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The Effectiveness of Deep Soil Mixing on Enhanced Bearing Capacity and Reduction of Settlement on Loose Sandy Soils

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A large portion of Iran railway routes are located in sandy desert areas. Therefore, paying attention to soil stabilization methods seems essential. In present study, in parallel to introducing the deep soil mixing as an efficient and economic method of soil improvement, in the frame work of a practical example, assuming loose sandy soil parameters, feasibility of the method application is investigated. For this purpose, by conducting the plate loading test (PLT) and direct shear test (DST) on the railway embankment and sandy subgrade materials, their shear strength as well as deformability parameters ware achieved. Further, by developing a two dimensional FE model using Plaxis code, the railway embankment stability on loose sandy subgrade is evaluated by using the C-Φ reduction method. The analysis is conducted for two separate cases of subgrade with and without soil-cement columns. The numerical results for embankment with 1.5 m height shows that for the loose sandy subgrade the embankment failure load limits to 447 kN corresponding to a safety factor of 1 while by using the soil-cement columns with diameter of 0.9 m to 1.2 m the failure load varies from 741 to 1274 KN and the safety factor varies from 1.26 To 1.66. Moreover, the total embankment settlement deceased up to 25% in the best arrangement of the columns.

1. Introduction

The higher safety, rapidity, ride comfort, low cost and the minimal environmental impacts, have made railway transportation eminent amongst the other modes of transport. As one of the most important parts of railway track system is subgrade, any damage in this component can cause interruption in serviceability of the whole track system. Many major failure modes in subgrade can be classified as: a) consolidation and massive shear failure b) progressive shear failure c) attrition d) excessive plastic deformation e) excessive swelling and shrinkage and f) frost heave and thaw softening [1]. Among these items, the failure modes of a, b and c directly depend on railway traffic volume and its repetitive nature. Meanwhile, the massive shear failure occurs due to increase in embankment weight during rainfall or excess in train axle load. In this type of failure, majority of the sliding surface passes through railway embankment and natural ground. Practically, to avoid such failure mechanism, usually the deep soil improvement methods such as insertion of stone columns, using micro piles in group form, utilizing jet grouting or executing of deep soil mixing can be applied. Amongst the aforementioned soil improvement methods, deep soil mixing (DSM) implies on the method which use the cement material for mixing with loose soils in dry or wet condition during a rotary drilling in down to top direction. Reviewing the technical literature in this regard shows that dry deep mixing method is utilized to improve soft subgrade of railway track in Sweden [2-5]. Moreover, in framework of INNOTRACK

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research project, the wet DSM method was utilized for soft subgrade stabilization [5]. In addition, many laboratory studies were carried out by many researchers (Dong et al (1996) [6], Al.Tabbaa et al (1999) [7], David Castelbaum et al (2011) [8]).

Scrutinizing on pervious researches evidently confirms no considerable numerical study on evaluation of DSM efficiency in increasing bearing capacity and controlling settlement of railways rested on loose sandy subgrades. Therefore, the first stage of the present research included the construction of five soil cement columns in a loose sandy soil by using the developed DSM apparatus at SRE (School of Railway Engineering). In continuation unconfined compression tests were carried out on soil cement samples. The load bearing capacities as well as elasticity modulus were obtained. The friction angle of soil cement was considered as a sandy soil and the cohesion of columns was assumed to be half of the ultimate bearing capacity. On the other hand, the sandy soil elasticity modulus was obtained through conducting plate loading test (PLT) (ASTM D1194-94) in loading chamber with a dimension of 1.2×1.2×1 meters. Moreover, the friction angle of loose sandy soil was evaluated by direct shear test (ASTM D3080-90). Knowing the soil cement columns' and sandy soil mechanical parameters a 2D finite element model of railway track was constructed for two separate cases of reinforced and unreinforced sandy soil as a track subgrade. In finale section of the research a series of sensitivity analyses were performed on the diameter and spacing of soil cement columns. The aim was to study the effects of such parameters on improving the bearing capacity and controlling the settlement of railway track.

2. Deep Soil Mixing Definition

The DSM method is a ground modification technique that improves the quality of soil by in situ stabilization of soft soil [6]. It is more frequently applied for stabilization of the soil to a minimum depth of 3m and is currently limited to treatment depth of about 50m [9].

The DSM columns can be configured in different patterns as in Figure 1. Each one of these patterns can be suitable for especial situations. For instance, the square or the triangular grid patterns of single or combined columns are usually applied when the purpose of deep mixing is reduction of settlement and in some cases improvement of stability. They are suitable for road and railway embankments [9].

