Finite Element Analysis of Micropile Reinforced Subgrade in Railway Tracks

Randhir Kumar Gupta and Sowmiya Chawla

Abstract Railways is a very old form of transportation in India with a vast network of railway track. A large majority of the railway network is old and built according to the codes and demands of the times when they were constructed. There is a need to improve the existing set of railway tracks to run heavier trains for present and future demands. This paper proposes to study the effect of micropile to reinforce the railway subgrades for increased load conditions. Micropiles can be used to enhance the load bearing capacity as well reduce settlements in subgrades. In view of this, the present study explores a finite element method (FEM) model for the simulation of unreinforced and reinforced subgrades with micropiles. Different arrangements of micropiles is considered and optimum configuration for maximum performance is found out. The efficiency of micropiles in improving the railway subgrade is evaluated by comparing the unreinforced and reinforced subgrades. The developed study is helpful in analyzing the mechanism of subgrade improvement using micropile and provides valuable inputs for the design and application of micropiles.

Keywords Micropile · Finite element method · Railway track

1 Introduction

Micropiles were originally invented to retrofit the historical structures that were deteriorating with time. The restoration of old monuments and structures involved working in restricted spaces and small diameter, drilled; cast-in-place reinforced pile was suggested to serve the purpose. Since then, micropiles have undergone advancements and are now applied to wide range of applications. Today, micropiles

R. K. Gupta (✉) · S. Chawla
Department of Civil Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, Dhanbad, Jharkhand 826004, India
e-mail: randhirkgupta@gmail.com

S. Chawla
e-mail: sowmiya@iitism.ac.in

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are used in retrofitting of old foundations, construction of new foundation support, onsite reinforcement of soils, slope stabilization of soil embankments, etc.

Railways is a very old form of transportation in India and majority of its tracks are old. Presently, there are urgent demands to increase the axle loads and train speeds to enhance transportation in the country. Replacement of the old tracks with the new ones for the vast network of lines is a difficult task. Therefore, it is necessary to find some alternative tool to upgrade the existing tracks which is fast and easy to perform.

Micropiles can be used to retrofit the old railway tracks. These are easy to install without the use of heavy machinery, and there is no disruption to railway traffic while performing the installation.

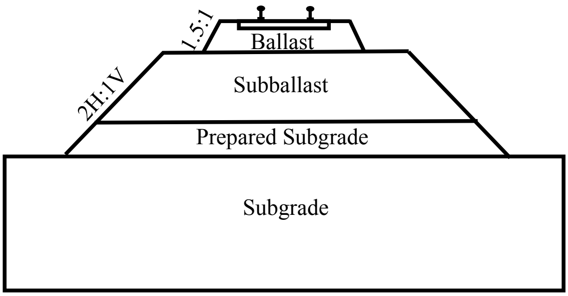
Micropiles have been used as reinforcing elements in railway subgrades in the past. A 12 m high railway embankment was stabilized using a micropile wall in Canada (Bruce et al. 2004). A study for the effect of static and dynamic loadings in the micropile reinforced subgrade was carried out by Wang et al. (2009). An experimental and numerical study has been performed by Esmaeili et al. (2012) for the use of micropiles in high railway embankments. Additionally, there are application of micropiles in the areas of slope stabilization, landslide treatment, highway embankments (Howe 2011; Guangwen 2001; Armour et al. 2000).

In this study, the feasibility of micropiles as a reinforcement for railway subgrades has been carried out. Finite element method (FEM) has been used to analyze the effectiveness of micropiles in old railway track formations. A FEM model representing an old railway track with inclusions of micropiles in the subgrade is modeled. The performance of micropile is assessed by comparing different arrangements of micropile installations, and the optimum configuration is found out. The effectiveness of micropile for the improvement of old railway track is established. Based on the study, suitable suggestions are made for the application of micropiles in railway tracks.

2 Problem Definition

The problem track section in which the behavior of micropile is to be studied is similar to the standard broad-gauge track section of Indian Railways. A schematic view of the typical test track is shown in Fig. 1. The track section shows different layers of railway track components. For this study, the subgrade dimensions are taken as 10 m wide and 7 m deep.

Fig. 1 Typical track section



3 Sensitivity Analysis Using Finite Element Method

3.1 Sensitivity Analysis

The performance of micropiles is assessed by performing a series of FEM simulations varying the configurations of the micropile in each run. The set of variations that can be performed are:

- Diameter of micropile
- Inclination of micropile installation
- Spacing of micropile (along the longitudinal direction)
- Number of micropiles (along the cross-sectional direction)
- Length of micropile
- Location of the micropile

The nature of variation in geometric parameters is illustrated by Fig. 2. Since the FEM model in this study is two dimensional, the analysis for variation in spacing of the micropile along longitudinal direction could not be performed. The length of the micropile is taken such that it does not interact with the boundaries of the subgrade and therefore the variation in length is not studied in this study. Moreover, the location of the micropile was judiciously chosen at the toe of the prepared subgrade layer and thus the variation in this has also not been studied.

