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Geo-Grid Combined with Concrete and Limestone Columns to Reduce the Embankment Subsidence Located on Inclined Layers of Soft Soil

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Abstract

Soft soil has low shear strength and its density is high; construction of embankments on them would cause problems such as large and non-uniform subsidence. One way to avoid these subsidence is using of geo-grid combined with cement and lime columns. Geo-grids due to their tensile strength, and cement and lime columns due to their bearing capacity and their body friction, reduce embankment subsidence. Extensive researches have been done in order to reduce the subsidence of the embankments located on the roads, but few studies have being done about the inclined embankments on soft soil layers. In this paper, the road embankment has been located on inclined soft soil layers; the study will try to reduce embankment subsidence and uniform them using geo-grid combined with cement and lime column subsidence. The results show that the realization of this issue will cause subsidence reduction and uniformity in the embankment surface.

Keywords

Inclined Layering, Integration of Subsidence, Geo-Grid, Cement and Lime Columns, Software Plexis

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1. Introduction

Soil reinforcement is one of the reliable and effective ways in improving soil's properties. Introducing polymer fibers such as Geo-textiles, Geo-grids, Geo-membranes, Geo-pipes, and etc., as soil arming elements, have created a great revolution in the construction of reinforced soil structures. Geo-grids are rigid or flexible polymer sheets that are perforated with numerous applications in civil engineering. Some of their uses can be reducing the embankment's subsidence located on soft soils. The main problem in construction of roads embankments are, large and non-uniform amounts of subsidence due to the different layers of soil beneath the embankments. Today, in order to solve these kinds of problems, there are several methods in improving the soil; one of these methods is geo-grid combined with a series of columns with different diameters, materials and lengths at different intervals, which is placed under the embankment. Geo-grids will cause reduction in embankment subsidence with their tensile properties and columns will do the same issue using body resistance and friction. Long columns strength and rigidity is more than short ones, so long columns are being used in extensive subsidence and shorter columns are being used in restrictive subsidence. These columns will uniform embankments subsidence and also would bear different loads caused by embankments and transportation vehicles, due to their bearing capacity and their body friction; also would unify soil amount and would increase its bearing capacity. Recently, many researches have been done on the field combined columns with embankments, which are as follows:

Chen (2001) did numerous analyzes on several columns combined with embankments [1]. Liu (2003) and Chen (2004) did experiments carried out on the compound embankments with two types of columns [2] [3]. Zhou (2004) did field tests on an embankment consisting of several materials for the column [4]. Zheng (2005) has provided a method for combined gray limestone column with embankment [5]. Yan (2003) has introduced a systematic method for designing multiple columns with composite foundations [6]. Hussein (2006) has done a numerical study on improving the soft soil using chemical plugs under the embankment [7]. Han (2006) did a two-dimensional numerical modeling of armed embankment with geo-grid, located on the top of the deep column deep [8]. Liang (2003) has done numerical analysis about floating composite columns with different types of candles [9]. Esna-ashari (2010) did his studies in the field of combined embankments with cement and limestone columns in the soft soil inclined layers [10]. Also several three-dimensional finite analyses have been carried out on gray limestone columns with different lengths and diameters by Zheng (2003 and 2008) [11] [12].

Despite numerous studies on the composite embankments with columns, there are few studies on the geo-grid combinations with composite lime and cement columns with embankments on inclined layers of the surface. In this study, using the software Plexis, a layer of soil on the inclined embankment of the Shahid Kalantari highway in Urmia-Tabriz will be simulated. After analyzing the model, the non-uniform subsidence will be noticed. In order to reduce this subsidence; at first cement and limestone columns were used and their best position was determined. Then geo-grid has been added to this optimal model, so embankment's subsidence has been decreased. This study will try to determine best material, length, and column distance which cause reductions and uniformities in embankment subsidence by putting geo-grid and a series of short and long columns with constant diameters under the embankment.

2. Model's Characteristics

2.1. Soil Amount and Boarders Condition

Figure 1 shows the soil profile and the embankment of the highway ShahidKalantari of Urmia-Tabriz (all dimensions are in meters). This highway is from Urmia and Tabriz and crosses over Urmia Lake. Part of this road is on the West Coast of the lake and passes over the loose soil and lake sediments, which are generally made up of fine Silty clay layers with low shear strength and high consolidation.

