Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICGRE 181
DOI: 10.11159/icgre22.181

Settlement Analysis of Field Monitoring Data at Kanchpur Bridge, Bangladesh

Dr. Hossain Md. Shahin[1], Saima Sadia[1], Mayesha Farzana Islam[1], Rafia Nusrat Khan Broti[1], Md. Shamsul Islam[2]
[1]Department of Civil and Environmental Engineering, Islamic University of Technology
Gazipur, Bangladesh
shahin@iut-dhaka.edu; saimasadia@iut-dhaka.edu; mayeshafarzana@iut-dhaka.edu; rafianusrat@iut-dhaka.edu
[2]ProSoil Foundation Consultant
Dhaka, Bangladesh
prosoil_9@hotmail.com

Abstract **–** Settlement of base ground due to imposed load is a concern for any Geotechnical Engineer. For the serviceability of subgrade of an embankment, the prediction of embankment settlement is a critically important issue. Calculation of settlement, especially differential settlement, ensures the design grade of the embankment. This study includes the settlement of an embankment at Kanchpur Bridge, Bangladesh, which is a location where the embankment was made on soft soil. The actual field settlement data is compared by the finite element method with the PLAXIS-2D numerical modelling software. Hardening Soil Model and Soft Soil Model have been used in this simulation as constitutive models. Reasonable agreements were obtained from the finite element analysis compared to the actual field monitoring data. Moreover, variations in total deviatoric strains for both models were also illustrated in this paper.

Keywords**:** Embankment, Soil Parameters, Finite Element Method, Hardening Soil Model, Soft Soil Model.

1. Introduction

Consolidation settlement is triggered due to the development of volumetric strain. Depending on the soil's permeability and water drainage conditions, the settlement process may be completed almost immediately or continue for a considerable period [1]. On soft clay, it is now possible to produce a nearly accurate estimation of embankment settlement. One-dimensional settlement analysis is applicable and the most acceptable approach in most circumstances where the embankment is designed to resist undrained instability during construction [2]. The paper includes a description of the study area, determination of soil profile and parameters, field monitoring record, and findings of numerical simulation.

The Finite Element Method (FEM) has been widely used for the calculation of settlement of embankment on soft soils in the last decade. However, due to the complexity of construction, spatial inhomogeneity of soils, and the dependence of the numerical simulation results on the variations in soil parameters, there is frequently a considerable disparity between numerical outputs and field observations [3]. For numerical analysis of this paper, the Finite Element Method is used where Hardening Soil Model and Soft Soil model are considered. The Hardening Soil Model is developed using the user-defined material model option in RS^2 and RS^3 [4]. Divergences are made between drained and undrained strength of cohesive materials. The analysis of field monitoring data outlines initial design and construction details, focusing on early performance details of the restoration work carried out on the embankment system [5].

2. Description of the Study Area

The main work of this paper includes the prediction of the settlement of embankments in soft soil. The Prosoil Foundation Consultant carried out the subsoil investigation work for the site at Kanchpur Bridge, Bangladesh. It is located near Dhaka city, the capital of Bangladesh.

3. Soil profile and Soil parameters

The investigation program consisted of soil boring and sampling at desired intervals for subsequent observation and laboratory testing to obtain reasonably accurate soil parameters.

The soil profile shown of the location in figure 1 consists of the 1st layer of light gray, stiff to very stiff low plasticity clay up to 3.0 meters below the base of the embankment, the 2nd layer of brown, very stiff low plasticity clay up to 9.50 meters, the 3rd layer of brownish, hard low plasticity clay up to 15.50 meters andt the 4th layer of gray, hard high plasticity clay up to 16.50 meters.

The data for this location of Kanchpur Bridge and the parameters are considered the basic design input for the model. Soil parameters are extracted from the USCS soil classification and SPT values using different co-relations.