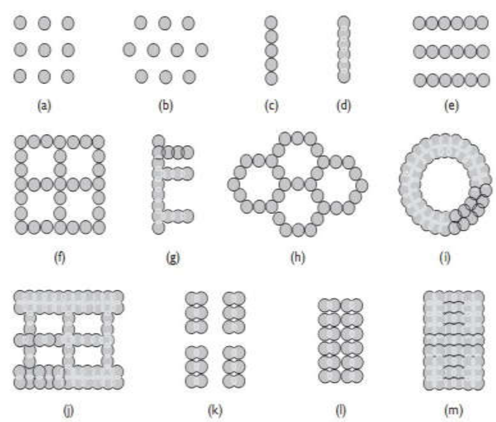

Figure 1. Examples of deep soil mixing patterns: (a), (b) square and triangular arrangement; (c) tangent wall; (d) overlapped wall; (e) tangent walls; (f) Tangent grid; (g) overlapped wall with buttresses; (h) tangent cells; (i) ring; (j) lattice; (k) group columns; (l) group columns in-contact; (m) block

3. Laboratory Test on Subgrade and Embankment Soil

3.1. The subgrade and embankment soil classification

Since a large portion of railway tracks in Iran are located on loose sandy soils with high settlements and low bearing capacity, poorly graded sand (SP) with 70% density for subgrade soil and clayey sand (SC) for embankment are selected. Figure 2 presents the particle size distribution curve of soils.

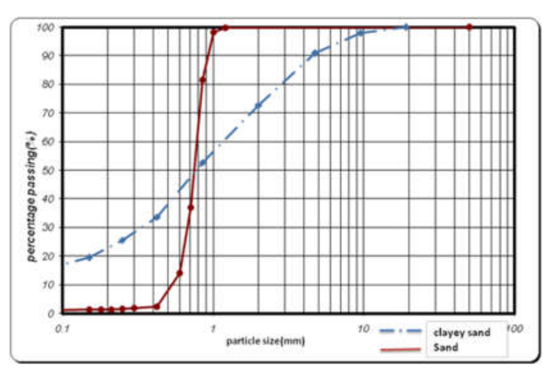

Figure 2. Particle size distribution curves of the subgrade and embankment soils

3.2. The direct shear test

The direct shear test was conducted on embankment and subgrade material samples and the following results including cohesion and friction were obtained, Table 1.

3.3. The plate load test of subgrade soil

The cyclic plate load test on subgrade and embankment soils was conducted base on ASTM D1194-94. Figure 3 shows the load-displacement curve, from the test on loose sandy subgrade. The loading on sandy soil accomplished in a steel box with dimensions of 1.2×1.2×1 meters and the plate dimensions were selected as 30×30 meters. The loading process continued until failure load in three different stages as shown in Figure 3. The maximum applied load reached to 3.3 ton at failure moment corresponding to 62 mm settlement. The loading chamber and the used PLT apparatus are shown in Figure 4.

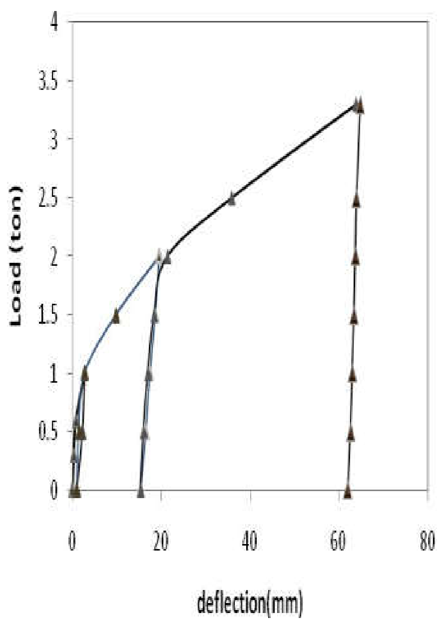

Figure 3. Plate load test for loose sand

4. Laboratory Tests on Soil-Cement Columns

A laboratory deep soil mixing device with a scale of 1:10 was developed at SRE, Figure 5. Five samples of columns with 10 cm diameter were made and cement mortar considered as a main material. Many Unconfined Compressive Test (UCT) were carried out on columns after 28 days in order to determine their load bearing capacities as well as elasticity modulus. The friction angle of the columns' material was considered same as the sandy soil while its cohesion was assumed as one-half of the obtained ultimate bearing capacity. Figure 5 shows DSM device and many produced soil – cement columns samples.

