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INFLUENCE OF BIAXIAL GEOGRID AT THE BALLAST INTERFACE FOR GRANULAR EARTH RAILWAY EMBANKMENT

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Abstract. The development of reinforcements for soil has made an impact in most of the civil engineering sectors especially transportation. The use of geogrids is frequent in roadways but they are also finding use in railways. The major impact that geogrids could have is providing desired stiffness to a section by reducing material and serving as a proper reinforcement material. In the current study, an attempt has been made to redesign the railway embankment economically with the help of geogrids. Biaxial geogrid is used to substitute the blanket layer (thickness up to 100 cm) in the railway embankment by fulfilling the strain modulus requirement of the embankment, calculated using a plate bearing test as per DIN 18134. The experiment is performed on the embankment replicated in a metallic test chamber with granular soil as subgrade and geogrid is placed beneath the ballast. The experimental study is validated by a 3-D numerical model using Midas GTS NX software. The experimental analysis shows an improvement of 31.47% in the second modulus of the earth embankment. For the implementation of this study, a design section of Indian

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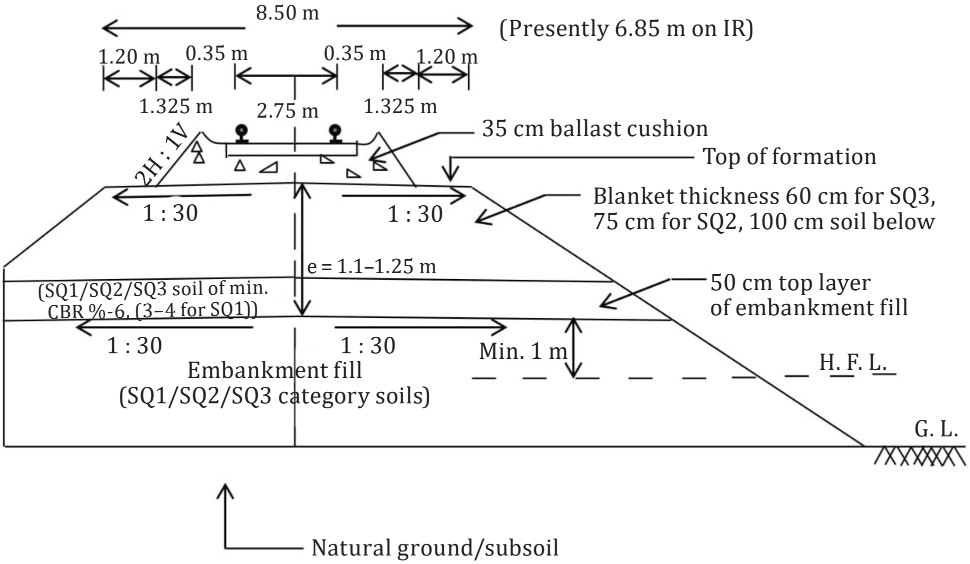
railways is adopted. With the help of geogrid, a reduction of 50% is observed in the embankment height, thereby reducing the overall costs.

Keywords: deformation modulus, geogrids, granular earth bed, high-speed embankment, plate load bearing test, reinforced embankments.

Introduction

Railways are one of the most used sectors in transportation. As transportation usually acts as the backbone of any economy, many countries are in the process of constant up-gradation of railways. A railway embankment is composed of various materials with varying stiffness such as ballast, sub-ballast (blanket material) and soil. The major function of the railway substructure is the distribution of the stresses to the natural ground. The ballast is laid on the top and bears the maximum stress before transferring to the layer beneath termed as a blanket layer. The blanket layer prevents the penetration of the ballast into the subgrade. But due to the increasing cost and limited availability of naturally occurring materials, some substitute materials



Proposed track formation for heavy axle load – 25T

Figure 1. Indian railway embankment section as per GE-14, 2008

or changes in the design should be introduced. One such possibility can be explored with the inclusion of geogrids. The main functions of geogrids as reported are reinforcement and containment (Shukla et al., 2009; Das, 2016). The use of geogrid under the ballast helps in increasing the stiffness by containment of ballast and prevents the breakage, hence reducing the frequent maintenance cycle (Indraratna et al., 2011a). Based on the type of usage, geogrids are uniaxial, biaxial, and recently developed triaxial geogrids.

The railway network of India is vast and people rely heavily on railways for commuting. Since India is the second-largest populated country in the world, the pressure is growing rapidly for faster and more economical designs. The height of the embankment plays a very crucial role in the distribution of the stress to the subgrade and eventually to the natural ground and as per Li & Selig (1998), the process of deriving the adequate thickness involves detailed study on factors such as type of soil, axle loads, number of repetitions of wheels, cumulative strains, plastic strains, annual tonnage, etc. However, by reviewing Indian railway design codes like GE-14, no such detailed study was provided in the codes. In the review of codes, it was found that the thickness of the embankment increased over the years and especially the thickness of the blanket layer up to 1.25 m. Many countries follow the concept that with the increase in height, a better distribution of stress is achieved but after a certain height, the construction costs and time for the railway embankments will increase rapidly. In most cases, due to the increased height stress is distributed to a larger area and the embankment stays safe but indirectly it is the case of overdesigning and uneconomical section. In the case of developed countries, the railway earth embankment design is based on crucial parameters such as strain modulus where the embankment height is less compared to the embankments in countries such as India. Indian railways designs are derived from the European code UIC 719R but the parameters used for the construction of the embankment need modifications with present and modern needs.