Table 1 shows the soil and embankment profile, **Table 2** shows the specifications of asphalt on the embankment and **Table 3** shows the profile of geo-grid. In the left half of the asphalt, there is an expanded uniformly load of 12 KN per square meter, and on the right half of the asphalt, there is a load with intensity of *8KN* per square meter. The coordinates of the points are shown in **Table 4**.

Boundary conditions which are considered for soil mass are standard. By applying these boundary conditions, backrest of soil mass bottom goes to be adjacent kind and side backrests of soil mass (left and right) would be in rolling kind. By doing so, soil is allowed to do vertical displacements.

Underground water levels are below the bottom of the embankment; in other words embankment is unsaturated and rest of the mass is saturated soil.

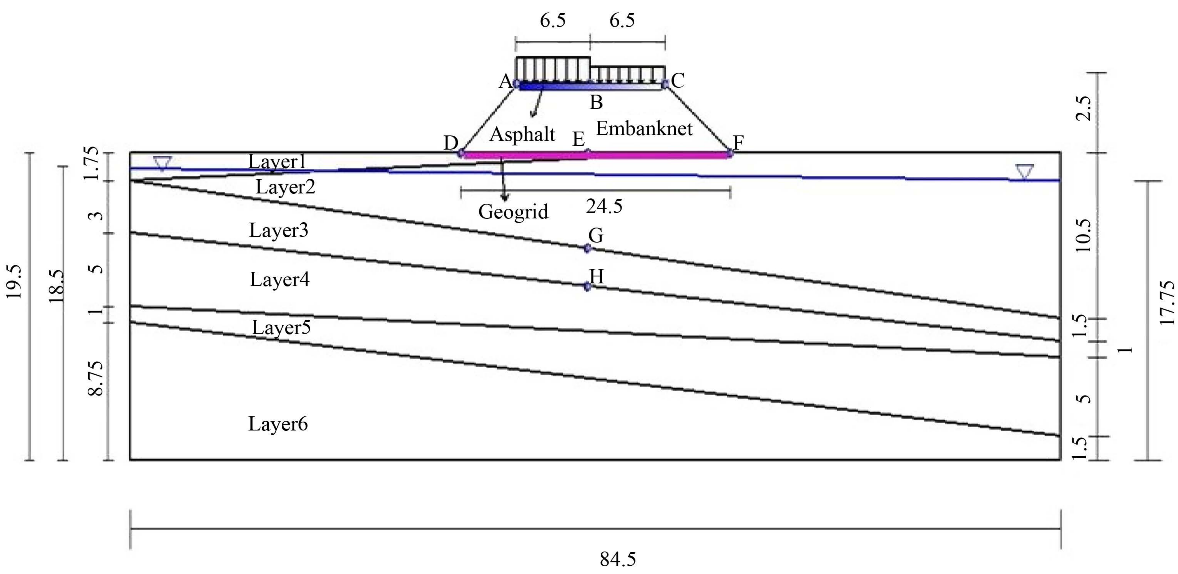

Figure 1. Overview of soil and embankment (all measurements are in meters).

Table 1. Soil mass and embankment characteristics.

Row	Parameter	Unit	Embankmet	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
1	Soil Name	-	-	CL	OL	CL	CL	OL	CL
2	Behavoural Model	-	Mohr-Columb	Creeper Soft Soil	Creeper Soft Soil	Creeper Soft Soil	Creeper Soft Soil	Creeper Soft Soil	Creeper Soft Soil
3	Draining Condition	-	Drained	UnDrained	UnDrained	UnDrained	UnDrained	UnDrained	UnDrained
4	γ_{unsat}	KN/m^2	13	15.5	14.8	15.5	15.5	14.8	11.1
5	γ_{sat}	KN/m^2	13	17	17	16	16	17	15
6	K_x	m/day	1	3e−5	3.5e−4	1e−4	1e−4	3.5e−4	3.09e−4
7	E	KN/m^2	5e4	-	-	-	-	-	-
8	υ	-	0.35	0.15	0.15	0.15	0.15	0.15	0.15
9	C	KN/m^2	1	20	5	20	20	5	20
10	φ	Deg	34	35	30	30	30	30	35
11	ψ	Deg	0	0	0	0	0	0	0
12	λ^*	-	-	0.06	0.12	0.07	0.07	0.12	0.098
13	K^*	-	-	0.015	0.037	0.02	0.02	0.037	0.19
14	M^*	-	-	2.5e−3	3e−3	2.8e−3	2.8e−3	3e−3	3e−3

Table 2. Coordination's of embankment asphalt.