Figure 4. Plate load test before and after loading

5. Numerical Modeling

5.1. Model geometry

The two-dimensional (2D) numerical model was developed for this case study using the Plaxis2D software with 1.5 m embankment height with considering depth of 7 m for subgrade soil as shown in Figure 6. The model is compared in two conditions of with and without soil-cement columns. In addition, two diameters of 0.9 and 1.2 meter with 4 different spaces from center to center of the columns were considered for the model including the columns. The material properties of soil cement column, subgrade and embankment soil were obtained from laboratory tests as shown in Table 1

5.2. Loading condition

Ballast and sub-ballast weight were applied on the 2.6 m width embankment crest as a distributed load as shown in Figure 6. The loading was increased to reach the failure point corresponding to a safety factor of 1 for the model without columns. The columns with

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Figure 5. Deep soil mixing device and sample of columns

Table 1. Material properties of soils and DSM column

Material Property	Column	Sand	Clayey sand
Density (kg/m^3)	2100	1590	1760
Young's modulus (MPa)	450	14.9	49.87
Poisson ratio	0.3	0.3	0.3
Bulk modulus (MPa)	375	12.42	41.56
Shear modulus(MPa)	173	5.73	19.18
Cohesion (kPa)	2800	-	25
Friction angle (Degree)	33	33	31

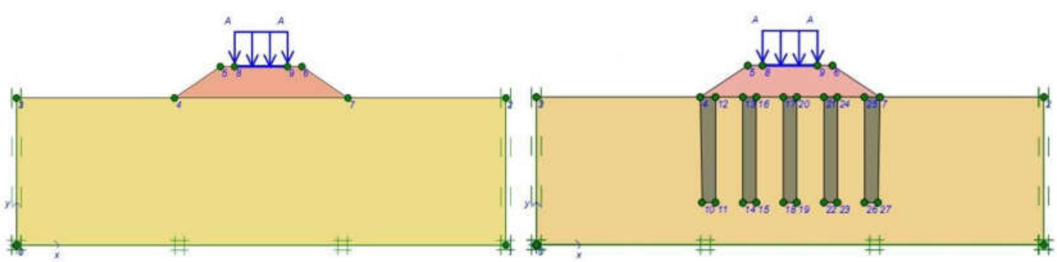

Figure 6. Embankment on a loose sandy soil in two situations of with and without columns

different diameters and spacing were placed into the subgrade and the corresponding safety factors and settlements were assessed, Table 2. Failure modes are presented in Figures 7 and 8.

From the results, it can be observed that a large portion of failure surface occurred in the subgrade. Therefore, using the deep mixing columns can be suitable for loose subgrade soils and low embankments height.

sizes of the spacing. However, higher settlements at the spacing between 2.5 to 3 when compared with the case of columns of 0.9 m in diameter are observed. On the other hand, an increase in the ratio of S/D causes the safety factor to decrease and settlement to increase in the presence of columns. In addition, the columns can lead the safety factor to an amount of 1.26 at the worst situation with low settlements.

6. Results and Discussion

Table 2. The results of model

Diameter (m)	Column space/column diameter	Load (KN/m^2)	Failure load(KN/m^2)	Settlement (cm)	Safety Factor	Number of columns
0.9	0	172	172	12.07	1	
	1.5	172	410	3.8	1.54	10
	2	172	315	5.6	1.38	8
	2.5	172	285	8.78	1.26	6
	3	172	305	8.02	1.27	5
1.2	0	172	172	12.07	1	
	1.5	172	490	3.72	1.66	6
	2	172	470	4.87	1.592	5
	2.5	172	360	9	1.4	4
	3	172	370	9.8	1.37	4

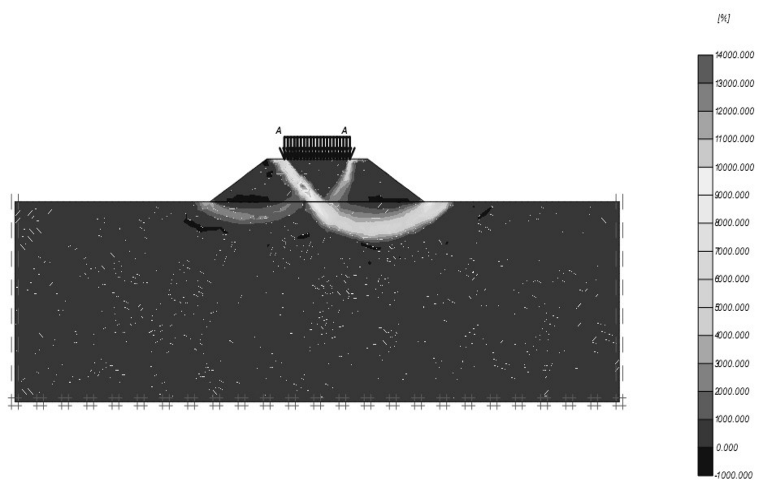

Figure7. Failure surface of unreinforced subgrade

The influence of different column diameters and spacing on safety factor and settlement is carried out and is presented in Table 2 and Figures 9 and 10. It is shown that for the columns with a diameter of 1.2 m, even with a lower number of columns compared with the case of the columns with a diameter of 0.9 m the performance is improved. It is also concluded that executing deep cement columns with 1.2 m diameter leads to higher safety factors for all