3.2 Finite Element Analysis

A two-dimensional FEM model of the railway track is prepared using a FEM software MIDAS GTS NX. The prepared model is shown in Fig. 3. A halftrack geometry of the original track is considered here due to symmetry. The width and depth of the subgrade layer is chosen to accommodate the length of the micropile and show no boundary effect. Hybrid mesh using automesh generation has been used here for fast analysis of the model. Interface elements have been used at the intersection of two

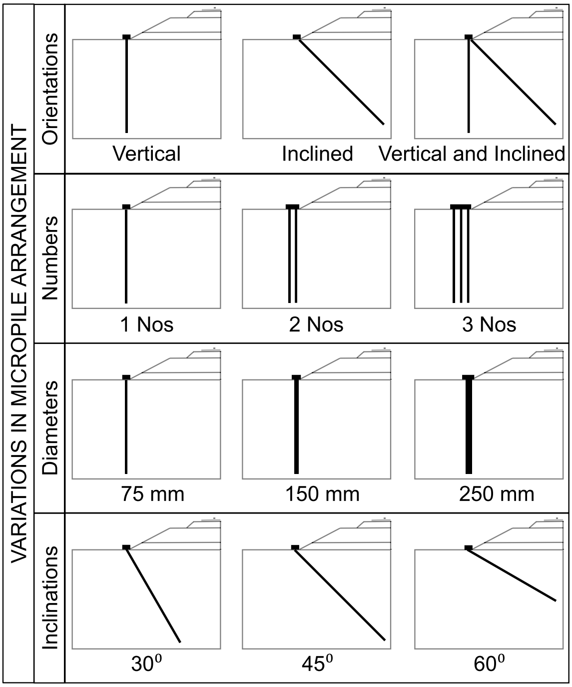


Fig. 2 Variation in geometrical parameters

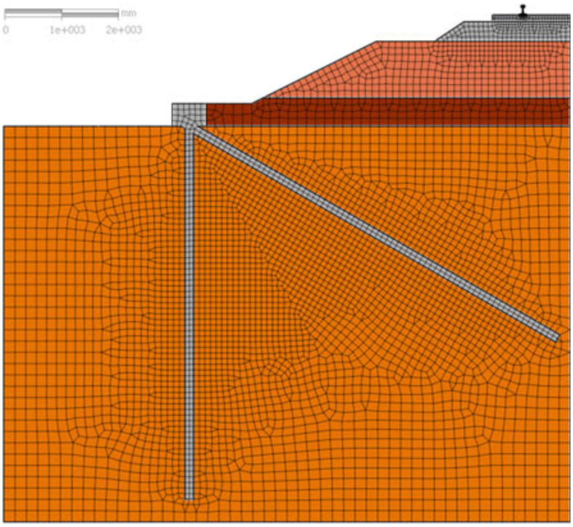


Fig. 3 Finite element model of the test track

Table 1 Material properties

Material	E (MPa)	μ	γ (kN/m^3)	C (kPa)	$\phi°$
Ballast	140	0.37	16.5	0.1	45
Subballast	70	0.37	16	0.1	40
Prepared subgrade	15	0.49	19	30	0.1
Subgrade	5, 10, 15	0.49	18	20	0.1
Rail	2×10^5	0.3	76.6 (60 kg/m)	–	–
Sleepers	30	0.2	25	–	–

layers of the model. Boundary conditions of roller supports for the vertical sides and fixed support for the horizontal bottom is used. The sloping and other horizontal boundaries are left free.

3.3 Material Properties

The material properties used in this study is shown in Table 1. The soil type for subgrade and prepared subgrade layer is clay the properties of which is taken from clay belonging to Dhanaury village in Haridwar district. Ballast layer material is that of crushed rocks and subballast material is that of stone dust from crusher plants. All the material properties are referred from previous literature (Sowmiya 2013).

The sensitivity analysis using FEM is performed in this section, the results of which are discussed in Sect. 4. The FEM model of one such variation showing the combined vertical and inclined micropile is as shown in Fig. 3.

4 Results and Discussions

4.1 Results of Sensitivity Analysis

The sensitivity analysis performed using FEM has given the detailed effect of each variations in strengthening the subgrade. The analysis of these results is presented in the following subsections.

