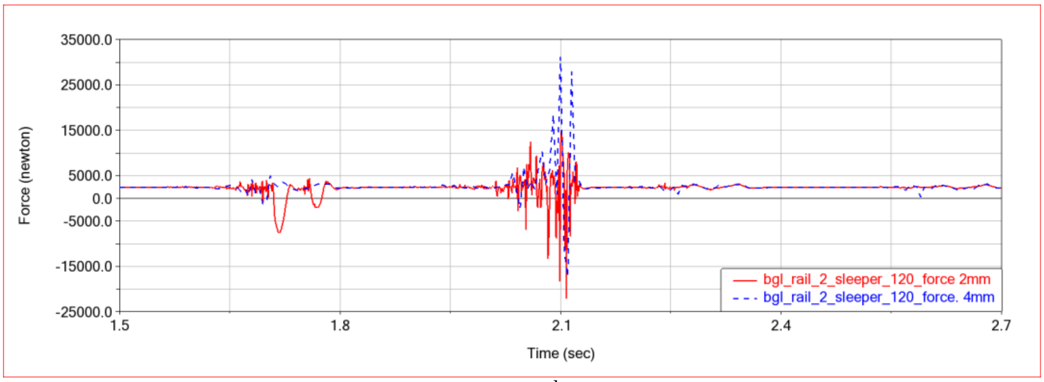


Figure 13: Contact force at 120th sleeper (badly supported)

Figures 12 and 13 show the transfer of force from the rail to the ground. In between, there is a sleeper when the train passes at a speed of 160km/hour. The nature of forces in the sleeper are different because in the 120th sleeper, we have given the sleeper void 4mm and 2 mm. In Figure 12, the force variation in the sleepers follows a W-shaped pattern, attributable to the superimposed forces from the first bogie wheelsets. The proximity of the intermediate W-shaped forces can be explained by the closeness between the rear bogie of the first coach and the front bogie of the second coach, which is closer in comparison to the distance between the front and rear bogie of each coach. There is a vertical shift in the force transfer from the rail to the sleeper and from the sleeper to the ground, primarily due to the sleeper's self-weight. Figure 13 illustrates the variation of force at the 120th sleeper (which is poorly supported) between the rail-to-sleeper force and two differential settlements of 2mm and 4mm. There is no force transfer occurring between the sleeper and the ground.
LHB shows the same trend as Train18. The only difference is the magnitude of the force.

3.3 BOXN Wagon

A wagon BOXN train is simulated at 120 km/hour with a tare load, and the results are shown below.

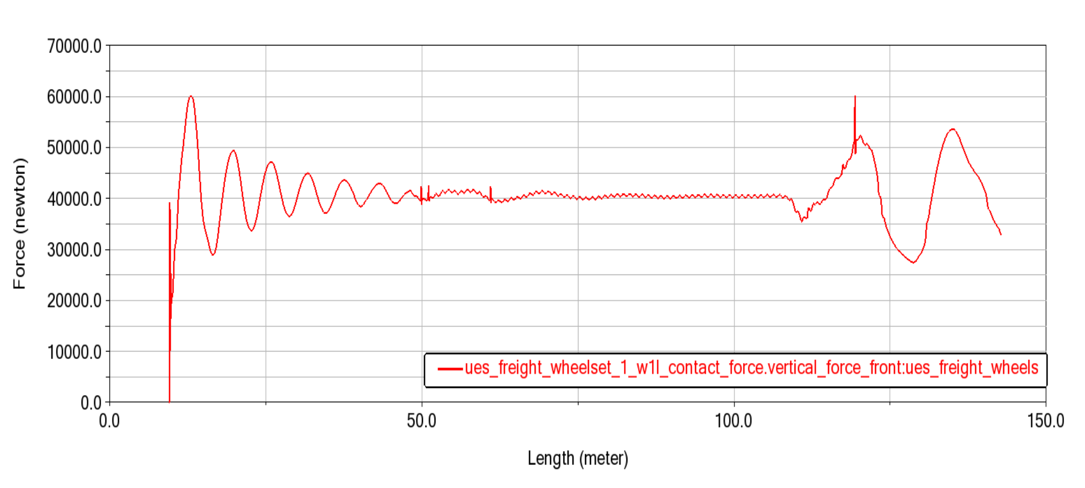


Figure 14: Wheel Rail Contact Force along the track

Figure 14 depicts the variation of wheel-rail contact force along the length of the track. At the beginning of the track, there is a significant variation in force as the vehicle overcomes inertia. After 110 meters, a spike in the force occurs due to the presence of a sleeper void.