7. Concluding Remarks

In the present study, the loose sandy soil and the sandy clay were considered as subgrade and embankment materials of railway track, respectively. Through many laboratory tests the mechanical properties of such materials were achieved. By developing DSM apparatus many columns were executed in loose sand and by doing UCT, their mechanical characteristics were obtained. Finally, by implementing the

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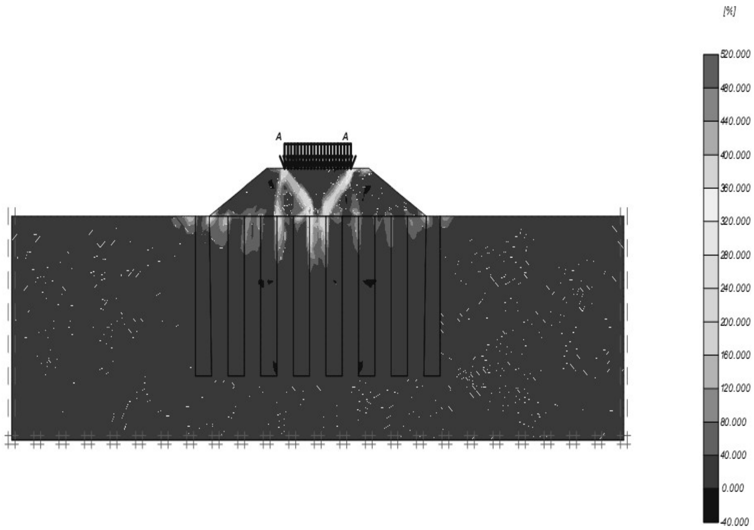

Figure 8. Failure surface of reinforced subgrade

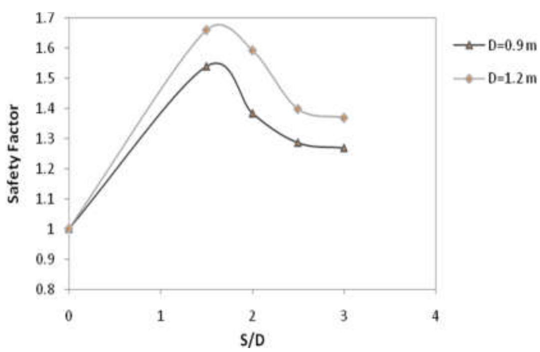

Figure 9. Safety factor vs. S/D (Space/Diameter

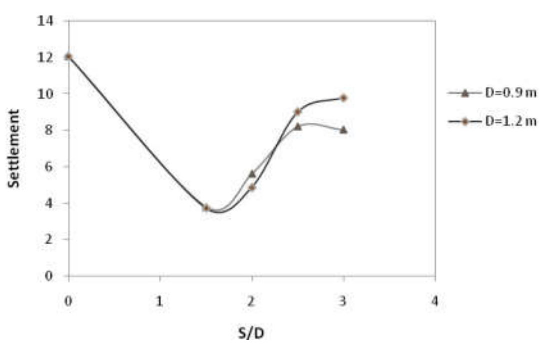

Figure 10. Settlement vs. S/D

laboratory test results in a 2D finite element model a comparison was made between the behavior of embankment rested on non-reinforced and reinforced sandy subgrade. The most important findings of the research can be summarized as:

1. Installation of soil-cement columns with 0.9 m diameter and S/D (Space/Diameter) 1.5, 2, 2.5 and 3 in loose sandy subgrade can cause 138%, 83%, 65% and 77% increase in embankment bearing capacity in comparison to non-reinforced embankment, respectively.
2. Execution of soil-cement columns with 1.2 m diameter and spacing 1.5, 2, 2.5 and 3 in loose sandy subgrade can cause 184%, 173%, 109% and 68% increase in embankment bearing capacity in comparison to non-reinforced embankment, respectively.
3. Installation of soil-cement columns with 0.9 m diameter and spacing 1.5, 2, 2.5 and 3 in loose sandy subgrade can cause 68.5%, 53.6%, 27.7% and 33% decrease in embankment settlement in comparison to non-reinforced embankment, respectively.
4. Execution of soil-cement columns with 1.2 m diameter and spacing 1.5, 2, 2.5 and 3 in loose sandy subgrade can cause 69.17%, 59.6%, 25.4%, and 18.8%

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decrease in embankment settlement in comparison to non-reinforced embankment, respectively.

The optimum S/D (spacing to diameter) are 3 and 2.5 with respect to 0.9 and 1.2 diameters of soil cements.

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