There are studies present in the literature which show that researchers and engineers are trying to include geogrids in the railway designs and promising results can also be seen. Gobel et al. (1994) conducted detailed research on increasing the bearing capacity of the railway tracks by adding geogrids. In total, 5 million cycles were imposed on a section in the laboratory to study the deformation modulus and bearing capacity behavior of the embankment. The study showed very promising results of a 31% increase in load-bearing capacity. In a series of full-scale testing on the embankment, Jain & Keshav (1999) reported a reduction of 20–40% for a single layer of geogrid and 30–60%

for two layers of geogrids of dynamic loads. Kim & Das (2002) showed 47% fewer settlements in track when one layer of geogrid and one layer of geotextile were used. The most significant finding of this study was the identification of the critical number of cycles “Ncr” after which ballast showed no further settlements. Indraratna et al. (2011b) studied ballast in-depth under different levels of fouling and triaxial testing for reinforced ballast and showed significant improvement in stress carrying capacity and low maintenance of ballasted tracks. Innotrack’s guidelines contain a detailed laboratory, numerical and field methods such as lightweight deflectometer to improve the ballast performance on the track. These guidelines use a parameter “deformation modulus” to evaluate the stiffness of the embankment and the study reported a 15% improvement in deformation modulus when geogrids were used beneath ballast. Another full-scale testing conducted by Crawford et al. (2001) stated that the use of a single point displacement method was capable of obtaining a very reasonable track modulus when compared with other methods. There are various correlations between the second modulus and dynamic modulus from the lightweight deflectometer test method. Tompai (2008) suggested the frequent use of the second modulus to evaluate earth stability for high speed embankments and suggested the additional use of dynamic modulus with the second modulus from the plate load test by using given correlations to improve quality assessment of railway embankments. Correia et al. (2009) reviewed performance-based tests to evaluate the modulus of the railway embankment and the plate load test was used as a reference test to evaluate the correlations with results from other tests such as lightweight deflectometer, soil stiffness gauge, etc. Kim & Park (2011) found useful relationships between well-established K30 and Ev_2 to increase the applicability of modulus calculation in Korea as both these parameters were frequently used in the evaluation of the bearing capacity of the earth embankments. The study conducted by Mittal & Meyase (2012) reported that the inclusion of geosynthetics in the ballasted tracks could show improved performance with the reduction of foundation area. The stiffness of the embankment could be measured by using plate load tests and tests on the inclusion of geogrids in gravels were also reported by Minažek (2013). Various stiffness evaluation methods for soils were correlated by Nie et al. (2018) with the compaction degree which showed a linear relationship with compaction degree. The compaction degree acts as a controlling factor for the soil while strain moduli act as indicating factors for stiffness of railway subgrade. Sun et al. (2016) derived a laboratory test for the determination of deformation modulus and validated it with the help of finite element method (FEM) analysis for effective evaluation of the stiffness in the lab. The study also suggested no effect of boundary on the FEM model while calculating the second deformation modulus numerically. Lehmann et al. (2020) suggested both plate load and lightweight deflectometer tests were essential at a site and correlations should not be used to convert from the second modulus to dynamic modulus or vice-versa in the absence of tests. There are numerous studies present in the literature that establish the importance of the soil modulus for earth embankments. The Indian railways as of now do not operate at high speeds above 150 km/ph neither there is any design methodology or parameter that somehow can upgrade the existing design methodology. The German standards (DIN 18134) are applied because, in the review of international codes and designs, the requirements needed by the earth embankments for high speed tracks are measured and maintained using DIN 18134. There are even standard values mentioned in the various codes that an earth embankment needs to maintain for sustained speeds of 300 km/ph. Hence, the objective is to achieve the European standard values on Indian earth embankments so that some improvement can be made to Indian design methodology. Therefore, a study was planned to evaluate the existing designs of the embankment for Indian railways, based on the stiffness parameter like second deformation modulus (Ev_2), which may help achieve an economic and efficient design.

