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Assessing the impact of ballast thickness under rail way on behavior of sub-ballast

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Abstract. Railways remain one of the most cost-effective means of transporting passengers and freight, and they offer a higher level of safety than road transport. Iraq possesses an extensive rail network linking its southern, central, and northern regions; however, much of this infrastructure is outdated, damaged, or degraded, and therefore requires regular maintenance. The construction of new rail lines that are low-maintenance, cost-efficient, and highly stable is thus a national priority. Achieving this goal presupposes a clear understanding of how rail tracks behave under train loading, which structural layer is most sensitive to variations in ballast layer thickness (H_b), and how deformations and stresses are distributed throughout the track system. This paper investigates the effect of H_b on rail deformation. Three finite element models with different ballast layer thicknesses were developed in ABAQUS 6.14-4. The values of H_b considered were 0.35 m, 0.40 m, and 0.45 m, while the sub-ballast thickness (0.20 m) and subgrade thickness (1.5 m) were held constant across all models. The results indicate that as H_b increases, both stresses and rail deformations decrease. The findings further show that the deformation at the ballast–sub-ballast interface for H_b = 0.45 m was lower than that observed for the models with H_b = 0.35 m and 0.40 m.

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1. Introduction

A more comprehensive understanding of the mechanical and physical behavior of the railway substructure, particularly the ballast layer, can significantly reduce the maintenance cost associated with ballasted track systems [1]. Recent research has therefore focused on the ballast layer thickness (H_b) and the layers beneath it. The depth and elastic modulus of the ballast were identified as the variables with the greatest effects on the stress distribution beneath the ballast layer [2].

A series of laboratory tests were conducted to investigate the stiffness characteristics of the clay, the quantity of geogrid layers, the ballast layer thickness and the positioning of the geogrid. Each of these factors was found to influence the behavior of the reinforced ballast layer. The testing employed three different ballast layer thickness: H_b = 0.20, 0.30, and 0.40 m, – with the ballast placed on top of 0.50 m of soft and stiff clay. Regardless of the ballast reinforcement, at H_b = 0.30 and 0.40 m, an increase in the applied load led to an increase in the vertical stress of both clayey soils. At H_b = 0.20 m, both the soil pressure and the uplift pressure increased relative to the 0.30 and 0.40 m cases.

This suggested that the ballast had effectively attenuated the generated waves [3]. The effect of ballast layer thickness and tamping repair on the displacement characteristics of ballasted rails were

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investigated through a series of cyclic loading experiments conducted on grounds model. Based on the results, when the roadbed compressibility is only moderately nonlinear, the standard H_b = 0.25 m is not effective in reducing settlement [4].

The stiffness of the ballast layer in railway tracks was also investigated. During the modeling process, three distinct ballast layers were constructed, and the stiffness of each layer was determined using a specifically developed pyramid model. The result indicated that the stiffness of the bottom ballast layer was up to 20 % higher than that of the middle and top layers [5]. A study of the track-ground system parameters that affect the critical speed included the modulus and thickness of the track subgrade as well as the materials used for the ballast. It was discovered that the ballast thicknesses and stiffness had no effect on the critical speed of the track-ground system [6].

A 2D plane-element model of the track superstructure was presented. Two parameters were found to exert the greatest influence on the shape of the load distribution: the elastic modulus and the ballast depth. A wider distribution of the vertical stress on the bridge track was observed at the greater depth of the ballast layer. Variations in ballast layer thickness had a more pronounced effect on the vertical stress distribution beneath the ballast layer than on the modulus of elasticity [7]. The finite element analysis (FEA) is a numerical method for estimating solutions to challenging engineering problems [8–11]. Since analytical solutions cannot be found for the majority of real-world engineering issues, numerical methods are required [12].

Since the principal objective of an ABAQUS user is to depict a particular circumstance or problem in order to ultimately discover a solution, the use of the program's native language becomes necessary; this includes building a model and analyzing it. These modules should be used to specify the geometry, characteristics of the materials, and other physical parameters before submitting the model for evaluation [13].

