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Dynamic Analysis of Ballastless Railway Track

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Abstract

In recent years, due to traffic congestions in road ways, the demand of high speed trains and heavier axle loads is increasing significantly. Therefore, the design of traditional railway tracks are now in a process of revolutionary change and the use of ballastless track is becoming popular for high speed trains. In this paper, an attempt is done to analyze the dynamic behavior of ballastless railway tracks. Hence, a three dimensional (3D) model of ballastless railway track has been created and the solution is done using a finite element based software named ABAQUS. It consists of three layers - a concrete bearing layer (CBL), hydraulically bonded layer (HBL), and frost protection layer (FPL, for freezing temperatures) over a subsoil base. In this study, FPL is silent and exchanged with a combination of HBL and CBL with variations in thickness. Mesh sizes are kept least to obtain the precise results and balance result precision and CPU time. Loading is done in the Static/Linear step and motion is performed in Dynamic/Implicit step. Broad gauge and UIC60 rails are used. In the current paper, the relationship between deformations verses various loading conditions and track conditions have been presented.

Keywords: *Ballastless Railway Track; Moving loads; Train Speeds; finite element modelling, ABAQUS.*

1 Introduction

Railway tracks are of two types according to the presence of ballast, i.e. ballastless track and ballasted track. The ballasted railway track substructure consists of three layers: ballast, sub-ballast and subgrade. All these are aggregate materials but with different properties i.e. grain size distribution, strength, CBR, and cohesion. The role of ballast is to transfer the load to the underlying layers. It absorbs vibrations from moving loads and also helps in drainage. Heavier wheel loads and excessive vibrations causes ballast fouling. Hence, it requires high maintenance cost. The fouled particles make the soil base impermeable, causing drainage problems, which is a major disadvantage of ballasted track systems. Such shortcomings motivates to develop an alternative, such as ballastless track systems.

In the ballastless track, sleepers rest on a concrete base layer (CBL) or asphalt base layer (ABL) below which a substructure is present. In this track, the ballast is replaced with a combination of CBL/ABL and elastic pads. Its design consists of anti-noise mechanisms and elastic pads to dampen the vibrations.

Though its initial cost is high, maintenance cost is negligible and it provides long-term benefits like reduction in life cycle cost and passenger comfort. There is uncertainty in calculating its overall behavior because any existing ballastless line has not yet completed the design period. This study will address the question of ballastless rail track design for high-speed trains.

To predict the dynamic behavior of ballastless railway track, the various methods are usually used: empirical methods, theoretical methods, numerical methods. Among various numerical methods (FEM, DEM, BEM, FE-BE), the finite element method (FEM) allows easier modelling for complex geometrical and irregular shapes, requires less computational time and gives higher degree of accuracy in results in continuum medium. Several researchers have used FEM for analysing the rail track model behaviours () . As in the early years, software technology was not so established that's why many researchers used only 2D mediums. Recently, some of the researchers have used 3D modelling for investigating the dynamic analysis of ballasted rail tracks. (Feng, 2011; Mallick et al., 2005). Mandhaniya and Chandra (2015) have considered moving load for analysis of the ballastless track. However, they did not investigate the rail track behaviour for different track-ground conditions. Main focus: investigating stress and deflection behaviour under various track-ground conditions as well as loading conditions.

2 MODELLING IN ABAQUS/CAE

ABAQUS/CAE uses graphical surface user (GUI) as well as a command-type interface for design and analysis. In this model, the GUI is used. The presented model consists of 5 deformable solid sections, which are subsoil, hydraulically bonded layer (HBL), concrete base layer (CBL), sleepers, and rails. The sleeper and rail are modeled as individual parts and the same pattern is used to replicate them over length. Sleepers are placed over CBL and rails over sleepers with tied constraints (mutual motion of contact surfaces). Fixed (Encastre) boundary condition is applied to all subsoil surfaces except at the top. All other surfaces are free from any kind of motion. Moving load is modeled as a wheel-axle assembly (half-bogie) of negligible mass loaded at its ends at the periphery placed over rails with general contact conditions including no friction. For motion, a half-bogie is coupled with the center of any wheel face and it is constrained with rigid body conditions as it should pass load to the structure but shouldn't deform itself by reactive force. The motion of half-bogie is studied using displacement boundary conditions over dynamic/implicit steps of different periods for different speeds.

Dimensions and properties of layers are given in Table 1. Also, a visual of the 3D model in ABAQUS is presented in Figure 1. The model is 50 meters long with rails dimensions similar to UIC60. Loads of 100kN at each wheel are applied (gross load = 200kN).