Row	Parameter	Behavioural Model	Unit	Amount
1	EA		KN/m	0.35
2	EI	Linear Elastic	KN·M^2/m	0.35
3	d		m	3.464

Table 3. Geo-grid characteristics of embankment beneath.

Row	Parameter	Behavoural Model	Unit	Amount
1	EA	Linear Elastic	KN/m	2500

Table 4. Geo-Grid characteristics of embankment beneath.

Row	Point	X (m)	Y (m)
1	A	34.8	21.9
2	B	41	21.9
3	D	30	19.5
4	E	41	19.34
5	G	41	13.2
6	H	41.25	11.3

Mohr-Clumb behavioral models is a perfect Elastic-Plastic behavioral model which has 5 parameters of E, V, ψ, ϕ, c. Also the behavioral model of inclined soft soil has M^*, λ^*, K^* parameters, in addition to ψ, ϕ, c parameters, which are obtained through audiometry test.

2.2. Columns

Columns which are used have a constant diameter and made of cement and limestones and have linear Elastic behavior, through **Table 5**. Also **Figure 2** shows the location of the short and long columns. This column arrangement is constant during the research, just material and column distances will vary. The left half of the embankment has short columns and the right half of the embankment consists of long columns (the columns' arrangements have been acquired after model analysis in non-column state; and for that side of the embankment with more subsidence (right side) the long column and for the other side (left side) the short columns have been used, that will be described subsequently).

2.3. Meshing

In meshing the soil mass, elements with 15 nodes and two degrees of freedom for each node are been used; and for columns, 5 node elements with 3 degrees of freedom have been considered (two transitional degrees and rotational degree). The medium meshing has been used for the meshing of the general meshing; and finer mesh has been used around the columns because of the sensitivity of the issue (**Figure 3**).

3. Loading Method and Calculation Type

It is assumed that the columns have been built in a day and geo-grid also has run on the same day; embankment also has done in five stages and 2 days has been considered for each stage in order to stabilize the soil. The soil will be consolidated for 4 years. Again, the upper surface of the embankment has been asphalted, and in accordance with the paragraph (2-1-1), has been loaded for a day. At this stage, the soil has been noticed under consolidation of the territory for 6/5 years. This consolidation will be continued until the pore water pressure is less than 1 kpa. Reaching the low pressure of pore water is complication of standard consolidation.

4. Compliance of the Considered Soil Model with the Real Model

Figure 4 and **Figure 5** show the embankment subsidence in the non-column issue after 9 years and 10.5 years after construction, respectively. Due to the figures, subsidence of this model is in accordance with the actual model that has been done by other researchers.

5. The Method of Modeling

In this research modeling has been done using finite element software Plaxis 8.2. This application is two dimensional and is appropriate for projects that have surface strain conditions. Because this research model is lengthy,

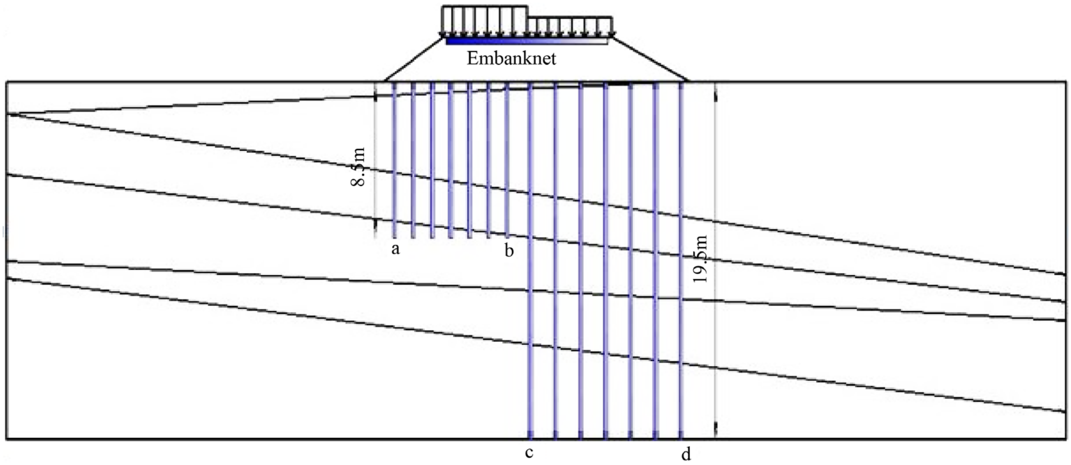

Figure 2. Implanting columns beneath the embankment.