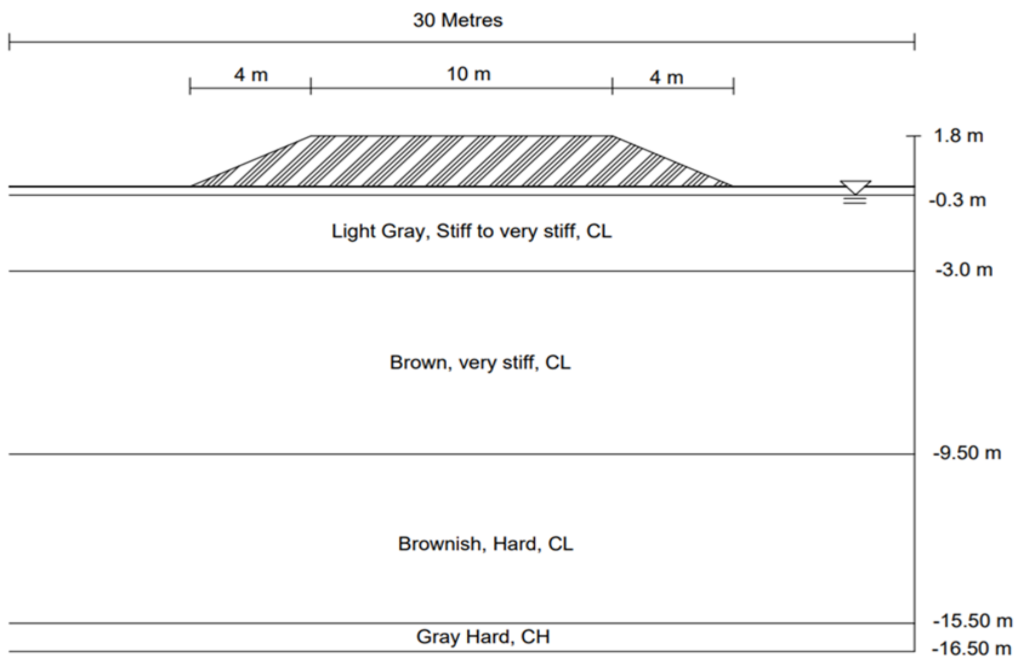


Fig. 1: Soil profile

The following tests were performed:

i. Particle size analysis-sieve
ii. Particle size analysis-Hydrometer
iii. Atterberg limits test
iv. Natural moisture content
v. Dry and apparent density
vi. Particle density
vii. Unconfined compressive strength
viii. Triaxial test (CU)
ix. Consolidation test

The soil parameters at the site is shown in table 1. The basic parameters which are being used are-

γ_{wt} = Wet (KN/m^3)
γ_d =Dry (KN/m^3)
c = Cohesion
ϕ= Angle of internal friction
e_o= Void Ratio
C_c= Compression Index
C_r= Recompression Index

Table 1: Parameters of Soil from Field data of Location 1 (B.W.T: 0.30m below from E.G.L.)

Layer	Depth (m)	Classification of Soil (US CSC)	Grain Size (%)			Avg. SPT	Avg. SPT		Consolidation Test			Direct Shear Test	
			Sand	Silt	Clay		γ_{wt} (KN/m^3)	γ_d (KN/m^3)	e_o	C_c	C_s	C	φ^o
1	0-3.5	CL	0.1	7.1	0.9	21	18.9	15.5	0.941	0.254	0.037	101	28
2	3.5-9.5	CL	1.7	4.9	0.5	36	19.61	16.5	0.773	0.081	0.005	59	27
3	9.5-15.5	CL	3.9	2.9	0.2	50	18	17	0.731	0.08	0.0234	190	25
4	15.5-16.5	CH	8.6	8.6	0.8	31	18	17	0.77	0.16	0.032	230	25

4. Field Monitoring Record

To record the magnitude and rate of settlement under a load, settlement plates are mounted where significant settlement is expected. Therefore, after installing the vertical drains, they are mounted immediately. In this study, the settlement-monitoring platform is connected to a reference rod and a protective pipe.

Settlement is calculated at intervals before the surcharge embankment is completed, and then the elevation of the top of the reference rod is determined at a reduced frequency. Figure 2 represents the field monitoring data at Kanchpur Bridge where the height of the embankment is drawn with time in days at regular intervals. On day-1, a height of 200mm is constructed on the leveled ground, and settlement is allowed to occur for a day. On day-2, the process is repeated but with 2 days of embankment settlement. As the embankment height increased, the duration of the settlement period varied while keeping the increment of embankment height of 200 mm. A total height of 1800 mm is constructed, and the settlement is monitored for a duration of 54 days. The information from the field monitoring data was used for drawing the staged construction in PLAXID-2D with calculation type, 'consolidation.'