The objective of this research is to analyze the impacts of the railway ballast layer thickness on deformation distribution at ballast–sub-ballast and sub-ballast–subgrade interface from the detailed finite element models created in ABAQUS.

2. Materials and Methods

2.1. Ballast

A railway track consists of a superstructure and a substructure, which together comprise the following components:

- rails,
- rail pads,
- fasteners,
- sleepers,
- ballast,
- sub-ballast,
- subgrade.

The ballast is the topmost layer of the substructure where the sleepers are buried and consists of crushed granules of uniform size. Its main objective is to sustain the forces applied to the sleepers in all direction in order to keep the track in the intended position. It also makes maintenance tasks easier, lessens the stress that traffic causes on the subsurface layers, and offers drainage [14]. The ballast layer thickness should be selected to load the subgrade as uniformly as possible [15]. Elevated-quality railway ballast is characterized by a restricted number of hairline cracks, angular particles, a rough surface, a high specific gravity, a high shear strength, a high toughness and hardness, and a high resistance to weathering [16–17]. Ballast serves as a drainage layer, facilitating water removal to essential function in railway infrastructure and other transportation systems [18].

2.2. Sub-ballast

The sub-ballast is a granular layer located between the subgrade and the ballast. It reduces the stress transmitted from the ballast to the subgrade and improves drainage. Moreover, it prevents fine particles from the subgrade from migrating upward into the ballast, and lessens ballast-induced deterioration of the subgrade [19–20]. For sub-ballast material to be used in railway tracks, it must primarily drain freely and be locally available. A course, well-graded material should therefore be used for the sub-ballast [21]. Table 1 shows characteristics of each layer.

Table 1. Input properties of a layer.

Layer	Elastic modulus, kPa	Unite weight, N/m^3
Subgrade	11000	21000
Sub-ballast	81000	18500
Ballast	152000	15900

2.3. Geometry of ABAQUS Model

There were three models (Fig. 1) with H_b = 0.35, 0.4, and 0.45 m, the sub-ballast thickness of 0.2 m, and the subgrade thickness of 1.5 m. It is recommended to use a rectangular or square mesh for best accuracy and fastest meshing. The mesh needs to be configured so that rectangular or square pieces are formed [22–23].

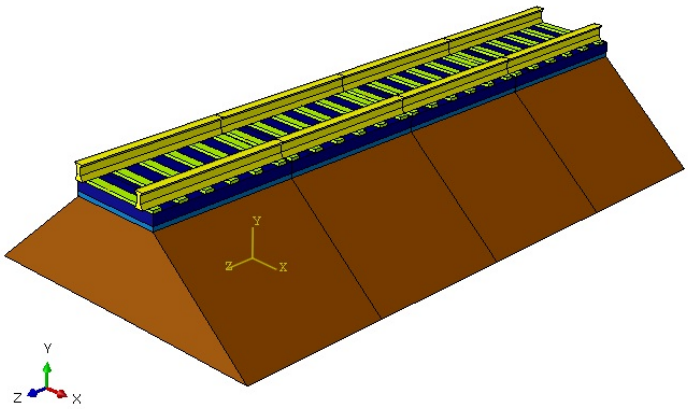


Figure 1. Railway model.

2.4. Finite Element Mesh

The entire model was built in ABAQUS using C3D8R finite element type, which can compute significant deformation [24–25]. In order to preserve the continuity of nodes across subsequent layers, the same geometry is simulated for each layer [13] as shown in Fig. 2.

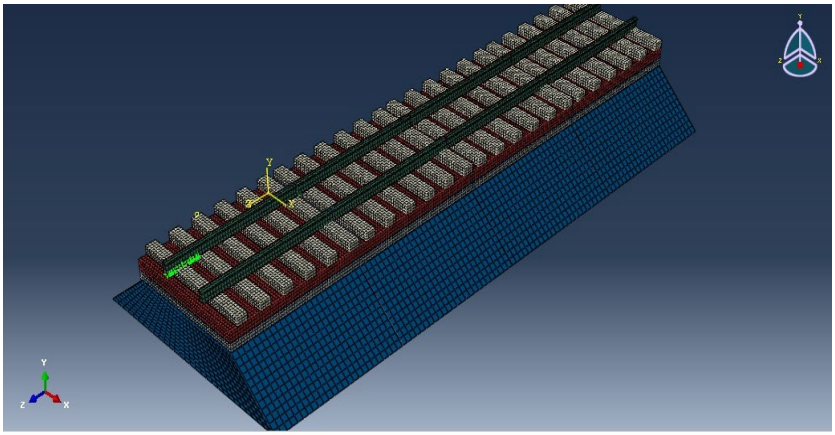


Figure 2. Mesh of all layers.