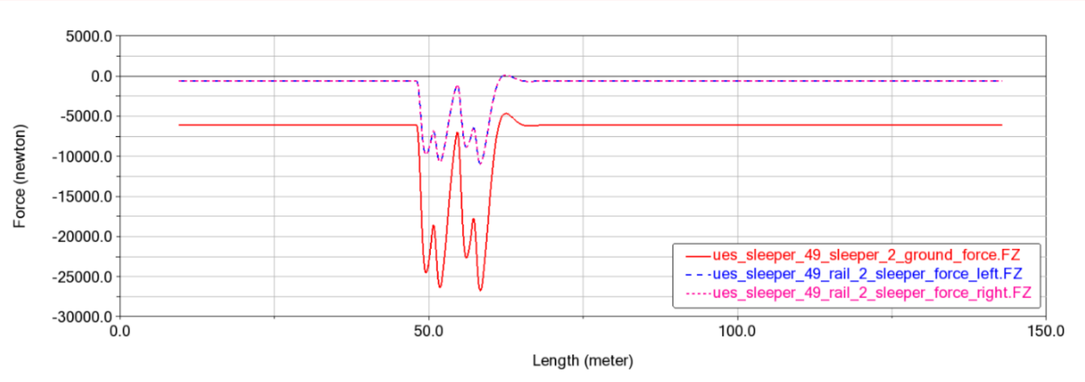


Figure 15: Contact force at 49th sleeper

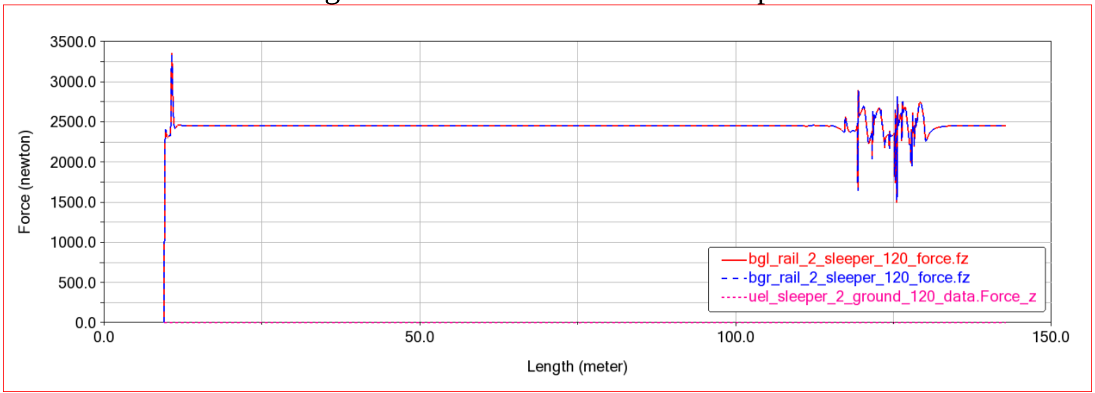


Figure 16: Contact force at 120th sleeper (badly supported)

Figures 15 and 16 show the transfer of force from the rail to the ground. In between, there is a sleeper when the train passes at a speed of 120km/hour. The nature of forces in the sleeper is different because in the 120th sleeper, we have given the sleeper a void of 4mm. In Figure 15, the force variation in the sleepers follows a W-shaped pattern, attributable to the superimposed forces from the first bogie wheelsets. The proximity of the intermediate W-shaped forces can be explained by the closeness between the rear bogie of the first coach and the front bogie of the second coach, which is closer in comparison to the distance between the front and rear bogie of each coach. There is a vertical shift in the force transfer from the rail to the sleeper and from the sleeper to the ground, primarily due to the sleeper's self-weight.BOXN Wagon shows the same trend as Train18 and LHB. The only difference is the magnitude of the force.

4 Conclusions and Contributions

The paper presents the modeling of track and vehicle dynamics using a multibody approach. In the transition from the embankment to the bridge, ten poorly supported sleepers were placed, each with a 4 mm and 2 mm void underneath. Simulations were conducted with the respective railway vehicles at their operating speeds to measure the variation of force from the rail to the ground. This data is crucial for designers

working on track transition zones, allowing them to optimize designs according to specific needs.
In reality, the differential settlement variation is nonlinear and could be modelled in future studies.

Acknowledgements

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References

[1] Wang, Haoyu, and Valeri L. Markine. "Methodology for the comprehensive analysis of railway transition zones." Computers and Geotechnics 99, 64-79, 2018

[2] Wang, Haoyu, and Valeri Markine. "Modelling of the long-term behaviour of transition zones: Prediction of track settlement." Engineering structures 156, 294-304, 2018

[3] Zhang, Shuguang, et al. "Effect of unsupported sleepers on wheel/rail normal load." Soil Dynamics and Earthquake Engineering 28.8, 662-673, 2008

[4] Shabana, Ahmed A., and Jalil R. Sany. "A survey of rail vehicle track simulations and flexible multibody dynamics." Nonlinear Dynamics 26,179-212 , 2001.

[5] Sañudo, R., Dell'Olio, L., Casado, J. A., Carrascal, I. A., & Diego, S. Track transitions in railways: A review. Construction and Building Materials, 112, 140-157,2016.

[6] Sayeed, Md Abu, and Mohamed A. Shahin. "Dynamic response analysis of ballasted railway track–ground system under train moving loads using 3D finite element numerical modelling." Transportation Infrastructure Geotechnology 10.4, 639-659, 2023.

[7] Wang, Haoyu, Valeri Markine, and Xiangming Liu. "Experimental analysis of railway track settlement in transition zones." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of rail and rapid transit 232.6 , 1774-1789, 2018

[8] Zhai, Wanming, Kaiyun Wang, and Chengbiao Cai. "Fundamentals of vehicle–track coupled dynamics." Vehicle System Dynamics 47, no. 11, 1349-1376, 2009.