1. Methodology

The test method includes a metallic box composed of hard-grade steel plates. The metallic box consists of three fixed walls and one removable wall having the total dimensions of the box as 1m×1m×1m. The loading plate used in the tests is 200 mm in size to prevent the boundary effects. In the test program, 4 dial gauges were used to measure the settlements of the plate at each corner. The recommended loading intensity as per DIN 18134 is 500 kN/m^2. As per Indian railways, the embankment is designed for three load variants: 25 T, 30 T, and 32.5 T. The design used in the current study is for 25 T but the actual load on the running lines as per IR is 16.5 T, whereas other loads of 30 T and 32.5 T are proposed loads and are currently not being used. After converting these loads into load intensities based on the average sleeper dimensions (2.75 m × 0.246 m), the intensities are 239.17 kN/m^2 (16.5 T), 368.21 kN/m^2 (25 T) 441.86 kN/m^2 (30 T) and 478.68 kN/m^2 (32.5 T). These loads represent the static wheel load and to include the dynamic effects, a dynamic augment factor (DAF) should be applied. In this study, a DAF of 1.5 is used as per GE-14 consideration of dynamic loads. After the application of DAF, the load is 24.75 T and the loading intensity is

364.53 kN/m^3. Therefore, considering the load requirement of Indian Railways, the use of load intensity of 500 kN/m^2 is valid for the current study as well as for the future scope. The setup for the tests can be seen in Figure 2.

The total settlement of the plate is calculated with the use of a second-degree polynomial equation:

$$S = a_0 + a_1 \cdot \sigma_0 + a_2 \cdot \sigma_0{}^2, \tag{1}$$

where

σ_0 = avg. normal stress below the loading plate in MN/m^2;
S = settlement of loading plate in mm;
a_0 = constant of second-degree polynomial in mm;
a_1 = constant of second-degree polynomial in m/(MN/m^2);
a_2 = constant of second-degree polynomial in mm/(MN^2/m^4).

The parameters calculated in Equation (1) are used in Equation (2) to calculate strain modulus for the first and second loading cycles:

$$Ev = 1.5 \cdot r \cdot \frac{1}{a_1 + a_2 \cdot \sigma_{0\max}}, \tag{2}$$

Figure 2. The test setup used in the laboratory showing ballast, dial gauges and loading plate

where Ev – deformation modulus, r – radius of plate, a_1, a_2 – constants from Equation (1);
$\sigma_{0\max}$ – maximum average normal stress below the loading plate in the respective cycle in MN/m^2.

2. Materials and preparation

The materials collected for the study were locally available. The ballast was collected from the Indian railway ballast yard and soil was collected in Haridwar city, India. As per the Indian standard soil classification system (ISSCS), the soil is identified as Silty sand (SM) and as per IR soil is classified as SQ2. The particle size distribution curve for both soil and ballast is shown in Figs. 3 and 4. The soil was placed in 5 layers of 100 mm each and each layer was compacted at its maximum dry density. The compaction of the soil was achieved with a hammer weighing 8 kg to achieve the required density of 14.8 kN/m^3. After placing the soil and achieving the thickness of 500 mm, geogrid was placed on top of the soil layer and then aggregates were placed. The aggregates were also compacted as per recommendations of RDSO and in the layer thickness of 150 mm each to achieve a standard overall thickness of 300 mm. Light tamping is used to compact the aggregates to the required density of 21 kN/m^3 and prevent early damage to the ballast.

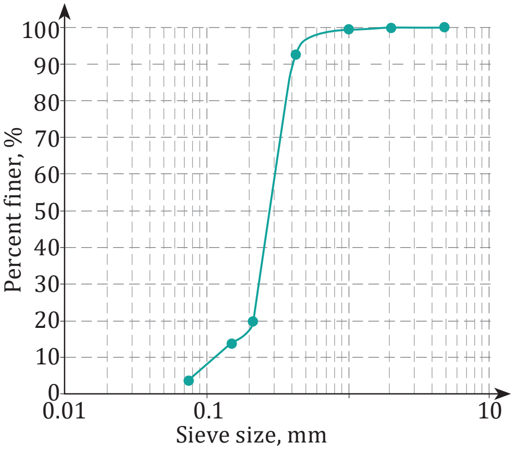


Figure 3. Particle size distribution curve for soil

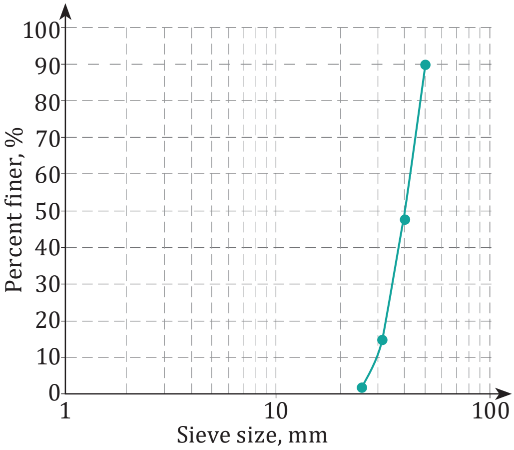


Figure 4. Particle size distribution curve for ballast

The evaluated properties of the materials used in the current study are shown in Table 1. As per the guidelines of Indian Railways, the thickness of the embankment is calculated based on the quality of the underlying soil. Indian railways classify the soil in three categories: SQ1, SQ2 and SQ3. The classification is based on the percentage of the fines as detailed in Table 2. GE-14 also recommends minimum Ev_2 for subgrade layers as well as for the sub-ballast/blanket layer as listed in Table 2.

