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CONTENTS

Numerical Analysis of Embankment on Soft Soils with Different Constitutive Models

Rohamezan Rohim.
Department of Civil Engineering, Universiti Teknologi MARA, UiTM P.Pinang Branch, 14000 Permatang Pauh, Pulau Pinang. mei_zan@yahoo.co.uk

Abstract

The problem related to the soft soils deposits is an important role in geotechnical works. Soft soil is very porous and fully saturated in nature. The degree of compressibility is high and low in undrained shear strength due to high amount of moisture content. With the existing equipment, engineers sometime forget or neglect the effect caused by the soft soils. The main problem faced by the structure built on the soft soil such as embankment, excavation and tunnel is the effect of time dependent deformation (during primary and secondary consolidation). Soft Soil Creep Model (SSC) and Soft Soil Model (SS) are standard models that are available in PLAXIS. Another two new models are Multilaminate Creep Model (MLC) and Multilaminate Soft Soil Model (MSS). These models were developed recently in the Institute of Geotechnical Engineering, University of Stuttgart. Simulations were conducted to investigate the horizontal and vertical displacements under specified loadings. MSS model shows higher settlement and horizontal displacement after the construction of embankment with 0.32m and 0.06m respectively. MLC model on the other hand shows the highest settlement and horizontal displacement with 2.4m and 0.25m respectively.

Keywords: ***Soft Soil, Embankment, Multilaminate, Creep***

Introduction and Basic Concept

Various soft soils deposits can be found all over the world. Some of them are extremely soft and sensitive, such as the marine clays in Scandinavia and on the Northern shoreline of Champlain Sea in Canada, lacustrine deposits in Austria and southern Germany, the alluvial deposits often encountered in the British Isles, peat deposits found in Sarawak, Malaysia and bay mud in San Francisco, California. The natural formations of soft soils are extremely complex as the mechanical and physical properties undergo long geological processes such as weathering, chemical and physical processes as well as biological processes. The composition of soft soils is mainly determined by the mineralogy and chemical composition of the parent material. The most important minerals composing soft soils are hydrous aluminium and magnesium silicates. The minerals, when moist, show the characteristic plastic properties (Gilott, 1968).

Soft soils are typically very porous and fully saturated clayey soils. Very often the water content of soft soil deposits is higher than the liquid limit. This fact displays the importance of inter-particle cementation of soft soils. Some other significant properties of soft soils are high degree of compressibility. The stiffness is relatively low and the eodometer modulus, (E_{eod}) ranges between 1 MPa and 4 Mpa. Comparing to the eodometer modulus of sand it is approximately 10 MPa to 50 MPa lower. High amount of water influences the plasticity of the soft soils. The undrained shear strength of soft soils is low. Bjerrum, 1967 explained that the undrained shear strength increases with the plastic index.

The relationship between the ratio of undrained shear strength and effective overburden pressure s_u/p against the plasticity index is shown in Figure 1. The range of overconsolidation ratio of normally and slightly overconsolidated clays is between 1 to 5. The value of OCR is obtained by dividing the maximum effective stress obtained in the past to the *in-situ* effective stress as it is shown in Figure 2.

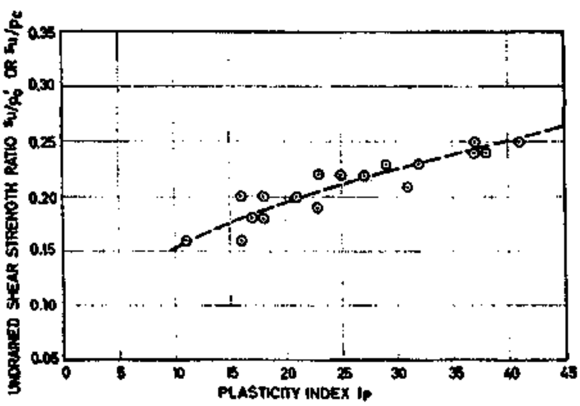


Figure 1. The ratio of undrained shear strength against plasticity index. (after Bjerrum, 1967)

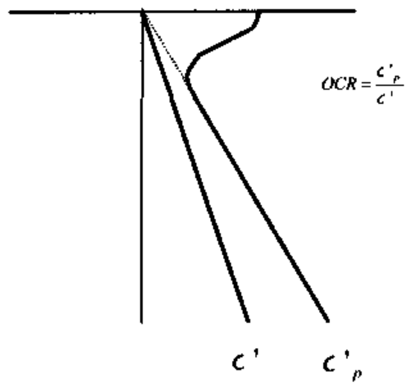


Figure 2. Typical variation of preconsolidation pressure and *in-situ* effective stress with depth.

Engineers are aware of the problems created by soft soils, however, due to the lack of availability of advance equipments, sometimes they are unable to investigate material characteristics which are needed to predict behaviour of soft ground. The best example to illustrate the problem of soft soils is the tower of Pisa in Italy.More than 150 years after construction, the tower tends to settle continuously under constant weight of 14,486 tonne and the settlement is approximately 2 mm per year (Meschyan, 1995).