Table 1: Properties of the model components

Component	Dimension (m^3)	Mesh Size (m)	E (GPa)	Density (kg/ m^3)	Poisson's ratio
Rail	UIC60 (approx.)	0.2	207	7850	0.28
Sleeper	0.25×0.21×2.6	0.25	70	2400	0.2
CBL	3×0.25×50	0.25	35	2400	0.2
HBL	4×0.25×50	1	5	2400	0.28
Subsoil	12×12×50	1	0.03	2400	0.4

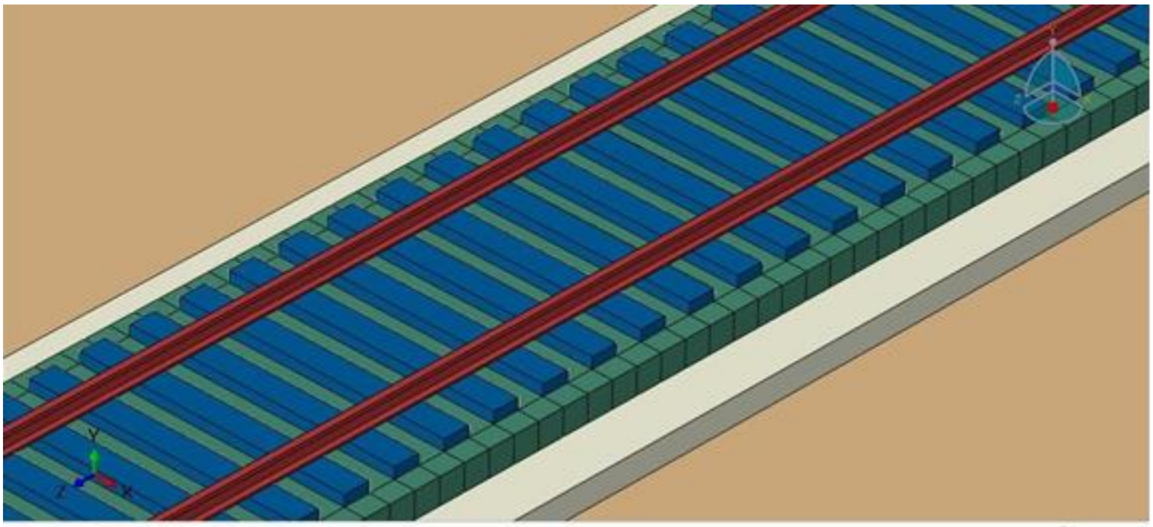

Figure 1. Assemble the model

3 DESIGN PHILOSOPHY

Choosing a length of 50m is adopted based on elaborate previous analysis. The problem with that model was that it cannot support the natural damping of displacement waves at higher speeds. If a wave is generated in any medium it will damp to almost zero amplitude at some point say infinity but an assumption is made about threshold amplitude below which there is a negligible displacement that will help reduce a problem from infinite length to finite length. Although the length and threshold amplitude can be manipulated to get finer results that require High Performance Computing (HPC).

Mesh sizes are kept minimum to achieve the desired results and scrutinize effects on the track. Also, the subsoil section is divided into two halves by cutting plane to retain less CPU time caused by symmetric mesh on both sides.

From the above, the accuracy of analysis can be improved by increasing model length, refining mesh sizes, and using less value of maximum increment in Dynamic/Implicit step. HPC can be used to decrease CPU time.

4 RESULTS AND DISCUSSION

In this paper, the deformation behavior of ballastless railway tracks were investigated for moving wheel load. Figure 2 shows the vertical deflection of ballastless railway track using the color band. It can be seen that maximum deflection occurs in railway track when the wheel passing the measurement point.