The maximum height of 1 m can be attained in the metallic box, whereas the actual height of the embankment is 2.4–2.6 m excluding the natural ground/sub-soil thickness/ gradient as per GE-14. To initiate the test program, a subgrade of a thickness of 400 mm is prepared in the tank and a PLT test is conducted. Then the height is raised to 500 mm and again test is conducted to evaluate both Ev_1 and Ev_2. After conducting the test, the strain modulus is matched to the recommended modulus values as per GE-14. In the same manner, the height of the embankment is raised to 1 m by the inclusion of the blanket as well as the ballast layer. The impact of geogrid is also explored by placing the geogrid under the ballast. The geogrid adopted for this study is biaxial (Bhardwaj & Mittal, 2020) and important properties of geogrid "G1" are shown in Table 3. The placement of geogrid in the test setup is shown in Fig. 5 (a)–(b).

Table 1. Engineering parameters of material used in the study

Material	Coeff. of uniformity, C_u	Coeff. of curvature, C_c	Density, kN/m^3	Classification
Soil	2	1.38	14.8	SM
Ballast	1.5	0.9	21	Highly angular, well-graded

Table 2. Classification of soils & strain modulus as per GE-14, Indian Railways

Type	Classification	Blanket thickness, cm	Ev_2 for subgrade, MPa	Ev_2 for blanket layer, MPa
SQ1	Fines > 50 %	100	45	100
SQ2	Fines 12-50 %	75	45	100
SQ3	Fines < 12 %	60	45	100

Table 3. Properties of geogrid adopted for the current study

Geogrid properties	**Longitudinal aperture (A_L), mm**	**Transverse aperture (A_T), mm**	**Width of long. Rib (W_{LR}), mm**	**Width of transverse rib (W_{TR}), mm**	**Junction thickness (T_j), mm**	**Thickness of longitudinal rib (T_{LR}), mm**	**Thickness of transverse rib T_{TR}**	**Load @ 5% (longitudinal), kN/m**	**Load @ 5% (Transverse), kN/m**
G1	65	65	3.6	4.5	6.4	2.3	1.7	22	25

3. Experimental studies

The test is conducted as per the guidelines of DIN 18134. The tests are conducted at first on the individual layer then on the combined embankment and finally with the inclusion of the geogrid. Once the test

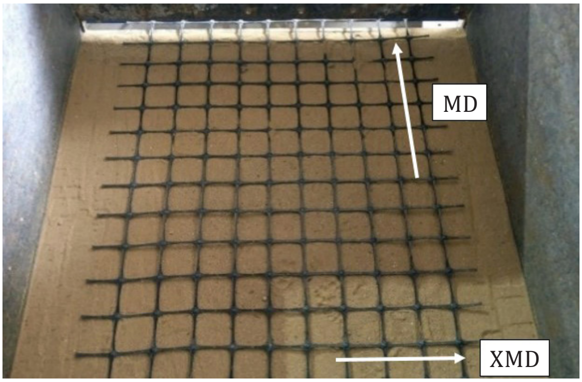


Figure 5. a) The placement of the geogrid in the test setup for the current study

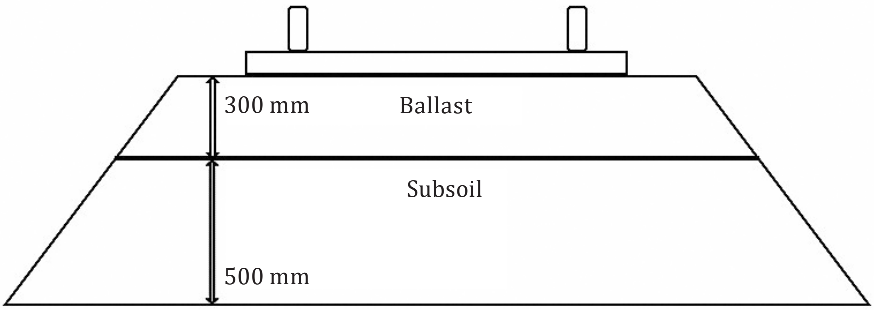


Figure 5. b) Section view of the test setup used for this study

is started, the settlements from the dial gauge and the stress intensity on the loading plate are noted for every load application. Both these observations are used in the evaluation of strain modulus using Equation (1) and the variables a_1, a_2, and a_3 are calculated using Equations (3)–(5).

$$a_0 \cdot n + a_1 \sum_{i=1}^{n} \sigma_{0i} + a_2 \sum_{i=1}^{n} \sigma_{0i}^2 = \sum_{i=1}^{n} s_i; \tag{3}$$

$$a_0 \sum_{i=1}^{n} \sigma_{0i} + a_1 \sum_{i=1}^{n} \sigma_{0i}^2 + a_2 \sum_{i=1}^{n} \sigma_{0i}^3 = \sum_{i=1}^{n} s_i \sigma_{0i}; \tag{4}$$

$$a_0 \sum_{i=1}^{n} \sigma_{0i}^2 + a_1 \sum_{i=1}^{n} \sigma_{0i}^3 + a_2 \sum_{i=1}^{n} \sigma_{0i}^4 = \sum_{i=1}^{n} s_i \sigma_{0i}^2. \tag{5}$$