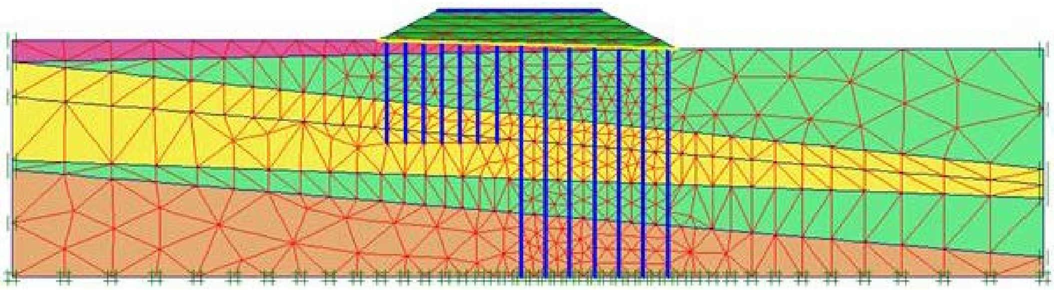

Figure 3. Model meshing.

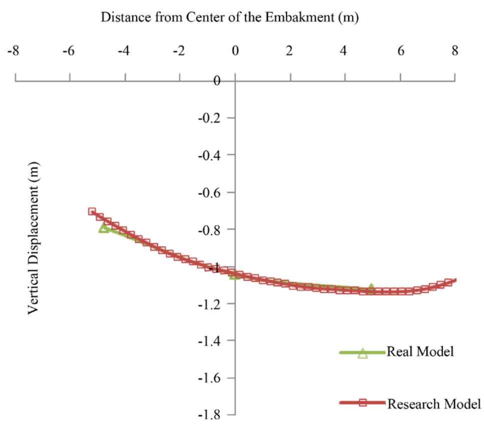

Figure 4. Comparison of Real Model Subsidence with research model in 9 years.

Table 5. Specific points characteristics.

Row	Parameter	Unit	Lime Column	Cement Column
1	Behavoural Model	-	Linear Elastic	Linear Elastic
2	EA	KN/m	2520.5	1.24e4
3	EI	KN.m2/m	26.47	132.35
4	d	m	0.355	0.355
5	υ	-	0.3	0.3
6	Column Length	m	Short Column is 8.5m and long column is 10.5 m	

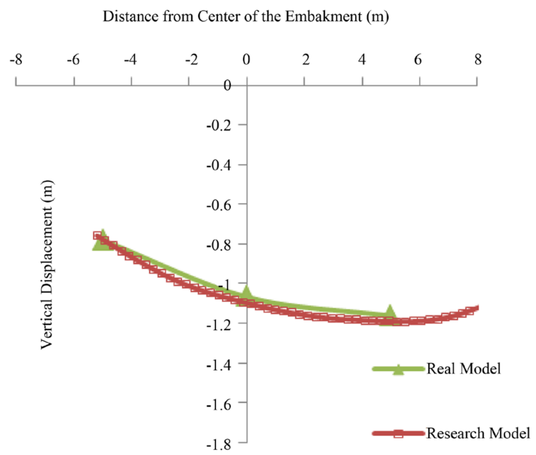

Figure 5. Comparison of real model subsidence with research model in 10.5 years.

so its strain length can be ignored and model can be considered as a surface strain. **Table 6** shows the studies in this field. Abbreviations are intended to facilitate expressions can be studies in **Table 7**.

6. Analysis of Results

Before providing any explanation it is necessary to mention that the results of the analysis, is related to the consolidation time (when the pore water pressure is low).

6.1. Analysis of Model 1: Analysis of Non-Column Model

Figure 6 shows the vertical subsidence of the embankment level. In this case the subsidence was non-uniform and the maximum value of that is more than 1/5 meters. Because of the presence of soft and thick inclined layers, the subsidence is high and non-uniform.