3. Result and Discussion

The results show that when the ballast layer thickness increases, the deformation at ballast–sub-ballast and sub-ballast–subgrade interface decreases and leads to reduction in the deformation of rails. Fig. 3, 5, and 7 show the time deformation relationships at sub-ballast at H_b = 0.35, 0.4, and 0.45 m, from which we noticed that the deformation in sub-ballast decreases with the increases in the ballast layer thickness. Also, Fig. 4, 6, and 8 show the deformations for model at H_b = 0.35, 0.4, and 0.45 m. Fig. 9 shows that the deformation in sub-ballast at Hb = 0.45 m is less than at H_b = 0.4 and 0.35 m. Fig. 10 shows that when the ballast layer thickness increases, the deformation in ballast–sub-ballast interface decreases.

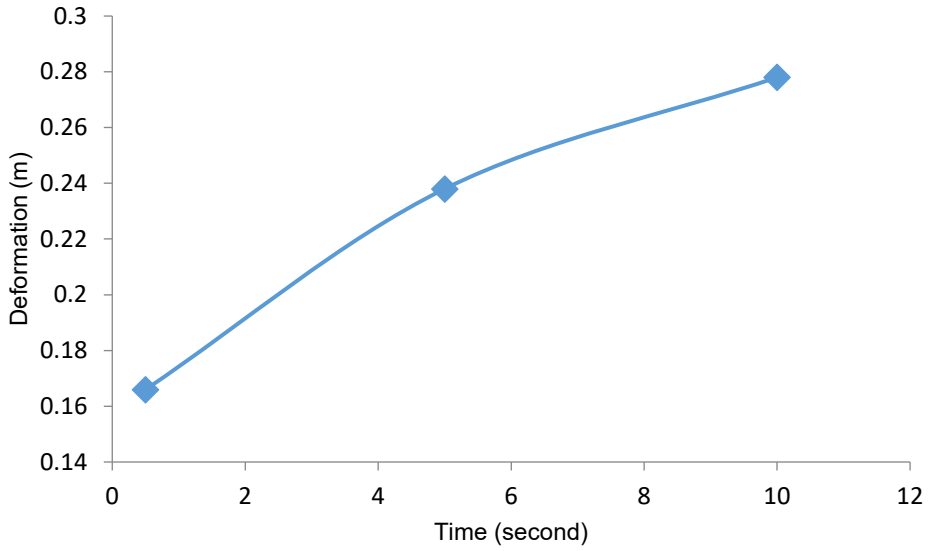


Figure 3. Time deformation relationship in sub-ballast at H_b = 0.35 m.

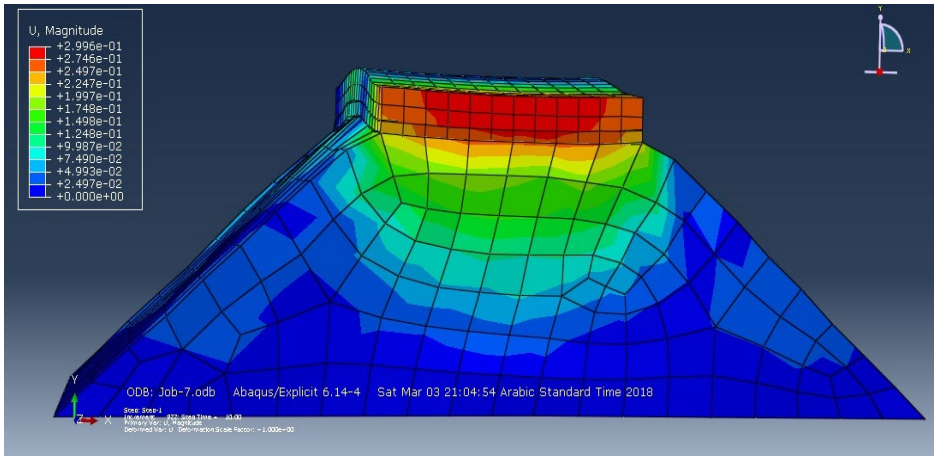


Figure 4. Deformation for model at H_b = 0.35 m (deformation in rail way is neglected).