After finding a_1 and a_2 from Equations (3)–(5), Ev_1 and Ev_2 are calculated using Equation (2). The results of the tests conducted are shown in Table 4. It can be seen that the required modulus recommended as per GE-14 is achieved in min. possible thickness of 400 mm and the same is the case for a 500 mm thick subgrade. Hence, for the inclusion of the ballast a subgrade of 500 mm is selected to further eliminate the boundary effects, if any. Once the thickness of the subgrade is fixed, a ballast layer of 300 mm thickness is placed on the subgrade. Then the test is conducted at a full embankment thickness of 800 mm and then further with the addition of geogrid. From Table 4 it can be inferred that there is no relation between thickness and strain modulus of the embankment. This means that having more height in the embankment does not necessarily mean better stiffness. Hence, the stiffness of the embankment depends more on compaction effort and material used.

Table 4. Strain modulus values on the different layers and various combinations of the embankment

Thickness, mm	Ev_2, MPa	IR specification	Remarks
Subgrade (400)	61.47>45	Min. required Ev_2 is 45 MPa	400 mm thickness is capable of required Ev_2
Subgrade (500)	68.86>45	Min. required Ev_2 is 45 MPa	500 mm thickness is capable of required Ev_2
Subgrade (500) +Ballast (300)	111.91>100*	Min. required Ev_2 on ballast layer is 120 MPa (France's guidelines)	800 mm thickness capable of required Ev_2
Subgrade (500) +Ballast (300) + Geogrid	131.47>100*	No data for Ev_2 on top of the ballast layer as per Indian guidelines	800 mm thickness more than capable of required Ev_2

* Minimum Ev_2 at the top of the blanket layer as per GE-14

With the full embankment, the strain modulus value on the top of the ballast with geogrid underneath is 131.47 MPa. Indian railways like many other countries do not specify the required modulus on the top of the embankment. To compare France's railway design requirements (Fei et al., 2020; Alamaa, 2016; Réseau ferré de France, 2010) can be referred. The recommended modulus on the top of the embankment in France's railways is 120 MPa and a thickness of 900–1200 mm is capable of achieving this required modulus. Hence, the modulus achieved in the laboratory experiments is relatable and is more than the required 100 MPa.

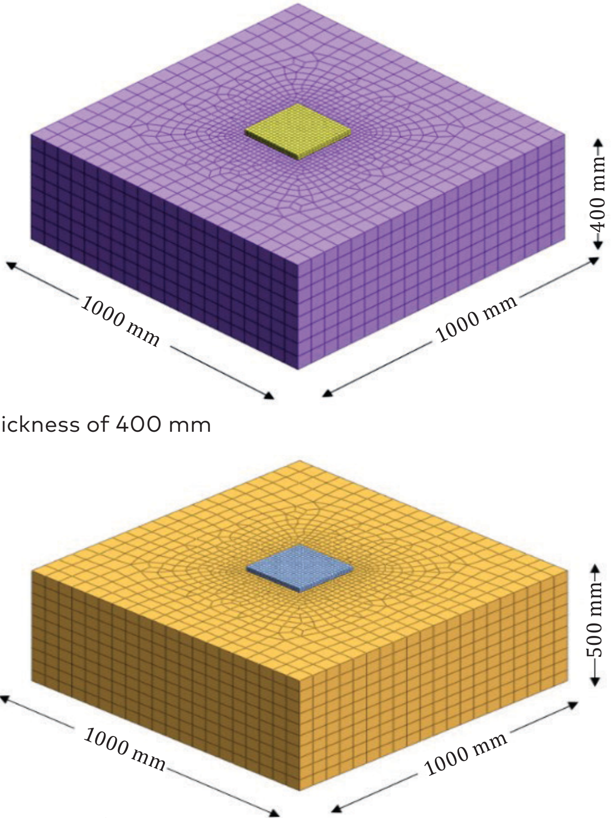
4. Numerical validation

The experimental studies are validated through a finite element 3D model using FEM software Midas GTS NX. A 3-dimensional model is created in Midas simulating the exact dimensions of the metallic tank of 1 m × 1 m × 1 m. The soil properties are evaluated with laboratory testing and the same is used in the validation. The soil and ballast are modeled using the Mohr-Coulomb elastoplastic model, while plate and geogrid are modeled with a linear elastic constitutive model. The elastic characteristics are represented by the elastic modulus (E) and Poisson's ratio (ν), whereas the internal friction angle (Φ), cohesion (c), and dilatancy angle (Ψ) are used as the input properties to express the plastic characteristics. The properties for ballast & plate are collected from the study conducted by Shahu et al. (1999) as listed in Table 5.