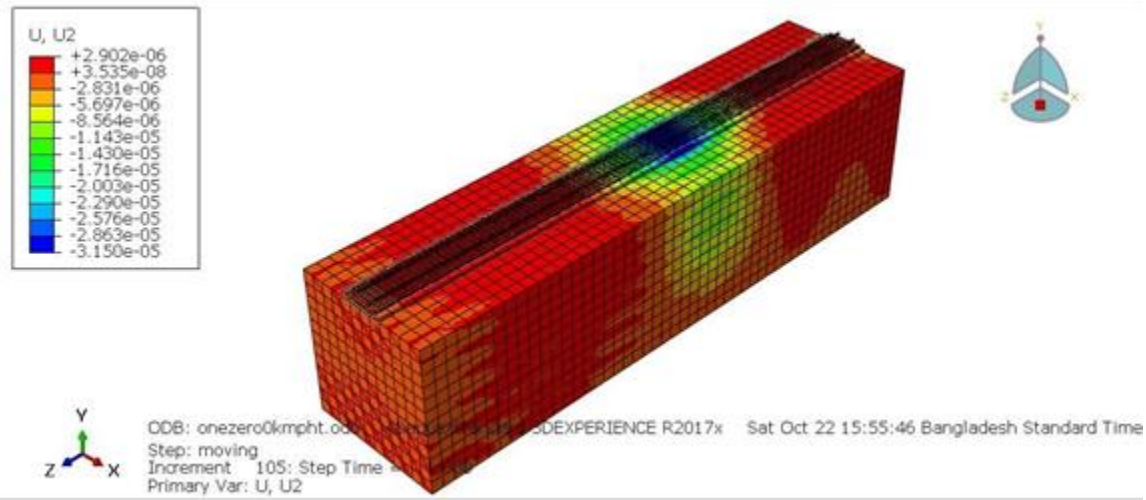

Figure 2. Simulation picture of modelling result

Figure 3 illustrates how the railway track deforms when subjected to moving loads of varying magnitudes. The results indicate that as the loading amplitude increases, the deformation of the track also increases.

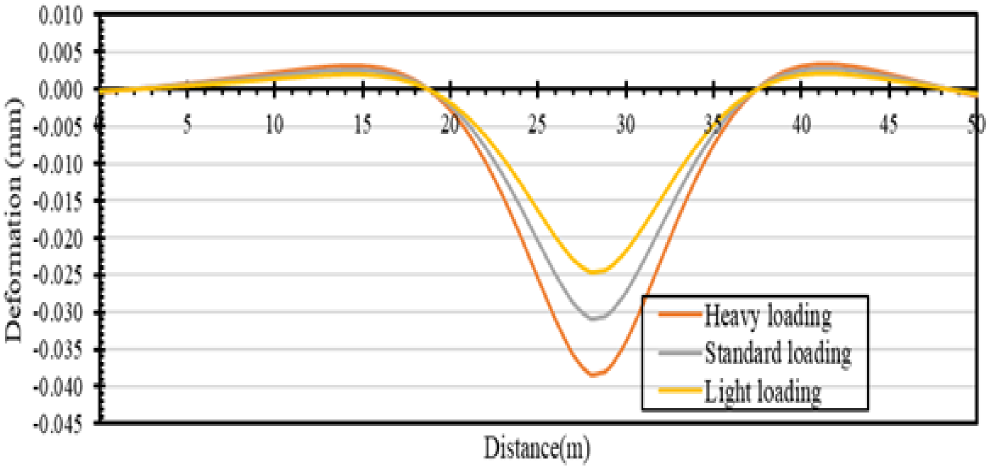

Figure 3. Deformation for various loading conditions

Figure 4 displays the stress levels experienced by the CBL layer when subjected to moving train loads of different magnitudes. The findings suggest that as the loading amplitude increases, the stress amplitude on the CBL layer also increases.

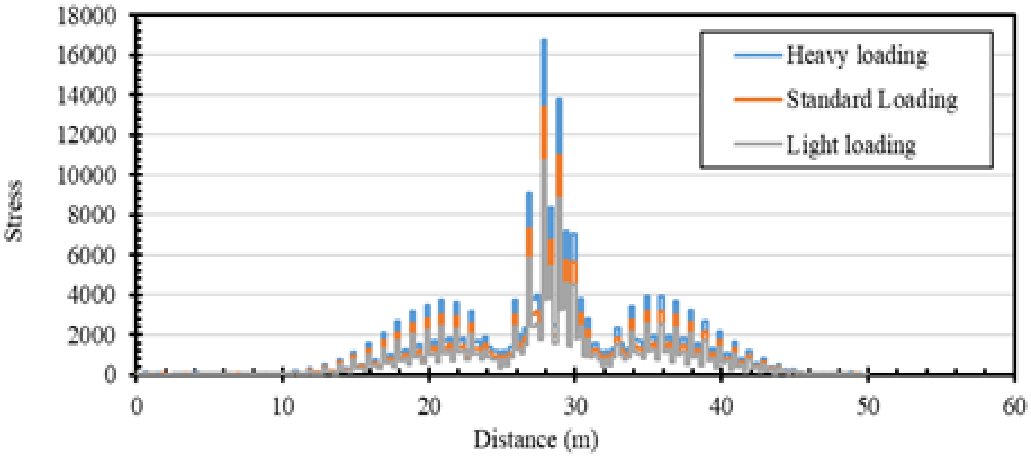

Figure 4. Stress for various loading conditions

The deformation behavior of ballastless railway track was also investigated for different modulus of elasticity of CBL layer, HBL layer and subgrade layer. Figure 5 shows the deflection of rail while the modulus of elasticity of CBL layer varies from 20 GPa to 50 GPa. It can be seen that the deformation of rail decrease with the increase of stiffness of CBL layer.

