International Journal of GEOMATE, Aug. 2023, Vol. 25, Issue 108, pp.257-264
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.108.s8656
Geotechnique, Construction Materials and Environment

AN APPROACH STUDY OF REDUCING THE SUB-BALLAST THICKNESS OF RAILWAY USING GEOTEXTILES

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ABSTRACT: Railway transportation in Iraq is irreplaceable for its significant role in economic growth. Due to inadequate maintenance and upgrading of the railroad, the Iraqi transportation system has deformed and poor-quality rails. The ballasted track is the traditional railway system where the ballast and sub-ballast layers provide structural support against the high dynamic stresses transmitted from moving trains. This paper attempts to study the effect of geotextile reinforcement on railway-ballasted track layers using the Abaqus program to examine the behavior of railroads' railway-ballasted trucks of varying thicknesses reinforced with geotextile. The study used the finite element method and adopted simulation to investigate the behavior of the railways. The sub-ballast thicknesses used are 150, 200, 250, 300, 350, and 400 mm, with 200 mm ballast thickness and 4 m subgrade thickness. The findings revealed that a 50 mm increase in sub-ballast thickness resulted in a 7.2% reduction in deformation. The findings show that utilizing geotextile atop the ballast layer is equivalent to increasing the sub-ballast layer's thickness by around 3.57 cm to reduce track distortion. The result showed that using geotextile would reduce model settlement with a range between (38-18) percent for total model settlement for the different models that have been tested. In addition, using geotextile under the ballast layer is more effective in reducing model settlement if there is an economical restraint to use only one reinforcement layer.

Keywords: Abaqus; Sub-ballast, Geotextile, Sub-ballast, and Equivalent Thickness

1. INTRODUCTIONN

A Finite element method is a broad approach for modeling the ballasted track system. Since 1960, several attempts have been made to overcome the limitations in track modeling using this technique. Meacham was the first attempt to develop a track model suitable for computerized analysis (digital and analog) [1]. The ABAQUS is an effective finite element software package. This has been utilized in many different engineering fields around the world. ABAQUS program can execute a static and dynamic evaluation and simulation of complicated engineering and non-engineering issues. The Abaqus program can handle bodies with different loads, interactions, properties, boundary conditions, temperatures, element types, and other environmental conditions.

Iraq is a developing nation. Its infrastructure has been destroyed due to military operations, neglect, and outdated railroads. Iraq must build a new railway to upgrade its transportation infrastructure and move people and heavy materials. Therefore, we require a robust railway that can withstand track deterioration and lateral instability. If we build a poor railway structure under railroad loading circumstances, this may become a complicated problem. [1].

Railway ballast is one of the main components in ballasted railway track systems [2]. The railway ballast layer consists of particles that aggregate due to the repeated heavy load of train deterioration due to increasing compressibility [3-6]. The effectiveness of Geosynthetic in railroad tracks has signified investigated in the past, and it's established that Geosynthetic generally increases rail performance by decreasing the deformation and degradation of ballast [7-15]. Limited research has studied the interaction between geosynthetic ballast aggregates when large strain happens due to heavy repeated loading [16, 17]. Suiker and de Borst [17] were studied by a numerical model to demonstrate the maximum plastic deformations produced during repeated loading. The effect of geotextile on improving the railway was investigated[18-20]. In addition to determining the structural impact of using geotextile at various points in the railway structure on deformation, vertical settlement, and lateral displacement of the railway, the analysis intends to quantify the impact of utilizing geotextile as opposed to thickening sub-ballast layers. The numerical analysis (FEM) technique was employed since laboratory studies do not fully explain what happens and the processes of stresses, strains, and deformations distribution in the layers of the railway as the train travels over the track 15 to illustrate the effect of using geotextile of railway using geotextile and sub-ballast layers, would be well analyzed in the following paragraphs.

2. RESEARCH SIGNIFICANCE

The significance of the study is determining the effect of using geotextile in increasing the strength of railroad structures and evaluating the best position to place the geotextile. Studying the impact of increased thickness of the sub-ballast layer in reducing deformation in railway, calculating the value of reducing the consumption of granular material when using the geotextile in railway structure.