4.1.1 Variation in Orientation of Micropiles

The micropiles are varied in different orientations—vertical, inclined and a combination of vertical and inclined. For this set of variation, the diameter is fixed at 150 mm and single micropile is used for vertical, inclined orientations. Combination

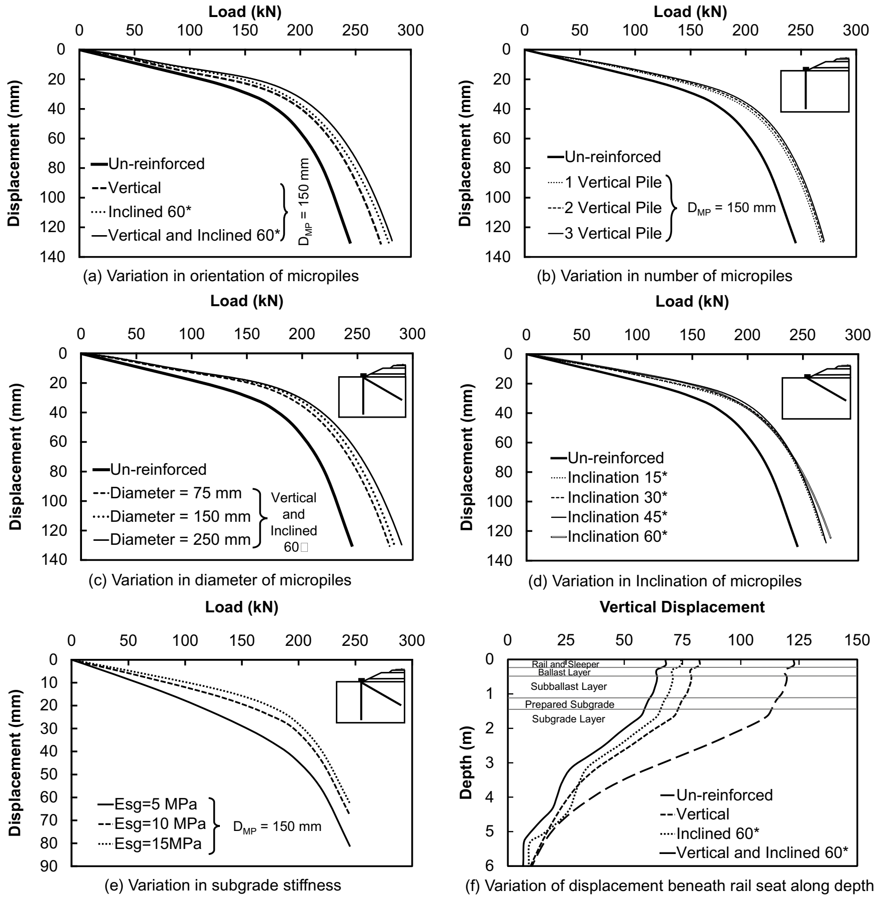


Fig. 4 Results of sensitivity analysis for various configurations

of vertical and inclined uses two micropiles—one vertical and one inclined. The result of the analysis is presented in Fig. 4a. From the figure, it is observed that the combination of vertical and inclined micropile performs the best in this set.

4.1.2 Variation in Number of Micropiles

Different numbers of micropiles are used in this variation. 1, 2 and 3 vertical micropiles of constant diameter = 150 mm are modeled. The result of this analysis is shown in Fig. 4b. It can be observed here that there is not much improvement by the increase in the number of micropiles. Since this is a 2-D model, the effect of this variation may be diminished, a 3-D model may reveal the effect. However, there is a significant improvement in load carrying capacity even with just one vertical micropile when compared with un-reinforced subgrade.

4.1.3 Variation in Diameter

Three different diameters of micropile—75, 150 and 250 mm are modeled in a combined orientation of vertical and inclined. The effect of this variation in the subgrade strength is shown in Fig. 4c. Here, as the diameter of the micropile is increasing the load bearing capacity of the subgrade increases.

4.1.4 Variation in Inclination

In this variation, the inclination of the micropiles is increased from 15° to 60° from vertical. The effect of this variation is shown in Fig. 4d. It can be observed that the effect of inclination on the load bearing capacity of subgrade is marginal. A 3-D model may reveal the effect of this variation.