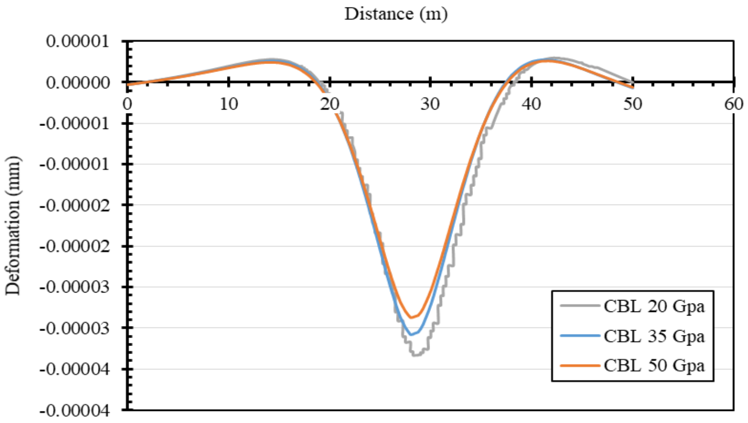

Figure 5. Deformation of rail for various modulus of elasticity of CBL

Figures 6 and 7 show the deformation of ballastless railway track for different modulus of elasticity of HBL layer and subgrade layer. To investigate the effect of HBL modulus of elasticity, 3 different values (i.e., 2.5 GPa, 5.0 GPa and 7.5 GPa) are considered. Similarly, to investigate the effect of subgrade modulus of elasticity, 3 different values (i.e., 0.01 GPa, 0.03 GPa and 0.09 GPa) are considered. In both cases it can be seen that with the increase of modulus of elasticity of materials, the deformation of railway track decreases.

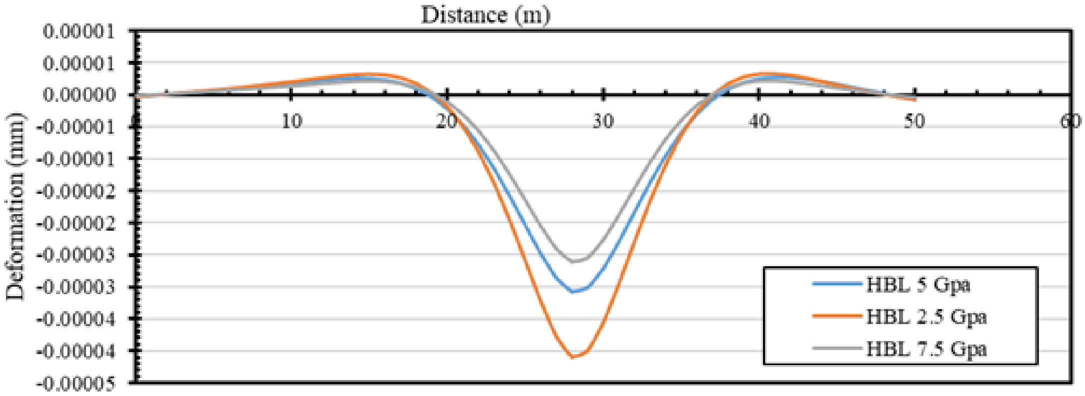

Figure 6. Deformation for various modulus of elasticity of HBL

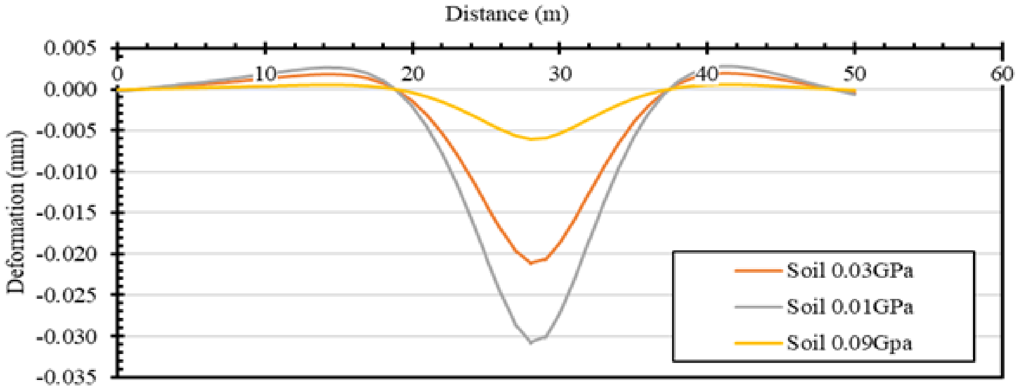

Figure 7. Deformation for various modulus of elasticity of Subsoil

6 SUMMARY AND CONCLUSIONS

In the current paper, a ballastless rail track was modeled using the 3D finite element method. The model qualitatively predicts the behavior of ballastless track. The following conclusions are observed:

- With the increase of the loading amplitude, the deformation of rail track increases.
- The stress amplitude on the CBL layer also increases with the increase of the loading amplitude.
- The deformation of rail track increases with the decrease modulus of elasticity of CBL layer, HBL layer and subgrade layer.

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