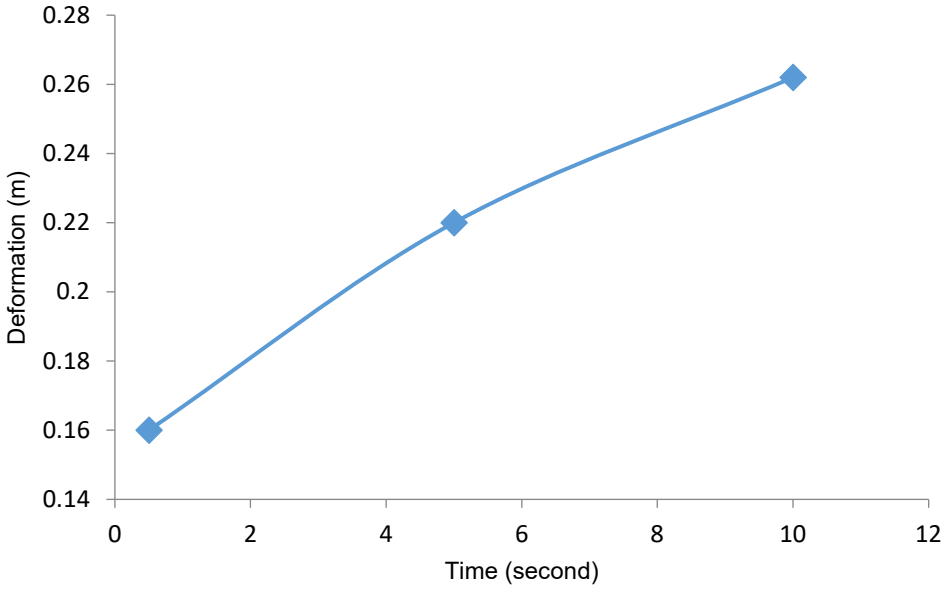


Figure 5. Time deformation relationship in sub-ballast at H_b = 0.4 m.

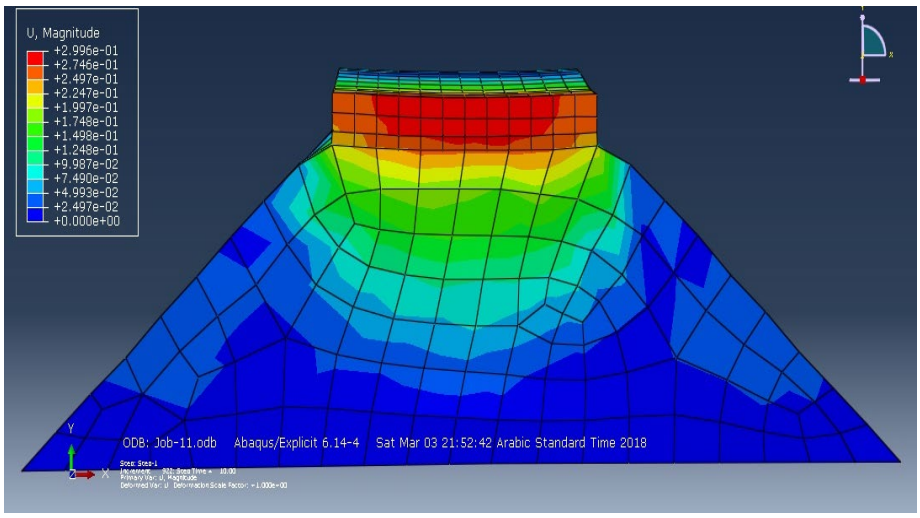


Figure 6. Deformation for model at H_b = 0.4 m (deformation in rail way is neglected).