6.2. Analysis of Model 2: Using Short and Long Cement Columns

To reduce vertical subsidence and to uniform that, all the columns of **Figure 2** are made of cement and their intervals are considered as 1, 1/5, 2, r − d = 2, l − d = 1/5 meters. Because embankment's right side subsidence is more than the left side, right columns are considered longer. **Figure 7** shows the vertical subsidence rates due to columns' interval changes. According to these figures, the best case is when the distance between columns are l − d = 1/5 and r − d = 2. In other words, if the distances of short columns are 1/5 meters and distances of long column are 2 meters, then we will encounter lower and more uniform subsidence. This model's optimal issue is b-s-m2.

6.3. Analysis of Model 3: Using Short and Long Limestone Columns

Now, we consider column (2) materials as limestone. **Figure 8** shows the effects of short and long limestone columns with distance effects. As shown in the figure, the lowest and the most uniform embankment subsidence occurs when the short columns interval is 1/5 meters and long columns distance is 2 meters (l − d = 1/5, r − d = 2). It's best state is b-s-m^3.

6.4. Analysis of Model 4: Combination of Cement and Lime Columns in b-s-m2

Results of paragraphs (2-6) and (3-6) show that if only cement or lime columns are been used, the issue b-s-m^2 is the best option. In this case embankment subsidence had been declined, but has reached somewhat uniformity. However, in order to reduce the effect of the non-uniformity of b-s-m2, a combination of lime and cement columns is used, as shown in **Figure 9**. This is called b-s-m4. **Figure 10** compares best options of implanting column in b-s-m2 and b-s-m3 and b-s-m4. As shown in the figure using a combination of cement and limestone columns (the b-s-m4) will cause uniformity in vertical subsidence of embankment surface.

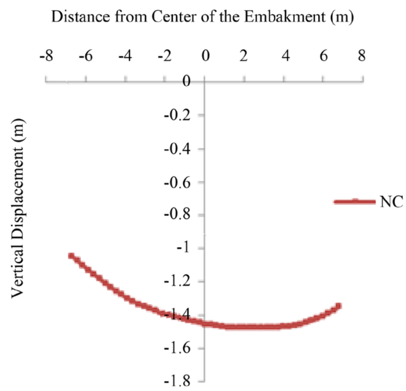

Figure 6. Vertical subsidence of embankment surface in model 1.

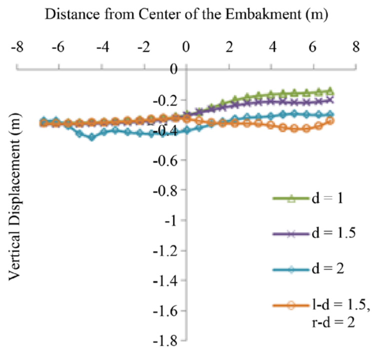

Figure 7. Vertical subsidence of embankment surface in model 2 with changing the intervals between columns.

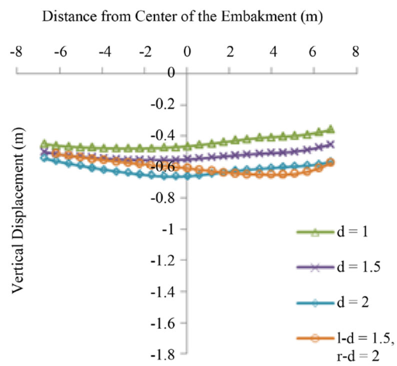

Figure 8. Vertical subsidence of embankment surface in model 3 with changing the intervals between columns.

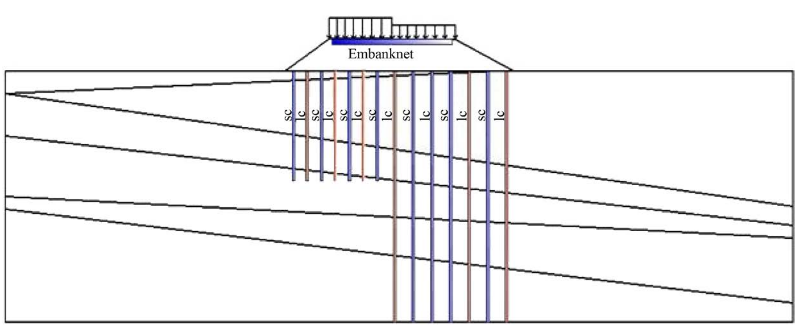

Figure 9. Composition of Cement and Limestone Column in b-s-m2.