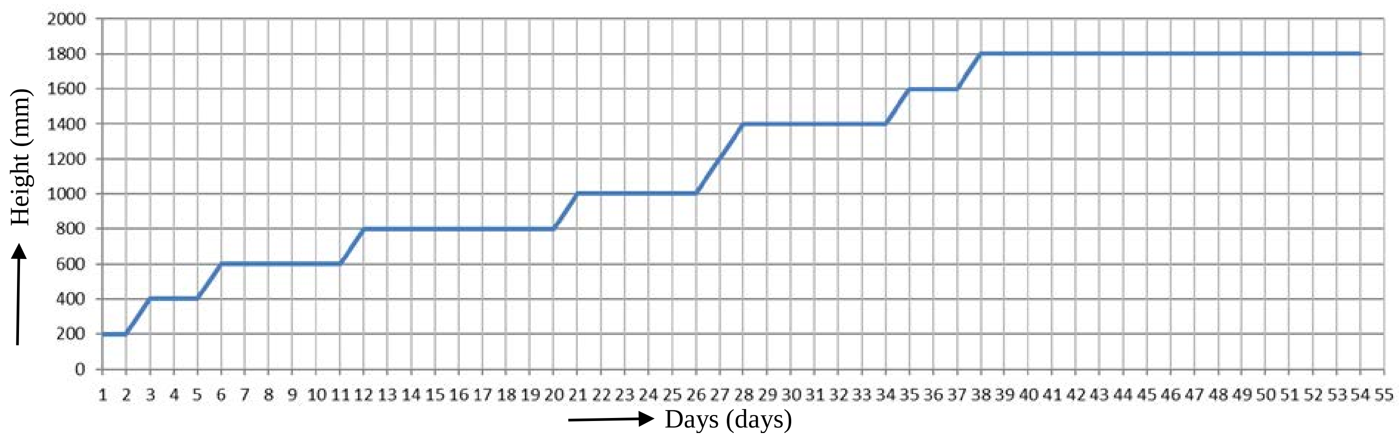


Fig. 2: Embankment Height vs. Day

Figure 3 represents the settlement values in correspondence to the time in days. From this figure, it is found that the maximum settlement of the embankment is 16 mm. This value is then compared with the maximum settlement simulated for both Hardening Soil Model and Soft Soil Model in PLAXIS-2D.

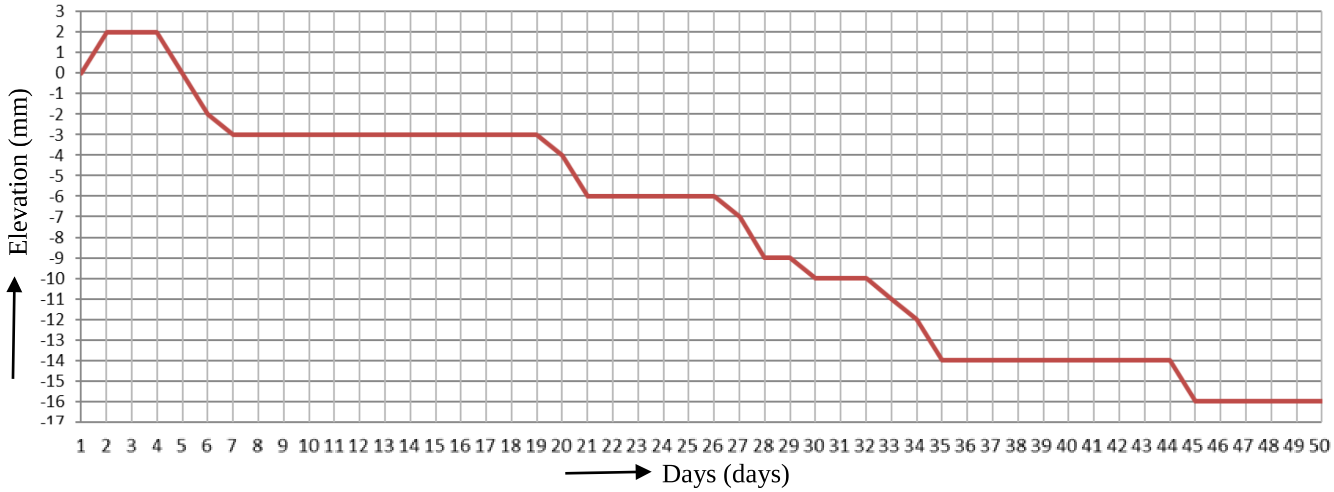


Fig. 3: Settlement vs. Day

5. Numerical Simulation Method

In this study, the finite element (FE) model of the soft ground under embankment is developed using PLAXIS-2D. The FE model determines consolidation settlement and lateral deformation. The mechanical behavior of the soil is accounted for by both Hardening Soil Model and Soft Soil Model. A plain-strain model and 15-noded elements are used in the simulation.