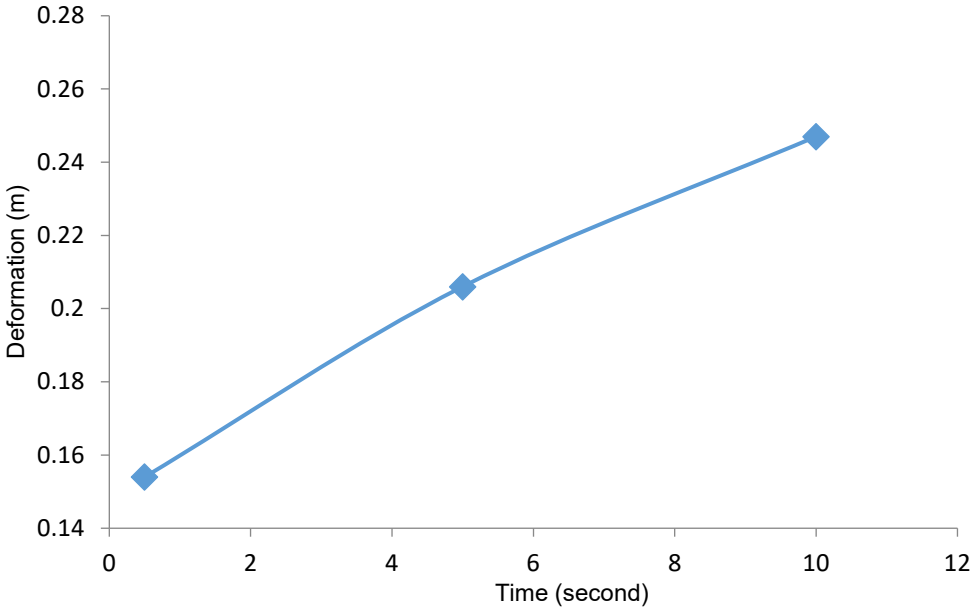


Figure 7. Time deformation relationship in sub-ballast at H_b = 0.45 m.

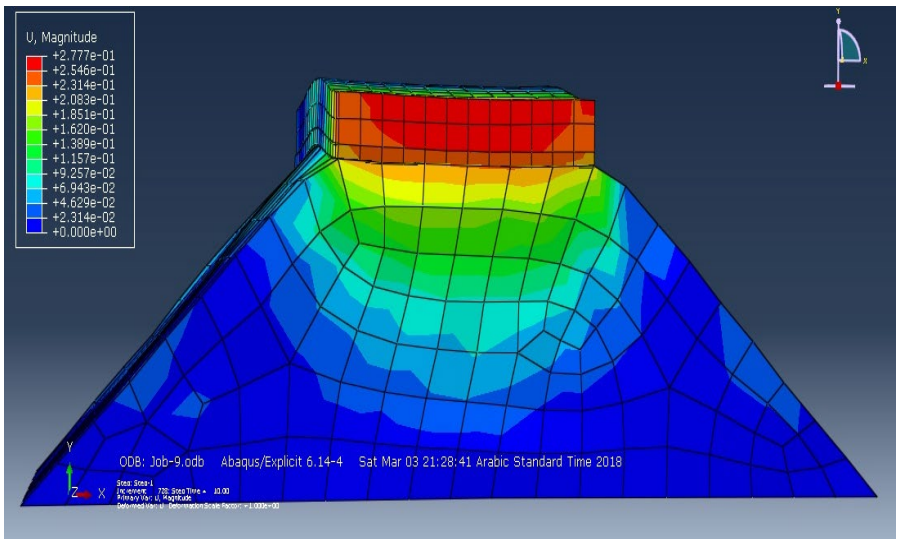


Figure 8. Deformation for model at H_b = 0.45 m (deformation in rail way is neglected).

