Staged construction of embankments on Soft Soil using Plaxis

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Introduction

A problem, which is rather common in the fields of geotechnical and highway engineering, arises when road embankments of moderate to large heights are to be constructed on very soft soils with low shear strength and high compressibility in the shortest possible time. But, owing to the low shear strength of the subgrade (foundation) soil, the full height of the embankment cannot be built at a time and the so-called staged construction has to be resorted to. To implement such a phased construction it is required to carry out an analysis to determine beforehand the sequence of construction to be followed in a given situation such that the embankment can be constructed as quickly as possible while ensuring a reasonable margin of safety.

Analysis of embankment stability using Plaxis

Plaxis (Version 8.0) has the provision for 2D (plane strain) stress-displacement as well as safety factor analysis of road embankments founded on layered deposit having any complex soil and pore water pressure conditions. Analysis can be done based on a number of options available, e.g., type of element, coarse mesh or fine mesh, soil models such as Mohr-Coulomb model (MC), Soft Soil Creep model (SSC), Hardening Soil model (HS) etc. Further, the updated mesh and consolidation options can be invoked for a more rigorous determination of embankment displacements and excess pore pressure dissipation.

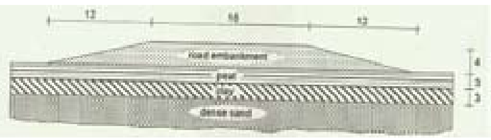

Figure 1: Road embankment on soft soil for the illustrative example

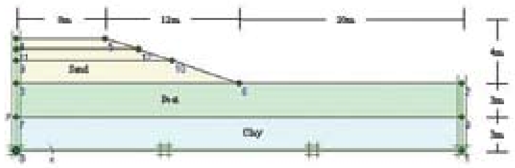

Figure 2: Plaxis model

Illustrative Example

Description

To illustrate the staged construction of a road embankment in the shortest possible time compatible with the safety requirements at the intermediate stages of construction as well as during its service life (long term), the embankment section exemplified in the Tutorial Manual (Lesson 5) has been selected for the present study (Figure 1).

The geometry model, material sets, mesh generation and initial conditions adopted in the Tutorial Manual (Lesson 5) have been retained. Specifically, a plane strain model with 15-node elements is utilized. The problem being symmetric, only one half is modeled. The deformations of the deep sand layer are assumed to be zero; hence this layer is not included in the model and a fixed base is used instead (Figure 2). The properties of the different soil types are given in Table 1. In the initial conditions, the hydrostatic pore water pressures are based on a general phreatic level at the base of the clay layer.

Safety Analysis for Staged construction

Since it is required to construct the embankment in the shortest possible time, the time of construction in each stage should be such that it is just sufficient for the stability of the embankment up to that height for a target factor of safety. The time of construction, therefore, depends on the target factor of safety. The larger the factor of safety, longer will be the time of construction in each stage. After the construction of a certain stage, some time interval needs to be allowed for the improvement in undrained strength due to consolidation, which is required for the stability of the increased height in the next stage. Further, after the construction of the total height is over, some amount of time needs to be allowed for a certain percentage of consolidation to take place for which Plaxis has a provision to calculate time of consolidation till the excess pore pressure becomes less than a certain pre-assigned value (e.g., 1.0 kN/m²). Thus, the total time required includes the actual time of construction in each stage and the time interval between two consecutive stages as well as after the final stage of construction. If the construction sequence thus obtained is available to a practicing geotechnical engineer, for various target factor of safety, it will enable him to make a trade-off between the time available for the completion of the project and the amount of risk involved in selecting a particular target factor of safety.

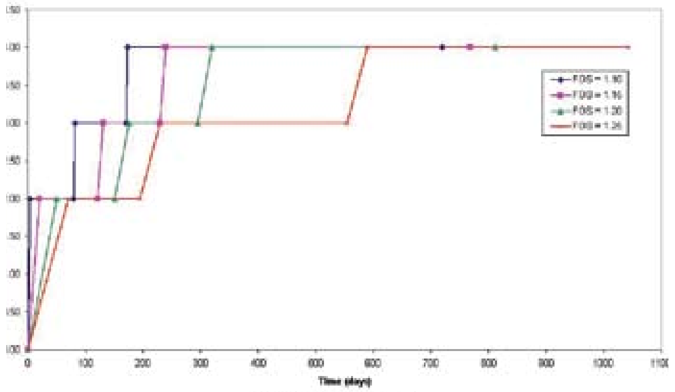

Figure 3: Construction sequence

Results

Sequence of construction

In the first stage, by trial runs, it has been observed that a height of 2.0 m can be built by allowing a minimum time of construction as 4, 20, 50 and 70 days corresponding to target factor of safety at the end of construction of 1.10, 1.15, 1.20 and 1.25 respectively. Before the second stage of construction begins, it is required to allow a sufficient time interval for substantial strength increase due to consolidation. However, it has been observed that even after allowing a large time interval of more than 1000 days, the increased strength is still not sufficient to raise the embankment by another 2.0 m to its final height of 4.0 m. It has therefore been decided to build the remaining height of 2.0 m in two stages, 1m in each stage, thus making it a 3-stage construction. In the second stage, the required minimum time interval comes out to be 75, 100 and 125 days corresponding to the target factor of safety at the end of construction of 1.10, 1.15, 1.20 and 1.25 respectively. In this case the minimum time of construction is 2, 10, 25 and 35 days respectively. Similarly, for the third stage, the minimum time interval and time of construction have been obtained. Finally, the minimum time interval between the completion of construction and the time of dissipation of excess pore water pressure to less than a value of 1 kN/m² has been found out. The entire sequence of construction thus obtained has been presented in Figure 3 for various target factor of safety. The long term factor of safety of the completed embankment is obtained as 1.390.