4.1.5 Other Effects

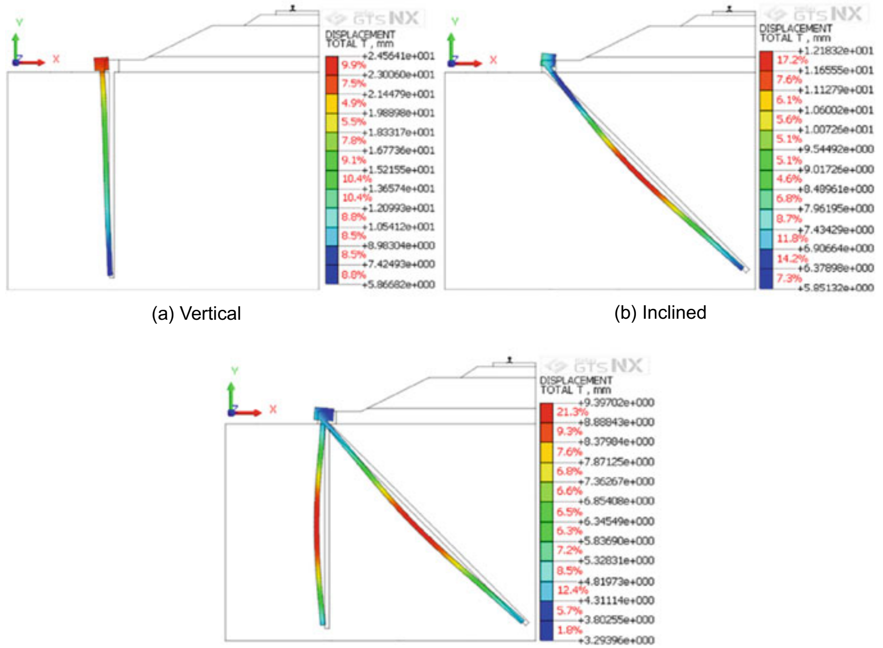
Effect of subgrade stiffness on micropile reinforced bed is shown in Fig. 4e. The micropile reinforced bed is studied for the variation in the stiffness of subgrade. Three different subgrade moduli of 5, 10 and 15 MPa is considered. There is improvement in the load bearing capacity for increased subgrade modulus.

Vertical displacement beneath the rail seat throughout the depth of track foundation is monitored for each micropile configuration. This is shown in Fig. 4f. The combination of vertical and inclined micropile performed the best in reducing settlements. The settlement curve of inclined micropile crosses with that of vertical micropile curve at a depth of about 4.5 m; this is due to the presence of inclined part of micropile beneath the rail seat at that depth. Similarly, the curve of vertical and inclined micropile shows a kink bend due to the same reason.

4.2 Deformation Behavior Along Micropile Length

The nature of micropile deformation in each arrangement of micropile is an important observation to understand the failure mechanism of micropiles in railway subgrades. For this, the deformation of micropiles throughout its length is depicted in Fig. 5a–c.

When only a vertical pile is used, it shows lateral shift moving outwards away from the center line of the track. This shift also decreases from top to bottom of the micropile and appears to tilt about a point somewhere in at the bottom of the



(a) Vertical

(b) Inclined

(c) Vertical and Inclined 45^0

Fig. 5 Deformation of pile along its length

micropile. For this mechanism, micropiles should be designed to withstand lateral forces that gets generated due to the axle load of trains.

The inclined micropile primarily shows bending effect with marginal lateral shift at the ends. The bending is more toward the mid length of the micropile which sags under the lateral pressure of the soil. Such mechanism suggests for the design of micropile to withstand bending behavior.

The combined vertical and inclined micropile shows bending and translation in both the legs. The vertical leg which did not show any bending previously shows bending now. The translation of the top of vertical micropile and the pile cap has also reduced from the previous case. The inclined leg seems to act as an anchor to the pile cap and top of vertical micropile, hence reduces the lateral shift of those. However, adding an inclined leg induces bending in the vertical leg. Such deformation behavior suggests for the design of micropile to withstand both lateral forces and bending.

4.3 Failure Zones in Soil Subgrade

The nature of possible failure of the track foundation layer can be understood by analyzing the shear strain pattern within the track layers. From Fig. 6a–d, it can