3. METHODOLOGY

The ABAQUS program provides extensive possibilities for simulating nonlinear and linear applications. When a problem is composed of several components, each one of the components is defined with the suitable interactions between them and specifying the appropriate geometry and materials models. During the problem analysis, the ABAQUS program can help automatically choose the tolerances of convergence and the suitable increment of load and continuously modify them through the analysis to ensure the solution is obtainable accurately and efficiently [5, 21]. In this research 3D finite element model was created to simulate the layers of a railway and made sure to be an accurate simulation by the small size of the meshing and use of material properties from lab testing to ensure precise program output.

The ballast, sub-ballast, and subgrade meshing were the same sizes to ensure the analysis result would not affect due to the difference in mesh size between model parts. The dimension of models is taken from the local railway dimension. The 3D railway layers are shown in Fig.1.

4. ESTABLISHMENT OF FINITE ELEMENT MODEL

The FE approach has been established to be a useful and valid method for predicting the responses of railway structures under loading conditions [1, 22-24]. The researchers have used the FE approach to investigate the behavior of rail track response below heavy loads by numerical simulations, which focused on the behavior of the ballast layer with and without geotextile [13, 16, 23].

5. MODELING

ABAQUS has proved its validation in analyzing geotechnical problems [25, 28]. In this investigation, a three-dimensional finite element model was built by simulating the railway with all its parts, multi-layer geotechnical material, including subgrade, sub-ballast, ballast, sleeper, and rail, as illustrated in Fig 1.

The rail track was simulated in the model with dimensions. The width and height of the subgrade are 12 and 4 m, respectively. For studying the effect of change thicknesses of the sub-ballast layer, five models were built with five sub-ballast thicknesses, 200, 250, 300, 350, and 400 mm, and the thickness of ballast and sleeper was 200 and 150 mm, respectively, for all models. Four models were built with layer thicknesses of sub-ballast to investigate the effect of geotextile and its position in the behavior of the railroad. Ballast and sleeper were 200, 200, and 150 mm, respectively, with different positions of placing geotextile.

The gauge between the two rails of the track is 1.68 m, and the length of the sleeper is 2.5m. The rail is simplified as a rectangle with a width of 16 cm and a height of 5cm to ensure that the total area is equivalent to a 60 kg/m rail [22, 27].

The model structure has the same layers for raw materials of the r subgrade railway ballasted truck (ballast, sub-ballast, and) except for adding a geotextile layer between railway layers. [29-31]

6. MATERIAL PROPERTIES FOR MAIN COMPONENTS

The critical aspect of Finite Element Studies is the use of appropriate material properties of the content characteristics; due to the fact that their conduct could often influence the responses with the modeling. The model materials have been assumed to react elastically and linearly to the displacement load as the loading is being applied in the linear perturbation step. These properties regard the input parameters of the program. These parameters are the elastic modulus (E), the Poisson's ratio (ν), and the density. The input material properties in the analysis are stated in Table (1). The input material properties of the ABAQUS models play an essential role in the results of the program. Table 1 illustrates the material properties used in the railway simulation, which are used in finite element analysis for railways [22]. The linear response simulates the subgrade, granular layers, and geotextile [14, 23].

7. EFFECT OF CHANGE THICKNESS OF SUB-BALLAST

To investigate the effect of change in thickness of the sub-ballast layer in decreased deformation, vertical settlement, and lateral displacement, the railway five thicknesses of the layer were used, which are 200, 250, 300, 350, and 400 mm.

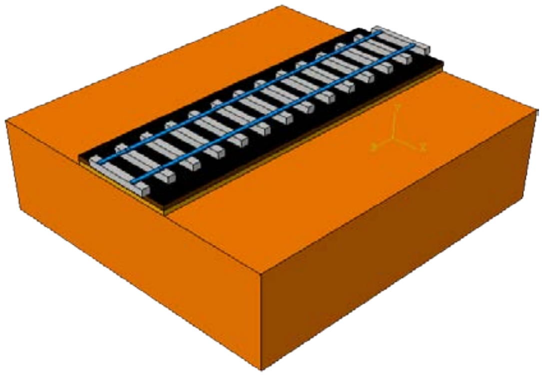

Fig. 1 ABAQUS Model Geometry

Table 1 Input Materials Properties [22]