The load is applied in a similar pattern as the test is conducted in the laboratory in two cycles comprising of 6 stages each as well as unloading stages. The displacement is read in the center of the plate where a node

Table 5. Material properties used in the validation of the study

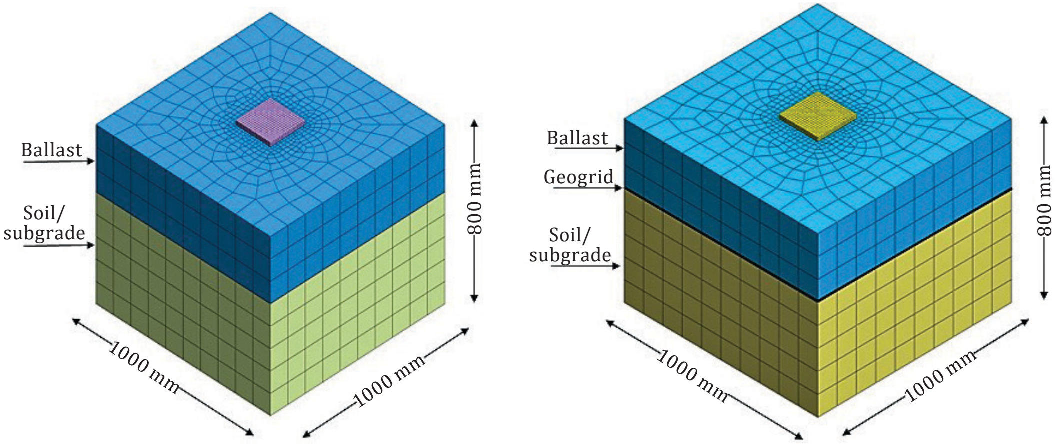
Material	Properties	Constitutive model
Plate	E = 205 GPa; ν = 0.3; Υ = 78 kN/m^3	Linear Elastic
Ballast	E = 180 MPa ; ν = 0.28; Υ = 21 kN/m^3; Φ = 47.92; Ψ = 0; c = 0	Mohr-Coulomb
Soil	E = 20 000 kN/m^2; ν = 0.22; Υ = 14.78 kN/m^3; Φ = 36; Ψ = 3, c = 6 kN/m^3	Mohr-Coulomb
Geogrid	As reported in Table 3	Orthotropic interface



a) for a thickness of 400 mm

b) for a thickness of 500 mm

Figure 6. Numerical model representing subgrade

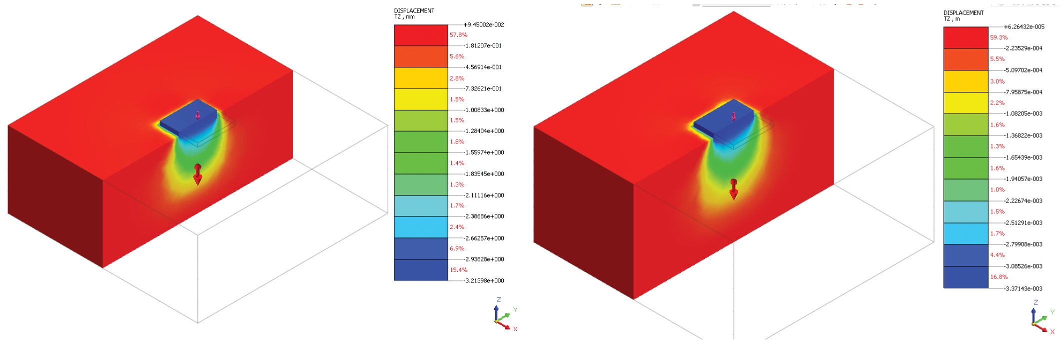


a) without the blanket layer

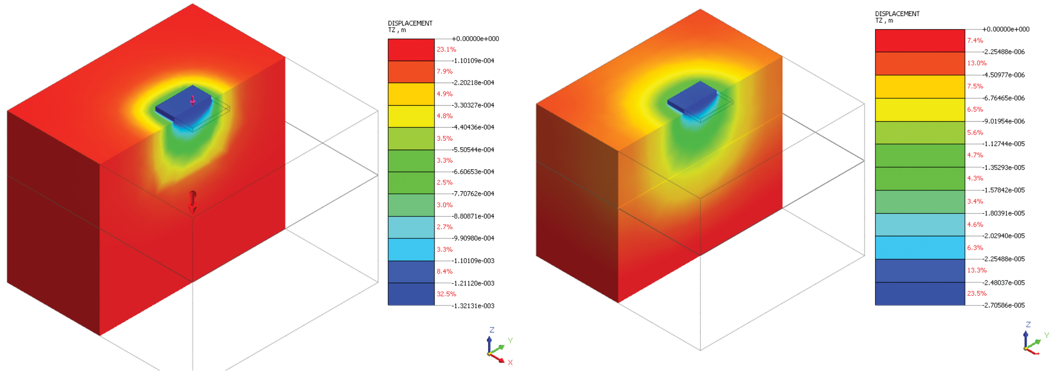
b) with geogrid in absence of blanket layer

