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Evaluation of Settlement of Coastal Embankments Using Finite Elements Method

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Abstract**—**Coastal embankments play an important role in coastal structures by reducing the effect of the wave forces and controlling the movement of sediments. Many coastal areas are underlain by weak and compressible soils. Estimation of during construction settlement of coastal embankments is highly important in design and safety control of embankments and appurtenant structures. Accordingly, selecting and establishing of an appropriate model with a reasonable level of complication is one of the challenges for engineers. Although there are advanced models in the literature regarding design of embankments, there is not enough information on the prediction of their associated settlement, particularly in coastal areas having considerable soft soils. Marine engineering study in Iran is important due to the existence of two important coastal areas located in the northern and southern parts of the country. In the present study, the validity of Terzaghi's consolidation theory has been investigated. In addition, the settlement of these coastal embankments during construction is predicted by using special methods in PLAXIS software by the help of appropriate boundary conditions and soil layers. The results indicate that, for the existing soil condition at the site, some parameters are important to be considered in analysis. Consequently, a model is introduced to estimate the settlement of the embankments in such geotechnical conditions.

Keywords**—**Consolidation, coastal embankments, settlement, numerical methods, finite elements method.

I. Introduction

THE major part of the research presented in this paper is related to the challenges in evaluating settlements in marine type of soft soils in coastal embankments. The early research on specific clay, Soft Bangkok Clay, is described [1]-[3]. Making an accurate estimate of coastal embankments settlement while construction is being implemented, can never be possible to ignore in safety control and design process. In accordance with this step, although there are sophisticated models in the previous studies regarding design stage, in coastal embankments especially in soft soils, reliable estimation of settlement is extremely difficult to be done because of little information. Thanks to the existence of two coastal areas placed in the northern and southern parts of the country, coastal engineering would be important. In this research, the validity of Terzaghi's consolidation theory has been evaluated. In addition, considering proper boundary conditions and soil layers, the settlement of these coastal embankments during construction are estimated by using specific methods in PLAXIS software. It is important to note that some scientific discoveries such as what happened in the ground improvement conference, 1983 at AIT gave great effects on the development of this field in SE Asia [4]. Reference [5] had a brilliant research on soft ground improvement. The recent publications on case histories by [6] have great contributions by Hansbo, Moh and Lin, Indratana, Hsi, Wong, Chu, Massarsch, Terashi, Kitazume which are notable for practicing geotechnical engineers. In addition, differential settlement is an important issue in approach embankments adjacent to bridge abutments, culverts and other structures founded on piles. Such settlements will vary the performance of the pavement [7].

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II. Definition of the Problem

Following the above-mentioned statements, validation of Terzaghi's consolidation theory has been implemented. Also, the settlement of embankments during construction utilizing specific methods in PLAXIS software considering correct and suitable boundary conditions and soil layers has been investigated. According to the embankment, modeling has been done over six phases, and the results are presented in various graphs.

TABLE I
MATERIALS

Material Identification	Boom Clay	Sand	Embankment	Soft Clay
Material Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Material Type	Undrained	Drained	Drained	Undrained
γ_{unsat}	18	17	18	12
γ_{sat}	22	21	20	16
K_x	0.01	8	15	0.1
K_y	0.01	8	15	0.1
E	25000	10000	30000	5000
υ	0.35	0.33	0.15	0.35
c	50	0.1	1	5
ρ	19	32	45	18

As can be seen in Table I, material properties utilized in this paper are classified in four types. In addition, primary modeling and mesh of this embankment have been displayed in Figs. 1 and 2, respectively.

It is noteworthy that material model used in this paper, as mentioned in Table I, is Mohr-Coulomb. In accordance with PLAXIS material models manual, the linear elastic perfectly-plastic Mohr-Coulomb model involves five input parameters, i.e. E and _ for soil elasticity, ' and c for soil plasticity and as an angle of dilatancy. It is notable that this Mohr-Coulomb model represents a 'first-order' approximation of soil or rock behaviour. It is recommended to use this model for a first analysis of the problem considered. For each layer, one estimates a constant average stiffness or a stiffness that increases linearly with depth. Due to this constant stiffness, computations tend to be relatively fast and one obtains a first estimate of deformations.