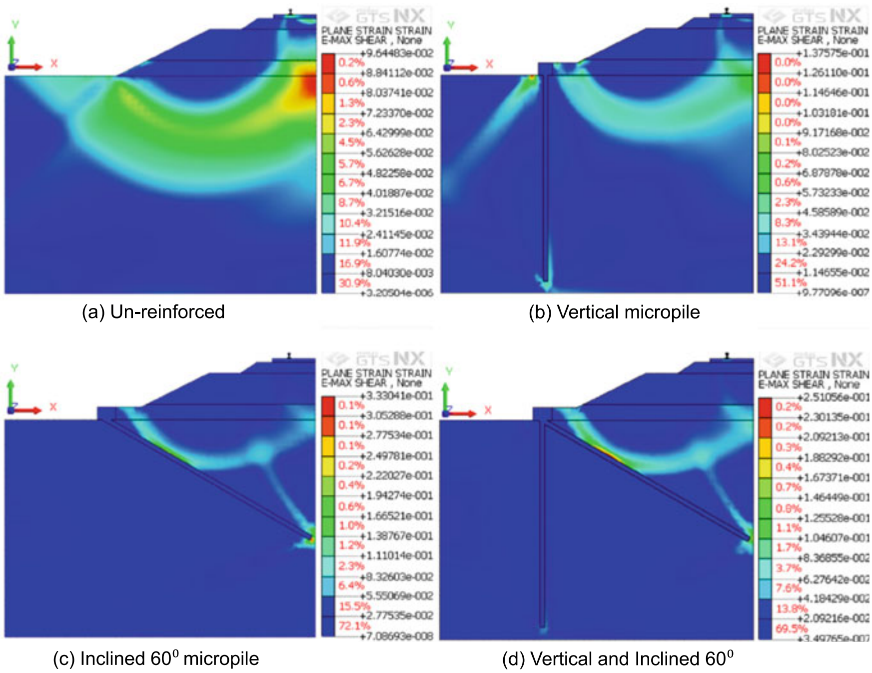


Fig. 6 Failure zones in soil subgrade

be observed that a clear radial zone of higher shear strain is formed. This zone of higher shear strain decreases with the implementation of micropiles in the subgrade. A vertical micropile reduces the zone of higher shear strain than that of un-reinforced section. The inclined micropile further reduces the zone of higher shear strain. But the shear strain zone in the inclined micropile section is similar to that of the combined vertical and inclined micropile section. Thus, in this comparison the inclined micropile has performed the best.

4.4 Effect of Pile Cap Below and Above the Top of Subgrade

The pile cap has been modeled to act as a cap beam along the length of the rail. First the pile cap was embedded just within the top of subgrade layer. Such arrangement caused heaving of the prepared subgrade layer which tends to flow over the pile cap, that can be observed in Fig. 7a. To mitigate this, the pile cap was raised above the top of subgrade and the lateral heaving was reduced, shown in Fig. 7b. The placement of pile cap above the top of subgrade helped in providing a lateral restraint to heaving soil and thus can be used as a counter measure to reduce heaving.

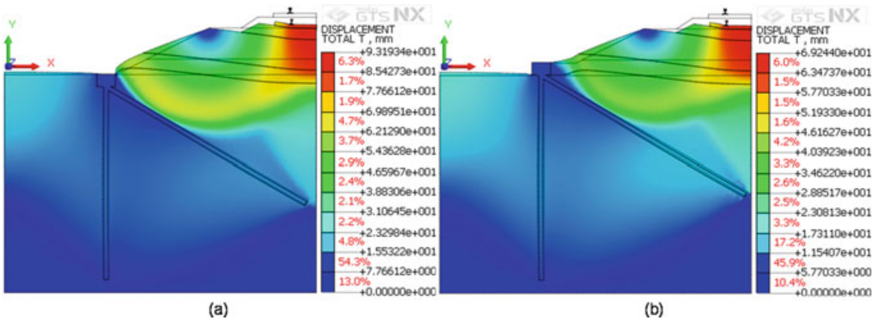


Fig. 7 Effect of pile cap below and above the top of soil subgrade

5 Conclusion

In this study, the application of micropile for reinforcing railway track foundation has been investigated. Single micropiles and in groups with variations in numbers, inclination, diameters and orientations have been studied. An analysis of the deformation behavior of the micropile in different arrangement has been carried out to understand the failure mechanism of micropiles. Failure zones within the track foundation layers are also studied with the help of maximum shear strain values. The effect due to location of pile cap above and below the top of subgrade has also been studied.

The main conclusions that can be drawn from this study are:

- A combined vertical and inclined 60° micropile has shown best performance among all the variations.
- The deformation behavior of each pile suggests the nature of forces acting throughout the length of the pile, hence provide valuable input for their design and application.
- The extent of the radial maximum shear strain zone decreases with implementation of micropiles. This helps in mitigating the failure subgrade.
- The lateral restraint offered by the pile cap when placed above the subgrade top proves beneficial in reducing the heave at the toe of prepared subgrade.

Although the combined vertical and inclined variation performs the best, yet mere application of micropile in any variation shows a significant improvement from that of unreinforced condition. Hence, the use of micropiles in subgrade of a railway foundation proves beneficial.

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