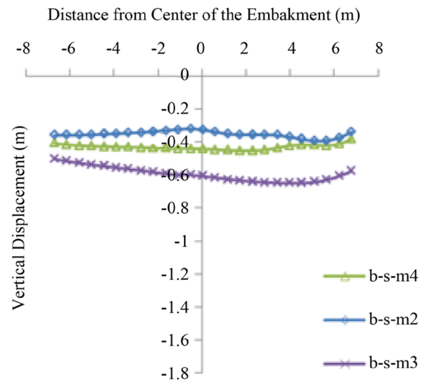

Figure 10. Comparison of optimal case of models 2, 3, 4.

Table 6. Specifications of studied models.

Model No	1	2	3	4
Implenting Columns	NC	Sc-Pc	Sl-Pl	Sc-Lc-Pc
Columns Distance (d)	-	0	0	-
	-	1	1	-
	-	1.5	1.5	-
	-	2	2	-
	-	L-d=1/5,R-d=2	L-d=1/5,R-d=2	L-d=1/5,R-d=2

Table 7. Abbreviations used in the text.

Row	Parameter	Abraviation
1	Cement Column	SC
2	Lime Column	LC
3	Columnless Embankments	NC
4	Long and Short Cement Columns	Sc-Pc
5	Long and Short LimeStone Columns	Sl-Pl
6	Long and Short Cement and LimeStone Columns	Sc-Lc-Pc
7	Combined Geo-Grid with Cemen and LimeStone Columns	Sc-Lc-Pc-G
8	Short Columns Distances are 1.5 m and Long Columns Distances are 2 m	L-d = 1/5 R-d = 2
9	Optimal Implanting of Column in Model 2	Δ
10	Optimal Implanting of Column in Model 3	b-s-m2
11	Optimal Implanting of Column in Model 4	b-s-m3
12	Optimal of Model 5	b-s-m4

6.5. Analysis of Model 5: Geo-Grid Combined with Cement and Limestone Column in b-s-m4

To reduce the embankment subsidence, we would combine s-b-m4 model with geo-grid; in other words implementing geo-grid beneath the embankment (over cement and lime columns) and calling this option as b-s-m5. As shown in **Figure 11** geo-grid will reduce embankment subsidence in order to its tensile property. Because the column distances in the right side of the embankment is more than the left side, so geogrid has a greater effect.

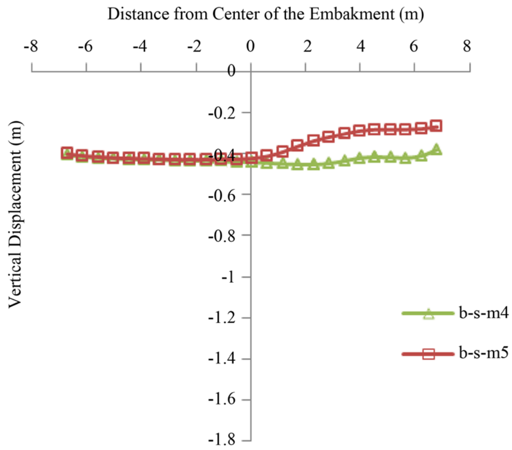

Figure 11. Comparison of optimal case of models 4 and 5.

6.6. Changes of Vertical Subsidence in Front of the Time

Subsidence changes diagram for H, G, E, D, B, A points against time for NC, b-s-m2, b-s-m3, b-s-m4, b-s-m5 states have been designed and shown by **Figures 12-17**. As it in geometric figures, the vertical displacements of all mentioned points in NC model are greater than the other models. Limestone columns' bearing capacity is low, but instead their subsidence is higher in comparison with cement columns. As it is obvious in mentioned figures, the geo-grid combination with limestone and cement columns will reduce the subsidence.

6.7. Surface Vertical Subsidence'

Figure 18 shows vertical subsidence of ground surface diagram for states of NC, b-s-m2, b-s-m3, b-s-m4, b-s-m5. As it is obvious vertical subsidence of ground surface in non-column state is more than any other state. We can also say that in models with a column, limestone columns cause increase in subsidence and geo-grid causes decreases in the subsidence.