Figure 7. Numerical model representing subgrade and ballast

was fixed for all load increments. The ideology behind the validation is that the displacements will be used to measure the settlements of the plate under the same load conditions as used in the laboratory, using a numerical model. The displacement values are used to calculate the total settlement of the plate and the use of Equations (1)–(5) will give deformation modulus for that particular numerical model. The models with different thicknesses and layer arrangements are shown in Figure 6(a)–(b) and Figure 7(a)–(b).



a) for 400 mm thickness **b)** for 500 mm thickness



c) subgrade + Ballast **d)** subgrade + Ballast + Geogrid

Figure 8. The analysed model of subgrade

5. Results

Figures 8 (a)–(d) show the analyzed model for a different combination of embankment layers similar to the laboratory testing. From Figure 8, it can be seen that the pressure bulb for the subgrade as well as for the total height of the embankment has not reached the boundaries. Hence, it can be said that there are no boundary effects even if the size of the model is small as compared to conventional studies as suggested by Sun et al. (2016). A small amount of stress can be seen on the boundaries of the tank, which can be associated with the stress generated due to soil at rest conditions in the tank. After reading the displacement values from the center of the plate, deformation modulus values (both Ev_1 and Ev_2) are calculated using the same Equations (1)–(5).

Table 6 shows the strain modulus values calculated using the displacements encountered at the center of the plate in the numerical model. From Table 6, it can be observed that with the increase in the height of the subgrade, the value of Ev_2 increases as is seen in the laboratory experiments. A similar trend can be seen in Figure 8, where the graph for both numerical and experimental studies is shown representing individual subgrade as well as ballasted embankment.

In the case of individual subgrade, the value of Ev_2 is 87% match to the experimental results whereas, in the case of a full embankment, the numerical values are 95.30% match when compared to laboratory results. This difference can be attributed to the fact that the basic assumption in the FEM method (Potts & Zdravkovic, 1999) is “continuous medium” which means soil, as well as ballast, is being considered the continuous media with only difference in the material properties. Since ballast is a high modulus material, in numerical analysis, it is acting as a thick sheet of high stiffness resulting in high displacements because of heavy loads which show prominent plastic behavior because of the Mohr-Coulomb model. In other terms, the behavior can be explained as the M-C model assumes associated flow

Table 6. Strain modulus values on the ballasted embankment from numerical studies

No.	Layer	Ev_1, MPa	Ev_2, MPa
1	400 mm Subgrade	30.05	54.86
2	500 mm Subgrade	33.29	66.52
3	500 mm Subgrade + 300 mm Ballast	39.94	117.43
4	500 mm Subgrade + 300 mm Ballast + Geogrid	44.47	136.54

rule, due to the dependency of plastic behavior on “φ” (one of the three parameters), once soil yields in the stress space of the constitutive model, it shows dilatant behavior and keeps on yielding which leads to dilatant plastic volumetric strains and hence higher displacements.

6. Discussion

The numerical model and the experimental studies are 87% and 95.3% match for single subgrade and full embankment as depicted in Figure 9. The increase in the height of the embankment is a well-established practice in developing countries to cater to the increasing demand for loads but there has to be an optimum value to bring out the efficiency in the design of the embankment. This study is a preliminary attempt in the same direction. The addition of high modulus materials such as ballast and geogrid enhances the overall modulus of the embankment which is evident from the current study. Comparing the numerical and experimental data sets, the experimental values are higher as compared to the numerical values because of the difference in particle size and various gradation of materials used in the laboratory studies. This allows the individual grain behavior to affect the results. However in the numerical model, since Ev_1 represents the elastic