In this location, soil type is accounted as medium fine containing Clay 19%, Silt 74%, and Sand 7%. As the percentage of the fines were almost similar for each layer, the Plaxis-2D software accounted all the soil type as medium fine. Drainage type is idealized to be Undrained (A) because stiffness and strength are characterized in terms of effective stress in short-term material behavior. Even above the phreatic surface, a significant bulk stiffness for water is automatically given to make the soil incompressible, and excess pore pressures are determined [6]. Tables 2 and 3 represent all the inputted parameters for running the exact analysis of real field embankment settlement in PLAXIS-2D for both the Hardening Soil Model (Case-1) and Soft Soil Model (Case-2).

Table 2: Parameters of soil for Hardening Soil Model Simulation in PLAXIS-2D

Layers	E_{50}^{ref} kN/m^3	E_{oed}^{ref} kN/m^3	E_{ur}^{ref} kN/m^3	e_o	C_c	C_s	C'^{ref} kN/m^3	ϕ' (º)	Ψ (º)	$k_{o,}$ x	$k_{o,}$ z	OCR
1	2197	1758	10.86×10^3	0.0941	0.254	0.037	101	28	0	0.8728	0.8728	2.22
2	6293	5034	73.40×10^3	0.773	0.081	0.005	59	27	0	0.8124	0.8124	1.90
3	6221	4977	15.31×10^3	0.731	0.08	0.0234	190	25	0	0.7738	0.7738	1.60
4	3180	2544	11.45×10^3	0.77	0.16	0.032	230	25	0	0.7738	0.7738	1.60

Table 3: Parameters of soil for Soft Soil Model Simulation in PLAXIS-2D

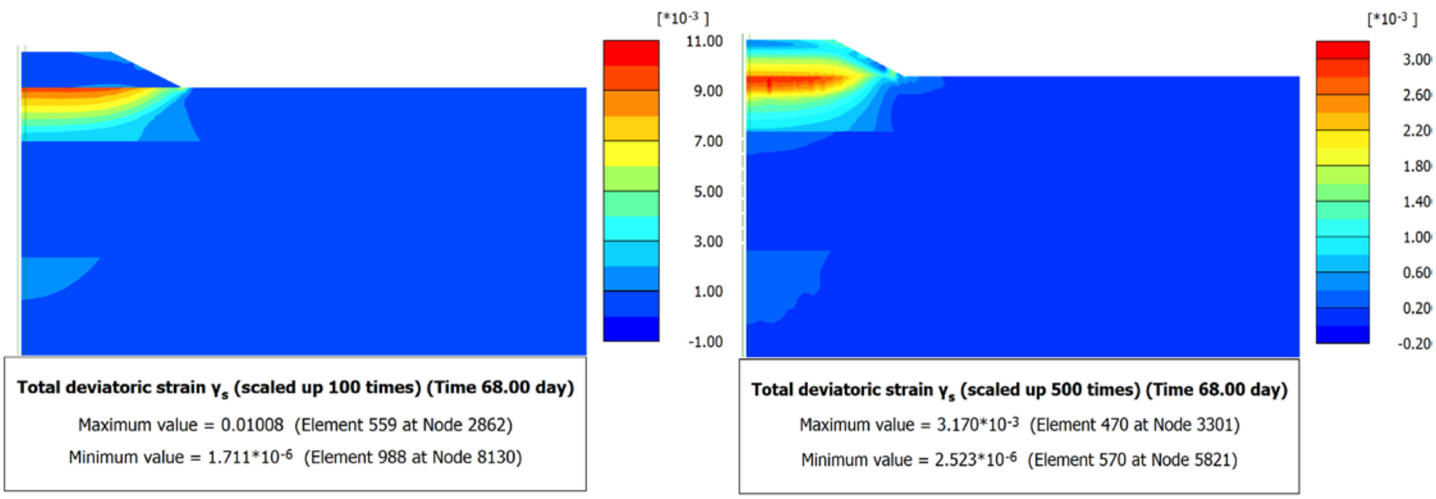
Layers	λ^*	κ^*	S_s	e_o	C_c	C_s	C'^{ref} kN/m^3	ϕ' (°)	Ψ (°)	$k_{o,}$ x	$k_{o,}$ z	OCR
1	0.0569	0.01658	18.42×10^{-6}	0.941	0.254	0.037	101	28	0	0.9625	0.9625	2.22
2	0.01986	0.00245	2.725×10^{-6}	0.773	0.081	0.005	59	27	0	0.8786	0.8786	1.90
3	0.02009	0.01175	13.06×10^{-6}	0.731	0.08	0.0234	190	25	0	0.8179	0.8179	1.60
4	0.03930	0.01572	37.12×10^{-6}	0.77	0.16	0.032	230	25	0	0.7272	0.7272	1.60