Property	Subgrade	Sub-Ballast	Ballast
Modulus of elasticit (N/m)	125×10^5	800×10^5	1200×10^5
Density (Kg/m3)	1632	1700	1590
Poisson's Ratio	0.4	0.35	0.25

8. EFFECT OF USING GEOTEXTILE

The effect of using geotextile in decreasing deformation, vertical settlement, and lateral displacement of railway investigate by putting the geotextile layer in different positions; at subgrade/ sub-ballast interface (above subgrade), at sub-ballast/ ballast interface (above sub-ballast), and at ballast/ sleeper interface (above ballast) and evaluate which position gives minimum deformation, vertical settlement, and lateral displacement in the rail track.

9. ELEMENT TYPE

All parts of the models used finite element type 8-node continuum three-dimensional brick element (C3D8R) [23]. The mesh size of elements changes from medium for subgrade to fine for rail, as shown in Fig.2a.

10. LOAD CALCULATION

Two types of loading were used for the analysis of the model first load was a gravity load in which the gravitational acceleration of 9.81(m/s2) was applied to the model. The second load was applied using the controlled displacement method, in which the load is represented by a displacement at a constant rate similar to the speed of the laboratory-tested model on an area similar to the area of the footing of the tested model.

The Boundary conditions significantly affect the prediction for finite element model responses. Therefore, the actual boundary circumstances substantially influence predicting the precise response from the model. The base surface of the model, as well as the sides associated with layers, is assumed to become fixed with the boundary conditions used in the analysis.

The load used in the simulation of train load was dynamic wheel load, empirically expressed as the static load wheel, with the value of 178.71 KN, which was considered to simulate a train speed of 80 km/h and a wheel diameter of 970 mm,[22, 31, 32].

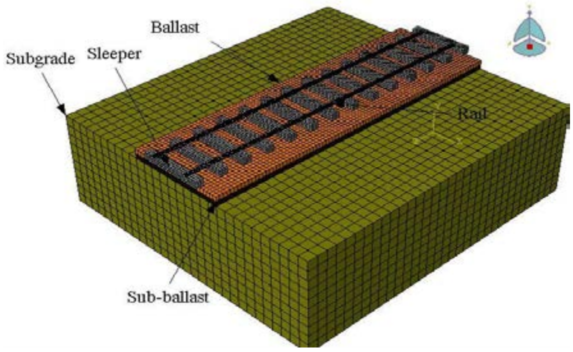

Fig. 2a Mesh of FE model

11. INTERACTION MODELING TECHNIQUES

The contact interaction between two layers of the model using ABAQUS (6.14-4) requires defining surfaces of interaction. Therefore, surfaces have been created at the top and the bottom of layers that be in contact with other layers. The ABAQUS program provides many contact formulations. Each formulation is founded on a choice of contact discretization, Some tracking technique, and a plan of “master” and “slave” roles toward contact types of surfaces. The duty of “master” and “slave” roles to your contact is used to model typically the interaction involving layers[33].

In addition, the interaction is a step-dependent substance, meaning it should define them, especially when choosing the step where the interaction can be active. The interference between the model's layers was modeled using Surface-to-surface contact, which represents interference between two surfaces. For the interaction between model layers with each other, a tie constrain module has been used. A complete interlocking between model layers and geotextile is assumed for the geotextile interaction with model layers.

Therefore, the geotextile-soil interactions were modeled utilizing two completely bonded enslaved person/ master contact areas. This ensures that no slippage could happen in the geotextile-soil interference. The dependent constraints of the surface tend to be forced the elimination of the degree of freedom from slave surfaces to preserve exactly the equivalent rotational as well as transitional movement, the same as the ones from the master surfaces. It was done by assigning the actual geotextile layer with a slave surface and soil layers with master surfaces.

12. MESH SIZE AND ELEMENT TYPES

The (3D) finite element evaluation was performed by taking the benefit of Abaqus capabilities. The model was constructed of 3014 elements along with 4368 nodes. The model meshed with two types of elements.