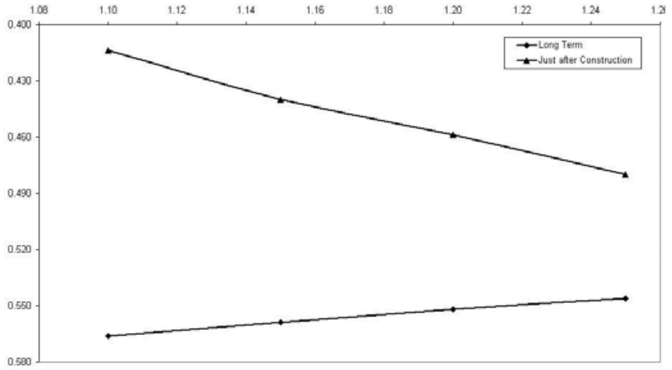

Figure 4: Variation of Top Vertical Diplacement with FOS

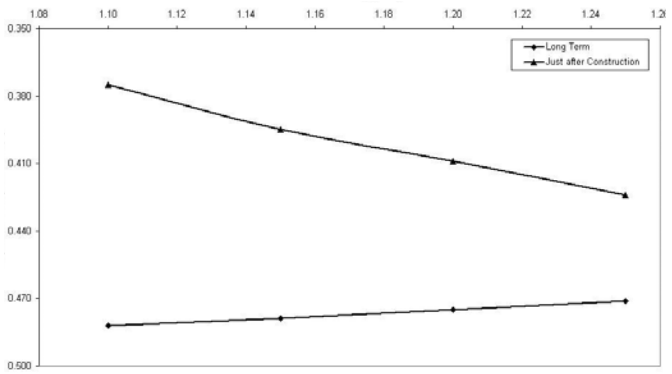

Figure 5: Variation of Top Vertical Diplacement with FOS (using Updated Mesh)

Correlation Between Factor of Safety and Displacement

Although safety analysis indicates the stability status of the embankment, a displacement analysis is of interest to ensure its serviceability requirement; in other words, the displacements occurring particularly at long term indicate whether the embankment would perform satisfactorily during its design life. Now, as discussed before, for the planning of staged construction, the geotechnical designer has to adopt a target factor of safety. The engineering judgment to be applied in this case is obviously based on the displacement estimated to take place at the end of construction as well as long term. For the geotechnical engineer, therefore, it would be very useful, if a correlation is available between the target factor of safety and the estimated vertical displacement at the end of construction as well as at long term. Figure 4 presents such a correlation in the form of a plot of factor of safety against displacement.

Utilizing the Plaxis updated mesh option, the above mentioned displacements have been re-evaluated and plotted against the target factor of safety in Figure 5. It may be mentioned here that such an analysis does not provide values of safety factor and, therefore, a revised construction sequence similar to Figure 3 cannot be obtained. However, it is observed that the time of consolidation following the end of construction comes out to be appreciably less than in the original analysis. This may allow the engineer-in-charge a little margin in this time interval before declaring the embankment ready for the construction of pavement structure.

Summary and Conclusion

In the present article an attempt has been made to demonstrate how the Plaxis (version 8) can be effectively utilized in providing the practicing geotechnical engineers with all the relevant results of safety and displacement analyses that will enable him to exercise engineering judgment in deciding on a judicious sequence of staged construction of a road embankment. It is understandable that the sequence of construction depends on the target factor of safety at the intermediate stages; the higher the target factor of safety the longer it will take for the total construction to be completed. However, the displacement, especially the vertical displacement at the end of construction as well as at the long term should be of concern to the designer of such a project. The displacement is obviously inversely proportional to the total time allowed and hence the target factor of safety. Thus it is a trade-off between the time available at hand and the maximum permissible vertical displacement i.e. settlement of the embankment. Keeping this in mind, the results of the entire analysis have been summed up in the form of two plots – one giving the height of construction vs. time for various factor of safety and the other, vertical displacement vs. target factor of safety.

Parameter	Name	Clay	Peat	Sand	Unit
Material Model	Model	MC	MC	MC	-
Type of Behaviour	Type	Undrained	Undrained	Drained	-
Soil unit weight above phreatic level	γ_{unsat}	15.00	8.00	16.00	kN/m³
Soil unit weight below phreatic level	γ_{sat}	18.00	11.00	20.00	kN/m³
Horizontal Permeability	k_x	1×10^{-4}	2×10^{-3}	1.00	m/day
Vertical Permeability	k_y	1×10^{-4}	1×10^{-3}	1.00	m/day
Young's modulus	E_{ref}	1000	350	3000	kN/m²
Poisson's Ratio	ν	0.33	0.35	0.30	-
Cohesion	c_{ref}	2.00	5.00	1.00	kN/m²
Friction Angle	ϕ	24	20	30	°
Dilatancy angle	ψ	0.0	0.0	0.0	°

Table 1: Material Properties of the road embankment and subsoil