7. Conclusions

In constructing the roads, construction of embankments is one of the requirements. These embankments pass lands that have multiple layers and ground water. Soil may be soft and may have low bearing capacity and high subsidence functionality that needs correction. One way to improve soil in this article is reinforcing the soil beneath the embankment by a geo-grid combination with cement and limestone columns. In fact, with these columns, a skeletal will be created in soil which will reduce the subsidence and bearing capacity of the soil, and also geo-grid will cause decrease in embankment by its tensile properties. This study has aimed to combine the geogrid with concrete and limestone columns in order to reduce and uniform the embankment subsidence located on layers of soft and inclined soil of Shahid Kalantari freeway of Urmia-Tabriz. Summary of the results can be expressed as follows.

1) The maximum amount of ground subsidence is in the middle part of the embankment and the maximum value is in non-column model.

2) If there is just cement or lime columns beneath the embankment, the amount of the subsidence would reduce and the embankment would be quite uniform.

3) A combination of cement and lime columns under the embankment will reduce the embankment subsidence of surface, and would have more effective uniformity in comparison with using columns with just cement or lime materials; because limestone columns have lower bearing capacity than concrete columns and cause more subsidence. High bearing capacity of concrete columns and high subsidence of limestone columns, are two effective factors in reducing the embankment subsidence and unfirming that.

4) Geo-grid combined with cement and limestone columns under the embankment, is more effective in reducing the embankment subsidence compared with non-geo-grid state. In addition to the columns, geo-grids also reduce the subsidence, in order to the presence of tensile properties.

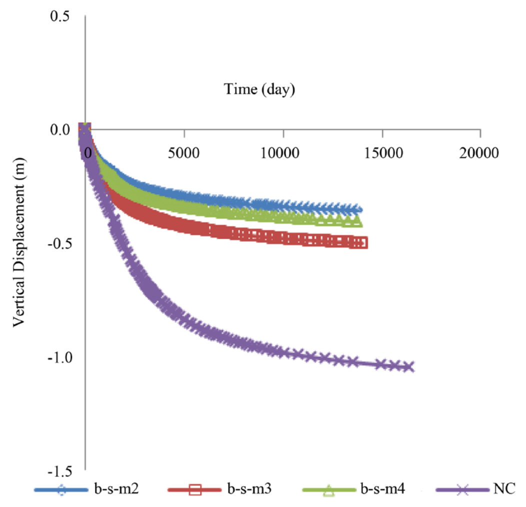

Figure 12. Vertical displacement of point a in front of time.

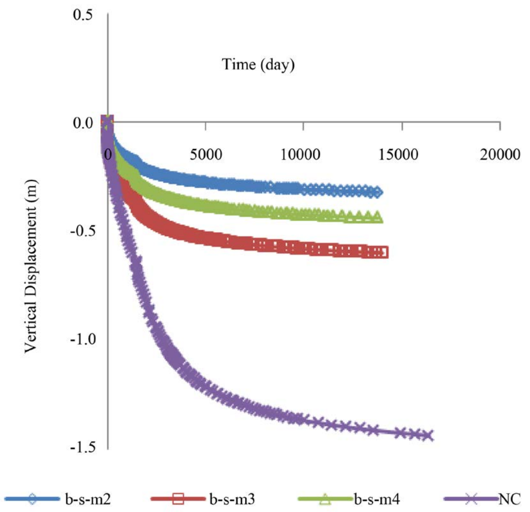

Figure 13. Vertical displacement of point b in front of time.

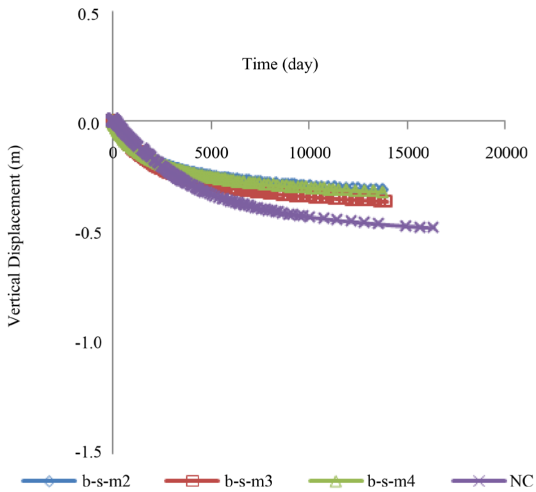

Figure 14. Vertical displacement of point d in front of time.