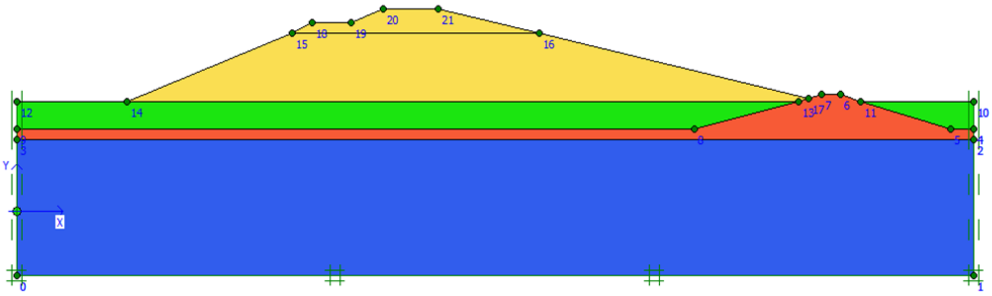

Fig. 1 Modeling of the present problem in PLAXIS

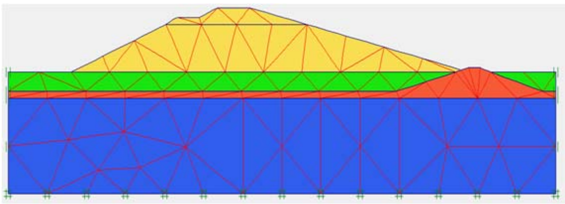

Fig. 2 Mesh of the present embankment in PLAXIS

For initial condition, it is assumed that level of ground water and foundation is the same and there is no embankment yet.

As mentioned before, the modeling has been implemented in six phases. In phases 1 and 2, there is no embankment, and foundation is only structure to be analyzed. During first phase, plastic analysis has been done and over second phase, settlement analyze is considered.

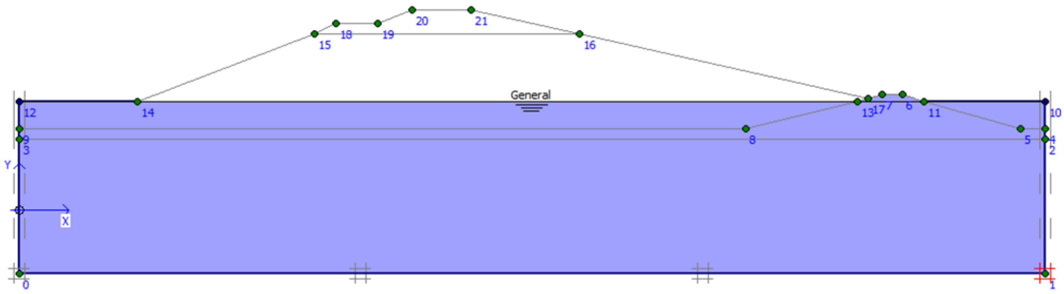

Fig. 3 Initial condition

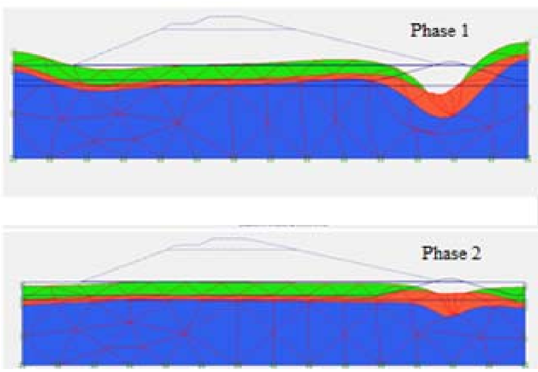

Fig. 4 Deformed mesh in Phase 1 and 2

At the end, during phase 6, all steps of the present model are completed, and below any results and output of PLAXIS analysis can be found.

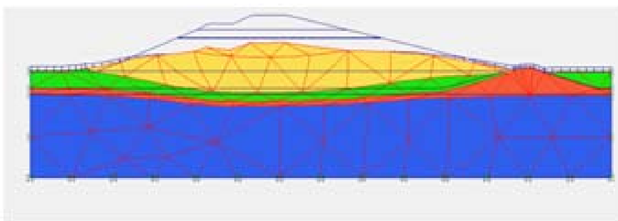

Fig. 5 Deformed mesh in phase 6

Fig. 5 shows deformed mesh during phase 6 where any steps of modeling and the assumed coastal embankment have been completed.

In Fig. 6, degree of saturation in considered domain can be seen. It should be mentioned that red color shows full saturated, and blue color displays less saturated domain.

Settlement in each loading step happened taking into account the previous applied settlement. It is important to note that this fact causes increasing in effective stress and the strength of soil in next step. Now, the results of analysis in the following graphs can be found, and evaluation of each one would come next.

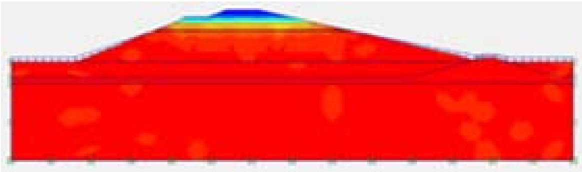

Fig. 6 Degree of saturation

III. Results

In the present paper, a submerged embankment with height 27 meters is studied. Bedrock of this embankment is a soft clay in 8 meters which is located on boom clay layer with 40 meters. Between these mentioned layers, a thin sand layer plays a drainage role.