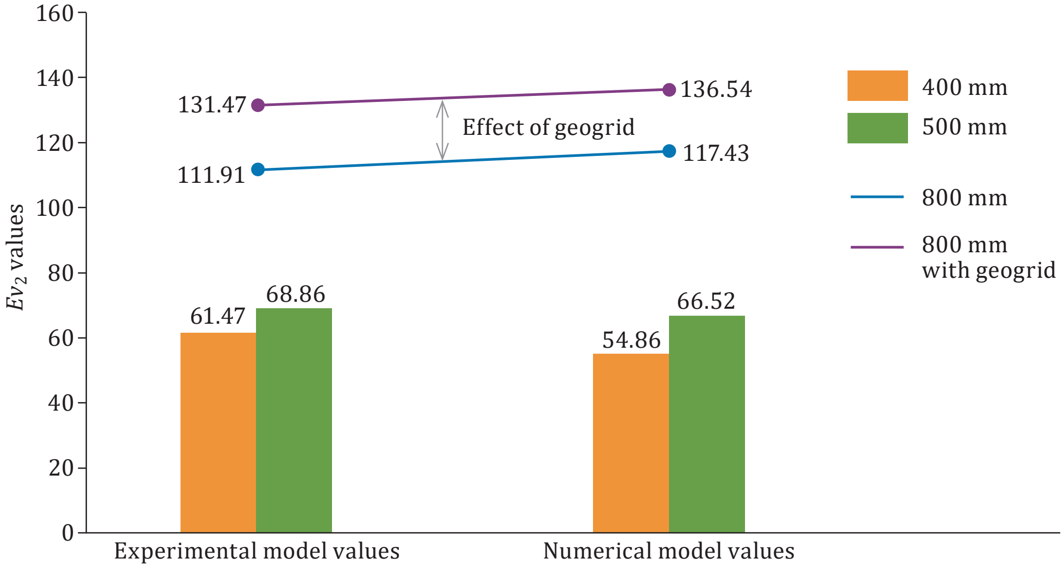


Figure 9. Comparison of experimental and numerical studies for Ev_2 values

characteristics of the embankment, due to low values of “ν” and “E”, the plate and continuous medium, show higher displacement as compared to lab tests. However, this case is reversed in the Ev_2 determination, as Ev_2 represents the plastic characteristics of the embankment, the numerical model shows higher values as compared to laboratory studies. Since in the lab, granular soil is being used, it shows the least plastic behavior due to compaction generated from first cycle loading, whereas in the numerical model, due to the dependency of plastic strains on ϕ, c, Ψ, and associated flow rule of Mohr-Coulomb, the model shows extended plastic behavior, hence, higher Ev_2 values. The overall effect of the geogrid inclusion is also evident from Figure 9, where the horizontal line represents the increase in the second deformation modulus of the embankment. Connecting both experimental and numerical values with a horizontal line, inclination depicts the increase in the modulus values in both cases. This makes the use of geogrids beneficial to the economic aspect as well as the technical design of the embankment.

Hence, the inclusion of geogrids and reduction in the embankment height is possible. As mentioned earlier, in comparison with modulus values at top of the embankment, a design methodology can be formulated based on the deformation modulus of the embankment. To see the extent of benefits derived in the current study on the existing design methodology of IR, a simple case study is adopted. In this case

Table 7. Comparison between the height of the embankment for the current study and GE-14 of Indian railways

No.	Item	IR specification	Current study
1	The thickness of the top layer of embankment fill (Subgrade)	500 mm	500 mm + Geogrid
2	The blanket thickness on top of the embankment fill	750 mm (for SQ2 type of soils)	
3	Ballast thickness on the top	350 mm	300 mm
4	The total height of the embankment above ground soil thickness	1600 mm	800 mm
5	The total reduction in height of the original embankment	–	50%

study, a general design section used frequently in India for the laying of the embankment is selected. The total height of the embankment is calculated based on parameters listed in Table 7 and the same is compared with the output of the current study. The percentage decrease in the height of the embankment is calculated based on the design parameter established by IR, which is the second modulus of deformation using DIN 18134. Here, the blanket thickness and ballast layer are reduced from the recommended thickness of GE-14 to achieve an optimum thickness of the embankment and to lower the cost of soil and aggregates as low as possible. The total reduction achieved in the case study is 50%.

Conclusions

The current study is an attempt to minimize the height of embankment with widely available new construction materials such as geogrids. The Plate load-bearing test as per DIN 18134 is used as a test measure that evaluates the design values recommended as per the GE-14 of Indian railways. The laboratory experiments are validated using numerical studies. Both sets of studies are in close agreement, pointing towards the accuracy of the study. After validation with the numerical model, the following conclusions can be made from tests conducted in the laboratory:

1. As per the design requirements of the IR, the modulus values were achieved in half the thickness of the original embankment.
2. Using stiffness as a parameter in the design of railway embankment can help in the reduction of the embankment height. In the adopted case study, 50% reduction was observed for the case of SQ2 category soils.
3. The geogrids having an aperture size of 65 mm × 65 mm (as recommended by IR for stabilization) can be used for improvement in stiffness. In the current study, a 16.27% increase in stiffness was observed using a single layer geogrid.
4. A new design methodology can be developed by including the second deformation modulus as one of the parameters in the laying of the embankments.

This study is a preliminary attempt to adopt deformation modulus as a primary parameter in the designing of the railway embankment thickness as these values are directly linked to high speed embankments in Europe. In future studies, the number of cycles in the experimental studies and different types of geogrids having varied stiffness may be included. A better correlation with field tests such as the California bearing ratio test (CBR) could be developed with deformation modulus to have a better degree of control over the laying of the embankment.

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Notations

Ev – deformation modulus
σ_0 – avg. normal stress below the loading plate in MN/m^2
s – settlement of loading plate in mm
a_0 – constant of second-degree polynomial in mm
a_1 – constant of second-degree polynomial in mM/(MN/m^2)
a_2 – constant of second-degree polynomial in mm/(MN^2/m^4)
$\sigma_{0\max}$ – maximum average normal stress below the loading plate in the respective cycle in MN/m^2
IR – Indian Railways
E – elastic modulus of soil
ν – Poisson's ratio of soil
Φ – friction angle of soil
c – cohesion of soil
Ψ – dilatancy angle of soil