6. Results and Comparisons

Results from both the Hardening and Soft Soil Models of PLAXIS-2D are compared with field monitoring data. The total deviatoric strain and total displacement in the vertical direction are represented using the following figures for both models. The maximum settlement obtained from the simulation in PLAXIS-2D is compared to the maximum settlement from the field monitoring data. As both constitutive models do not consider time-dependent behavior of soil, the similar settlement-day graph could not be extracted.

6.1. Total Deviatoric Strain-FE analyses

Figure 4 shows the total deviatoric strain for Hardening Soil Model and Soft Soil Model, obtained from finite element analyses. The distribution of the strain illustrates that in case 1, the most stressed zone extends to a depth of about 3.0 m below the base of the embankment, and the maximum total deviatoric strain of 1.008% is observed at the baseline of the embankment. In the Soft Soil Model, the most stressed zone extends to a depth of about 4.5m below the base of the embankment and 1.4 m above the bottom of the embankment. The maximum total deviatoric strain of 0.317% is observed at the baseline of the embankment. From the obtained information, in case-2, effective stress distribution is seen to distribute over a larger area across the embankment than in case-1. Thus, the total deviatoric strain is much lower compared to case-1.The most stressed zones indicated by deviatoric stress and deviatoric strain in PLAXIS-3D give better insight into the distribution [7].