All the model parts are modeled using the 8-node continuum three-dimensional brick element (C3D8R) with reduced order numerical integration available in Abaqus (6.12-3). This element can represent large deformation, geometric, and material nonlinear Solid element (C3D8R) has three degrees of freedom at each node. All layers are simulated with the same shape to preserve the continuity of nodes between consecutive layers [33]. as shown in Fig.2b.

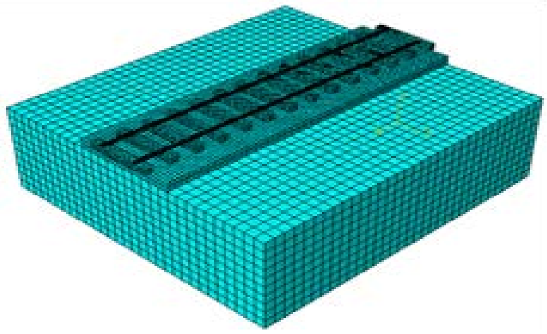

Fig.2b Model size meshing.

12. RESULTS AND DISCUSSIONS

12.1 Effect of Change Thickness of Sub-Ballast

The deformation, vertical settlement, and lateral displacement were measured at the surface of the ballast layer under the sleeper, which plays a crucial role in the railway's stability and the train's safe pass. The analysis results illustrated that the increase in the thickness of the sub-ballast layer led to decreases in deformation, vertical settlement, and lateral displacement of the rail track, as shown in Figs 3-5, respectively. The geotextile position and the number of geotextile layers are noticeable in reducing the settlement amount. Geotextile offers an enhanced combination of interlock within stabilizing railway ballasted truck infrastructure via confinement of both ballast and sub-ballast particles. The amount of settlement increased with increasing the simulated load.

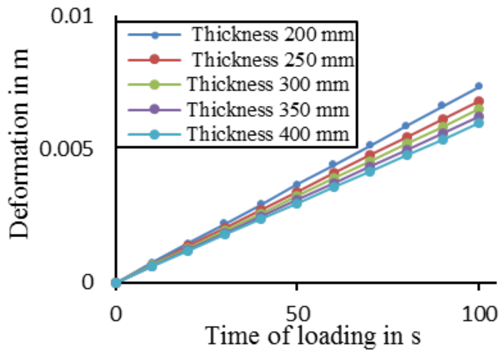

Fig.3 Deformation and thickness of sub-ballast for thicknesses 200, 250, 300, 350, and 400 mm

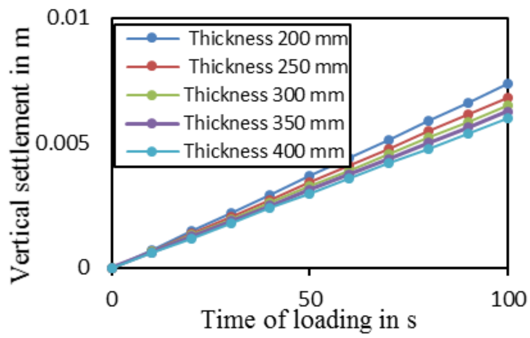

Fig. 4 Vertical settlement Vs. Thickness of sub-ballast

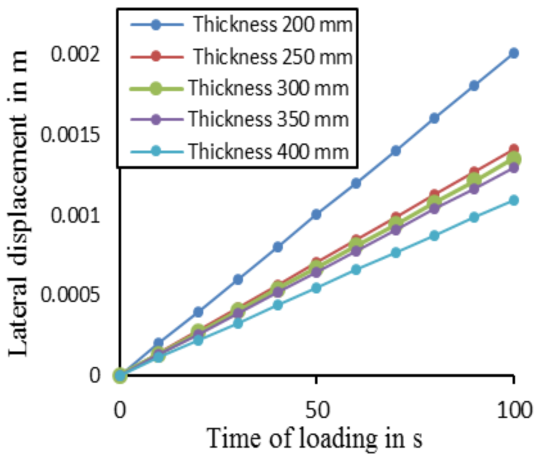

Fig. 5 Lateral displacement vs. thickness of sub-ballast for thicknesses 200, 250, 300, 350, and 400 mm

Figures 6 and 7 show the relationship between the deformation, vertical settlement, and lateral displacement in rail tracks. The thickness of the sub-ballast layer illustrated that the deformations decreased as the thickness of the sub-ballast increased.