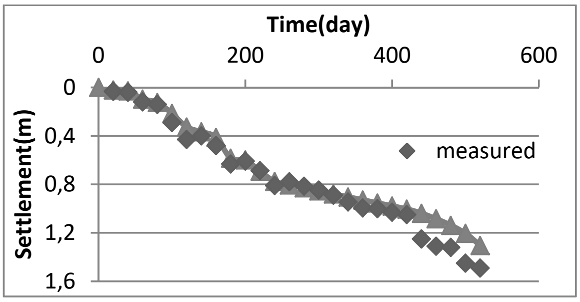

Fig. 7 Settlement versus time implemented with PLASIX

To verify this analysis, a numerical evaluation has been done, then the revealed results can be seen in Fig. 8. It is obvious that the output can be appropriately accepted.

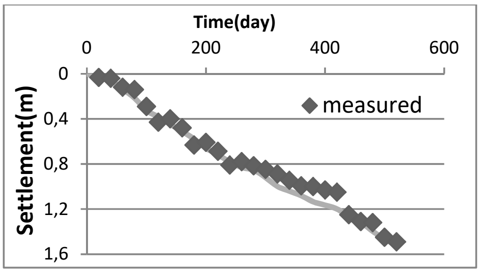

Fig. 8 Settlement versus time implemented with numerical solution

For numerical solution, involving appropriate boundary condition can never be ignored. Both ordinary and partial differential equations require boundary conditions to find a way of dealing with the problem. Various types of boundary conditions can be forced on the boundary of the studied domain. The choosing of the appropriate boundary condition is fundamental for the resolution of the computational problem: a bad imposition of boundary condition may cause the divergence of the solution or to the convergence to a wrong solution. The Dirichlet boundary condition is a specific type of boundary condition that specifies the quantity that the unknown function requires to take on along the boundary of the domain. The Neumann boundary condition is another type of boundary condition. Since it is imposed on an ordinary or a partial differential equation, it states the values that the derivative of a solution is going to take on the boundary of the domain in an exact way. In this research, four types of boundary conditions have been regarded in beneath the embankment.

Finally, presence of a soft muddy bed in this domain is evaluated. Results show that the stiffness of muddy bed has got significant role in analysis. In the following figures, different results with various quantities of soft muddy bed stiffness are shown.

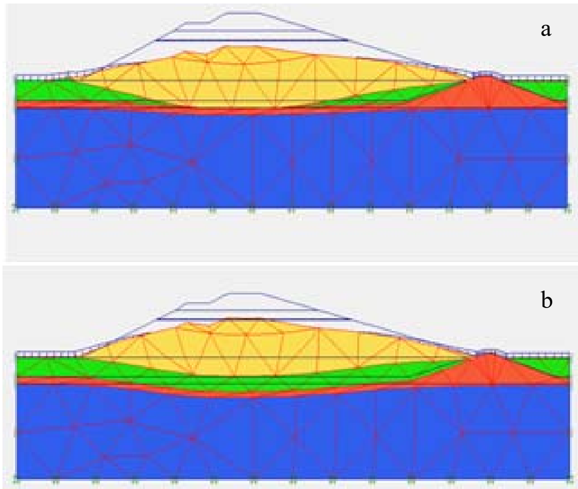

Fig. 9 Mesh deformation of studied domain with various stiffness (a) stiffness equal to 1000 (b) stiffness equal to 20000

It is clearly obvious that higher stiffness causes less deformation as can be expectable.

IV. Conclusion

In this research, first of all the validity of Terzaghi's consolidation theory has been investigated. Additionally, the settlement of these coastal embankments at the same time of construction is estimated by utilizing particular methods in PLAXIS software considering appropriate boundary conditions and soil layers. Several coastal areas are located on weak and compressible soils. Capturing of during construction settlement of coastal embankments is significantly important in design and safety control of embankments and appurtenant structures. Accordingly, choosing and establishing of an appropriate model with a reasonable level of complication is one of the considerable challenges for engineers. Although there are very modern models in the literature regarding design of embankments, there is not enough information on the estimation of their associated settlement, particularly in coastal areas that have got a considerable soft soil. Finally, taking into account the presence of soft muddy layer, some analysis have been implemented in this regard. The results reveal that in soil condition same as the one that is taken into account in present paper, some important parameters should be considered in analysis. Consequently, the results are presented in some graphs.

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