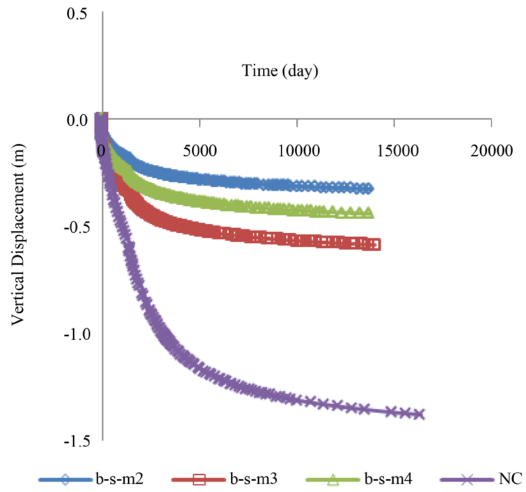

Figure 15. Vertical displacement of point e in front of time.

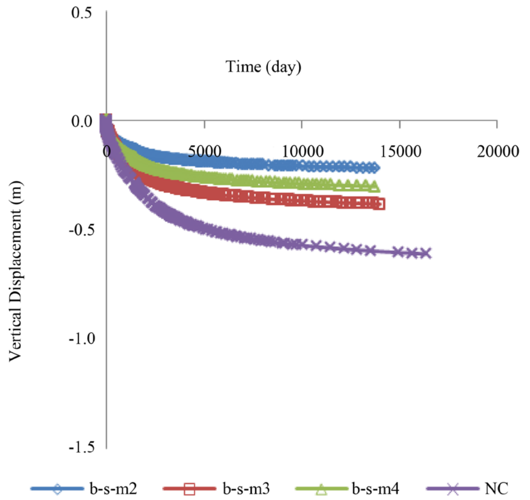

Figure 16. Vertical displacement of point g in front of time.

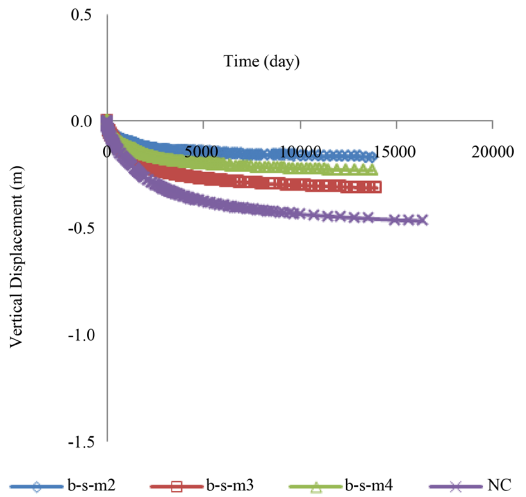

Figure 17. Vertical displacement of point h in front of time.

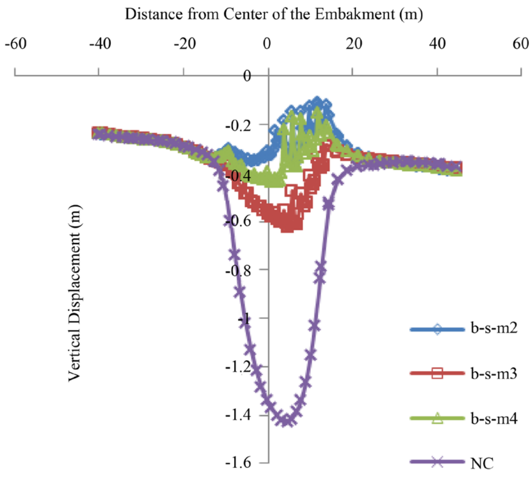

Figure 18. Vertical displacement of ground surface.

5) With assessing the amounts of subsidence in different points of embankment in front of the time, we conclude that in the non-column state the maximum time is needed to consolidate, and the minimum time is in relation with the case just concrete column has been investigated. Also it can be noted that the presence of geo-grid cause subsidence reduction in different points of soil and embankment.

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