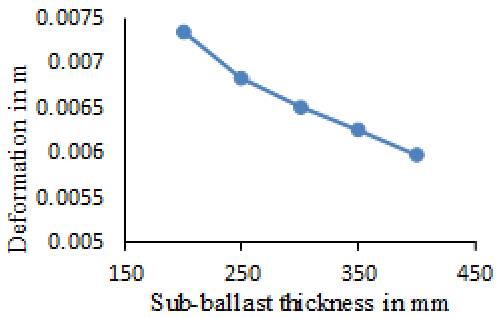

Fig. 6 Deformation and sub-ballast thickness for thicknesses 200, 250, 300, 350, and 400 mm

12.2. Effect of Using Geotextile

To investigate the effect of geotextile in reducing deformation, settlement, and lateral displacement in rail track, the geotextile was put in three positions, above subgrade, above sub-ballast, and above ballast layer. The result shows that the maximum.

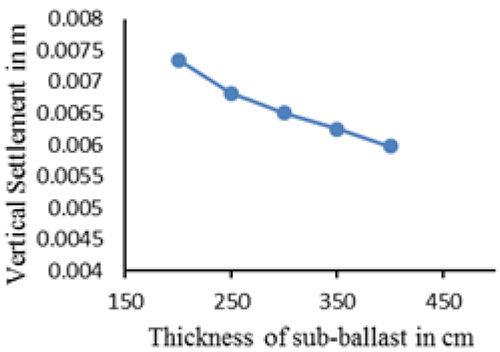

Fig.7 Lateral displacement vs. sub-ballast thickness

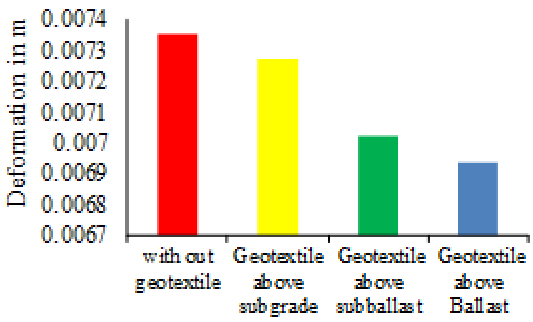

Fig. 8 Relationship between the position of geotextile and deformation in the rail track

The effect of geotextile in reducing deformations and vertical settlement was when putting it above the ballast layer, as shown in Figs. 8-9, respectively. The results also show that putting geotextile above the sub-ballast layer was less effective than putting it above the ballast in decreasing deformations and vertical settlement. Placing geotextile above the subgrade was given minimum effect in reducing deformation as illustrated in Figs. 8-9. It shows that the use of geotextile led is very essential to a decrease in lateral displacement at the surface of the ballast. In contrast, the increased thickness of the sub-ballast led to a decrease in lateral displacement.

12.3. Comparison Between Models

The thickness of sub-ballast and the effect of position of reinforcement of geotextile in reducing deformation, vertical settlement, and lateral displacement of rail track. The bar diagram with the red color shown in the figures represents a railway without reinforcement and with a sub-ballast thickness of 20 cm, which is considered a reference (origin) model for comparison between all models.

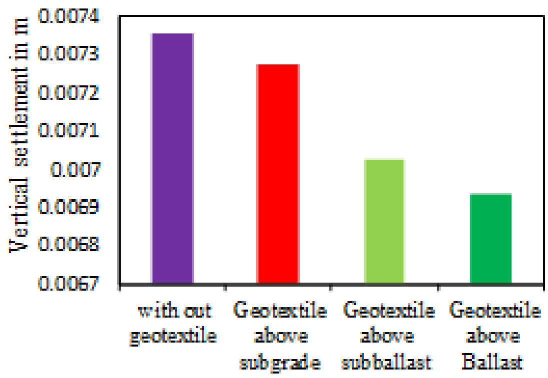

Fig. 9 Relationship between the position of geotextile and vertical settlement on the rail track

Figure 10 demonstrates the deformation for all models. From the figure, we can see that the increase in thickness of the sub-ballast layer affected decreasing the deformation of the rail track. Fig. 10 illustrates that are two models with deformation so close each one to the other. One of the models with a thickness of sub-ballast 25 cm, which has a deformation 0.00682m and another one with geotextile reinforcement was put above a ballast layer which has a deformation 0.00693m.