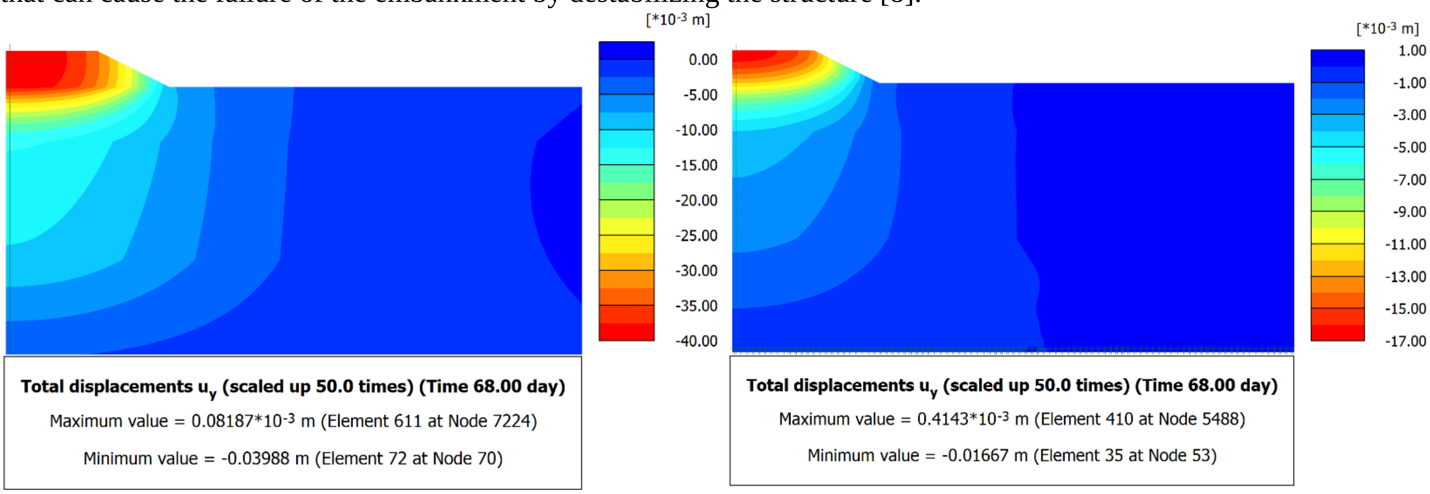
(a) Case-1: Hardening Soil Model

(b) Case-2: Soft Soil Model

Fig 4: Total deviatoric strain γ_s -FE analyses

6.2. Total Displacement-FE analyses

Figure 5 shows the total displacement for Hardening Soil Model and Soft Soil Model, obtained from finite element analyses. Total displacement shows the effect of load on the nodes and how much the area got affected for that certain load, demonstrating whether the structure can go through the specific amount of load on the portion and when that might fail. In Hardening Soil Model, the maximum displacement is 39.88 mm, and in the Soft Soil Model, the value is 16.67 mm. The illustration below shows that the maximum displacement occurs at the top of the embankment, and the Soft Soil Model shows a much lower settlement than Hardening Soil Model. The total settlement also represents the failure of imposed load that can cause the failure of the embankment by destabilizing the structure [8].



(a) Case-1: Hardening Soil Model (b) Case-2: Soft Soil Model

Fig 5: Total settlement -FE analyses

The maximum settlement from the field monitoring is 16 mm. The Soft Soil Model produces almost the same maximum settlement, which is 16.67 mm, resulting in only 0.67 mm of difference with the field data. On the other hand, Hardening Soil Model simulated a maximum settlement of 39.88 mm, resulting in 23.88mm of difference with field data.

The Soft Soil Model gives almost accurate results in clay or silty clay soil and agrees well with the field data, where Hardening Soil Model provides a much higher settlement in the soft clayey soil. In addition, Hardening Soil Model is formulated in the framework of the classical theory of plasticity, where the total strains are calculated using a stress-dependent stiffness.

7. Conclusion

In this study, settlement due to the embankment load in soft soil is monitored, and the corresponding numerical simulations are carried out with PLAXIS-2D software. It is found that for clay and silty clay soil, the Soft Soil Model can predict the settlement of the ground better than that of the Hardening Soil Model. Furthermore, the Soft Soil Model can precisely predict the settlement of the soft clayey soils if the soil parameters are rational.

Therefore, it can be said that the constitutive model of soil should be selected based on the soil type for an accurate prediction of the settlement.

Acknowledgments

The authors would like to express appreciation towards Mr. Mozaher Ul Kabir, Lecturer, in the Department of Civil & Environmental Engineering for the support given to this research.

References

[1] Z. Zhang, G. Ye, Y. Cai and Z. Zhang, “Centrifugal and numerical modelling of stiffened deep mixed column-supported embankment with slab over soft clay,” *Canadian Geotechnical Journal,* vol. 56, no. 10, pp. 1418-1432, 2019.

[2] G. Mesri, D. o. K. Lo and T. W. Feng, “Settlement of embankments on soft clays,” in *Vertical and Horizontal Deformations of Foundations and Embankments*, 1994.

[3] Z.-l. Wang and R. Shen, “Correction of soil parameters in calculation of embankment settlement using a BP network back-analysis model,” *Enigineering Geology,* vol. 91, no. 2-4, pp. 168-177, 2007.

[4] T. Schanz, P. Vermeer and P. Bonnier, “The Hardening soil model: Formulation and verification,” in *Beyond 2000 in Computational Geotechnics*, 1999, pp. 281-296.

[5] A. Arulrajah and M. Bo, “Finite element modelling of soft soil treated with prefabricated vertical drains,” *International Journal of Geotechnical Engineering,* vol. 4, no. 2, pp. 165-179, 2010.

[6] P. V. Lade, “Overview of Constitutive Models for Soils,” in *ASCE Geotechnical Special Publication*, 2005.

[7] M. Y. Fattah, B. S. Zbar and H. H. M. Al-Kalali , “Three-Dimensional Finite Element Simulation of the Buried Pipe Problem in Geogrid Reinforced Soil,” *Journal of Engineering,* vol. 22, no. 5, pp. 60-73, 2016.

[8] H.-J. Kim, J. Jamin and M.-S. Won, “Finite-Element Analysis on the Stability of Geotextile Tube-Reinforced Embankments under Scouring,” *International Journal of Geomechanics*, vol. 15, no. 2, 2015.