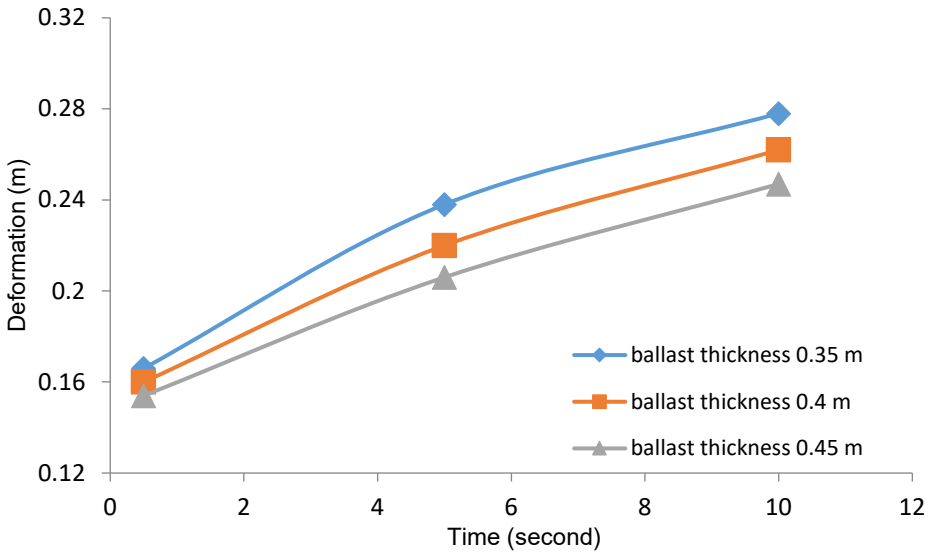


Figure 9. Deformation in sub-ballast with time.

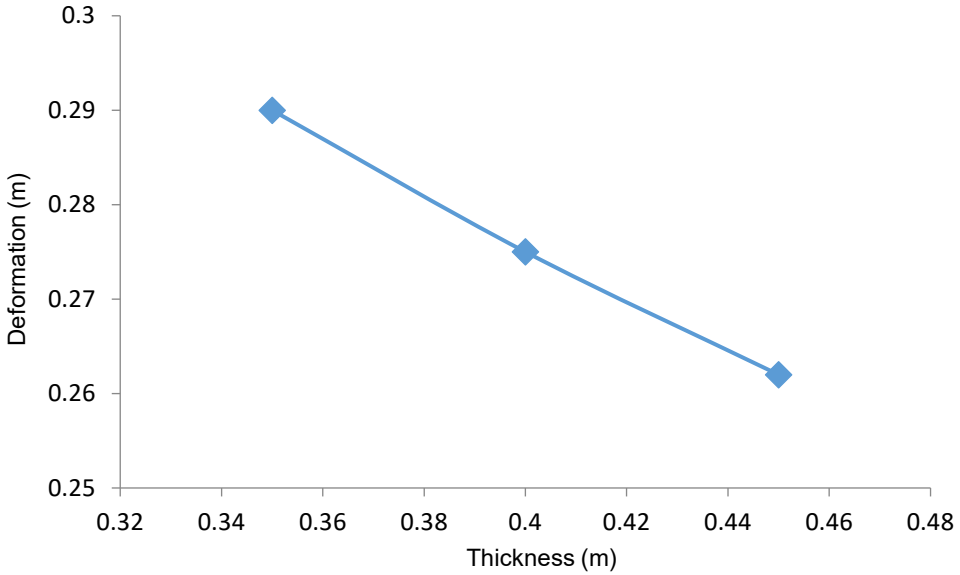


Figure 10. Effect of the ballast layer thickness on the deformation at the ballast–sub-ballast interface.

4. Conclusion

The effects of the ballast layer thickness on the deformation of rails were investigated by building three models in ABAQUS with Hb = 0.35, 0.4 and 0.45 m. The following conclusions were reached:

- When the ballast layer thickness increases, the deformation at ballast–sub-ballast and sub-ballast–subgrade interfaces decrease and leads to reduction in the deformation of rails.
- There is less deformation in the sub-ballast layer at H_b = 0.45 m than at H_b = 0.4 and 0.35 m.
- The ballast layer thickness should be selected so as to distribute the load on the subgrade as uniformly as possible and to reduce rail deformation.

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