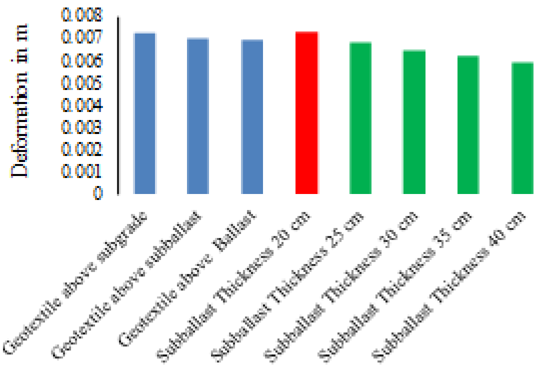

Fig. 10 Deformation for all models

Figure 11 shows the vertical settlement for all models, illustrating that the change in thickness of the sub-ballast was more effective in reducing vertical settlement than geotextile. Also, the figure shows that the slightest deformation, vertical settlement, and lateral displacement in rail tracks were for rail tracks with a sub-ballast thickness of 40cm. For the lateral displacement for all tracks, the figure is illustrated that using geotextile led to an increase in lateral displacement at the surface of the ballast. In contrast, the increased thickness of the sub-ballast led to decreased lateral displacement.

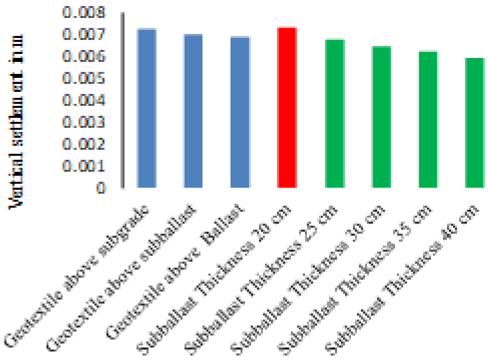

Fig. 11 The vertical settlement for all models

12.4 Percentage of Reduction in Deformations

Fig. 12 shows the percentage of reduction in rail track deformation for each model, illustrating that the model with a sub-ballast thickness of 40cm has the most significant percentage of reduction in deformation, and the model with reinforcement at subgrade has the smallest rate of decline in deformation.

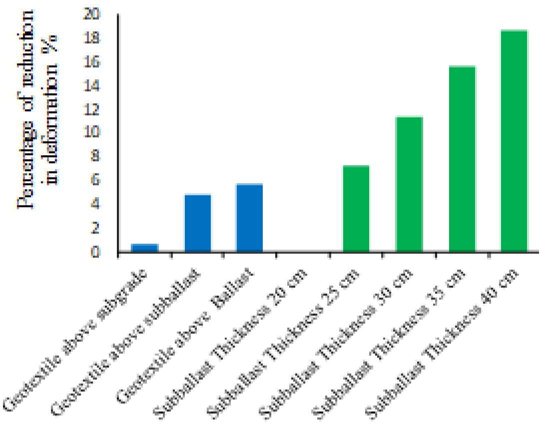

Fig. 12 Percent of reducing deformation in Models

12.5 The Sub-Ballast Thickness that Geotextile Equivalent It

The deformation value obtained from the geotextile was 0.00693 when putting the reinforcement above the ballast layer. From the relationship between deformation and the thickness of the sub-ballast thickness, it’s found that geotextile is equivalent to 3.57 cm of sub-ballast thickness, as shown in Fig. 13. Table 2 illustrates the equivalent thickness of the sub-ballast and the position of the geotextile.

Table 2 Illustrate the Geotextile position equivalent to the thickness of sub-ballast

Geotextile position	Equivalent to sub-ballast thickness (cm)
Above ballast	3.57
Above sub-ballast	2.85
Above subgrade	N/P

13. CONCLUSIONS

There is a noticeable effect of the geotextile position and many geotextile layers in reducing the settlement amount. Geotextile offers an enhanced combination of interlock within stabilizing railway ballasted truck infrastructure via confinement of both ballast and sub-ballast particles. The amount of settlement increased with increasing the simulated load. The double geotextile reinforced model has the best result in settlement reduction compared to the equivalent single geotextile model. The ballast-geotextile model is firmer and gives much more strength than the equivalent sub-ballast reinforced model. Geotextile reinforcement is more effective for the ballast layer because the ballast has a significant role in Transmitting and distributing the load to formation uniformly.

The following conclusions are obtained from this research.

1. The increase in the thickness of the sub-ballast layer by 5 cm decreases the deformation by about 7.2% by reducing the stress reaching the subgrade and increasing the track's strength stab.
2. The increase of the sub-ballast layer led to a decrease in vertical settlement through an increase in the distribution of loads coming from the train.
3. As the thickness of the sub-ballast increase, the lateral displacement decreases through a decrease in the stress at the sub-ballast/ subgrade interface.
4. Using geotextile reinforcement at ballast decreases the deformation in the rail track by about 5.71 % through the distribution of the stresses at the sleeper/ ballast interface.
5. Using geotextile reinforcement at ballast decreases the deformation in the rail track by about 5.71 % through the distribution of the stresses at the sleeper/ ballast interface.

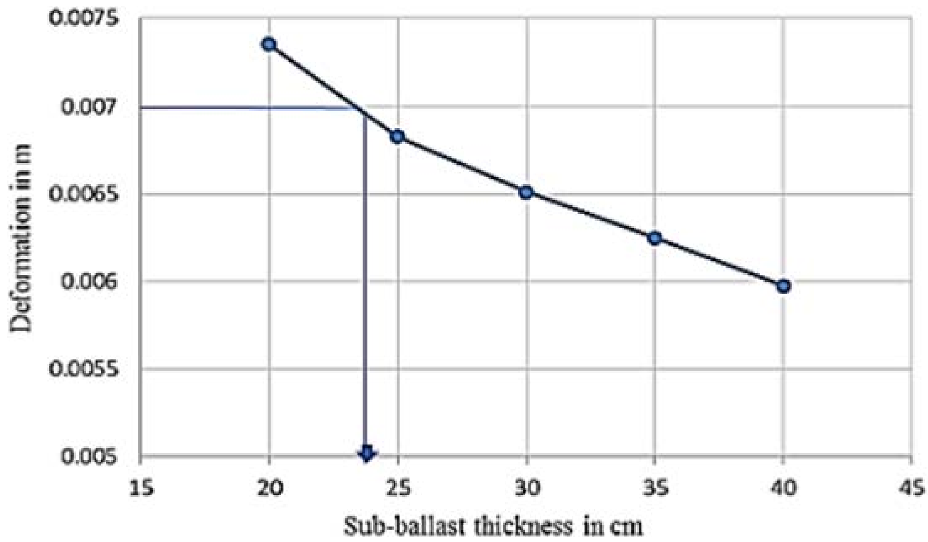

Fig. 13 Calculation of equivalent thickness of sub-ballast

6. Using geotextile reinforcement at ballast decreases the deformation in the rail track by about 5.71 % through the distribution of the stresses at the sleeper/ ballast interface.
7. Using geotextile at the ballast/ sub-ballast interface decreased deformation by about 4.65%, while using geotextile at the sub-ballast/subgrade interface decreased deformation by about 0.68 %.
8. The maximum useful position of geotextile as a reinforcement layer to reduce deformation in rail track was above the ballast layer, and the minimum influence of position reinforcement was above a subgrade layer
9. The maximum percentage of reduction in deformation was for rail track with a sub-ballast thickness of 40 cm, and the minimum percentage of reduction deformation was when reinforcing with geotextile above the subgrade layer.
10. The result shows the effectiveness of the ABAQUS program in the simulation multilayer layers system of granular material.[29, 30]

14. LIMITATIONS OF THIS STUDY

The properties of geotextile play a crucial role in increasing the benefit of using it; in this paper, the modules of elasticity of geotextile were 120 MPa, and the geotextile, which has a modulus of elasticity less than 120 MPa not evaluated. More investigation before using geotextile above subgrade, sub-ballast, and ballast is needed.

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