Problem Statement and Objective of Paper.

Population growth and massive development has resulted in engineers being limited on choice for areas to develop. Very often they have to improve the infrastructure in and around densely areas, which take place in poor ground conditions such as soft soils. The need to construct on soft soils become unavoidable and any problem arising must be faced by engineers. Although new construction and field observation techniques have been developed to ensure that embankments, tunnels and deep excavations can be built safely under these difficult conditions, the design is still predominantly based on empirical rules and simplifying assumption rather than on a sound theoretical basis.

Currently, the geotechnical design is still based on conventional methods, which are sometimes uneconomical or even unsafe. The development of modern techniques in design methods has to be combined with the understanding of the mechanical behaviour of soft soils. Advanced knowledge on numerical techniques, constitutive models and laboratory techniques are required to develop models for use in geotechnical design. The demand on understanding the mechanical behaviour of soft soils has become a great challenge to engineers.

The objective of the paper is to describe and present results of simulations using Soft Soil Creep Model, Soft Soil Model, Multilaminate Creep Model and Multilaminate Soft Soil Model in investigating the horizontal and vertical displacements under specified loadings.

Methodology

The commercial finite element software for soil and rock analyses, PLAXIS, is used to simulate the behaviour of Poko clay after being loaded with embankment. Poko clay is a marine clay type found near the medieval town of Porvo in southern Finland. The embankment was simulated after construction and after consolidation. The results are also presented after construction and after consolidation..

The Models

The constitutive models that were used to simulate the behaviour of Poko clay are Soft Soil Creep Model (SSC), Soft Soil Model (SS), Multilaminate Creep Model (MLC) and Multilaminate Soft Soil Model (MSS). SS and SSC models are the standard models implemented in PLAXIS code, whereas MSS and MLC models are the new models developed recently in the Institute of Geotechnical Engineering, University of Stuttgart. The new models are implemented within the user defined soil models facility in the PLAXIS program.

Soft Soil Model (SS)

Soft Soil model is based on the Cam Clay model, and only the primary compression of nearly consolidated clay type of soils is taken into account. Cam Clay model was originally known as Cambridge Clay. It has an advanced feature such as the so-called cap yield surface for compressional strength, which is formed by the ellipse. Mohr Coulomb criterion is used for the shear strength. By combining these two surfaces, the simulation of soft soils becomes more realistic.

Soft Soil Creep Model (SSC)

In many soft soil problems, creep or secondary compression is impossible to be simulated using models such as Soft Soil or Hardening Soil models. When the soil is imposed with an extra load, the soil skeleton will try to sustain and stabilize the load by exhibiting creep after primary compression. All the soils experience time dependent behaviour (creep and relaxation), when large primary compressions are induced. Structures such as embankments, dams and foundations need extra precautions since they will face this kind of straining during and after construction.

Multilaminate Soft Soil Model (MSS)

Multilaminate Soft Soil model is a new model developed at the University of Stuttgart (Cudny, 2003). This model is an advance model for Soft Soil Model implemented within so-called user defined soil model facility in PLAXIS code. The formulation of Multilaminate Soft Soil model considers the effect of structural anisotropy and the destructuration in the clay material. The Soft Soil and Soft Soil Creep models use hardening procedure and thus not account for anisotropic effects.

Multilaminate Creep Model (MLC).

The Multilaminate Creep (MLC) model is multilaminate version of the Soft Soil Creep model (SSC) which is an elasto-viscoplastic model. Figure 3 shows how the formulation of MLC-model is represented. Here, Mohr-Coulomb criterion with a function of strength parameters j and *c* to describe the failure line is used.

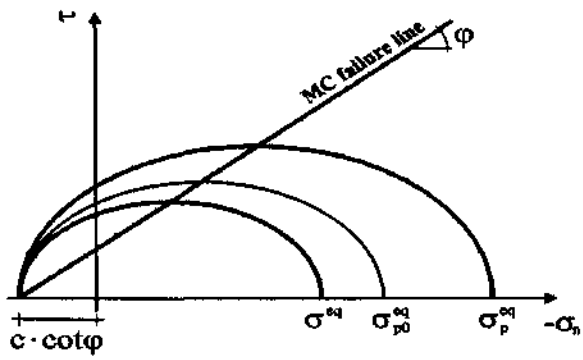


Figure 3 Mohr-Coulomb failure line and cap surface of the MLC-model on an integration plane.

The elliptic cap is not a yield surface in the case of MLC-model since it can move freely with time, and this cap is combined with Mohr-Coulomb failure line, which is fixed. (Vermeer & Neher. 1999)

Embankment Simulation.

In this study, embankment is built on the soft Poko clay soil in two layers of height of one meter as shown in Figure 4.The embankments material was simulated with Mohr Coulomb linear elastic plastic model and it is assumed to be drained. Only half of the structure is considered due to the symmetrical cross section. Water table is assumed to be two meter below the surface. The first layer of embankment is 14 meters wide from the centre line and is followed by 10 meters wide second layer. Both layers have a slope of 1: 2 (1 meter height and 2 meter wide). The material parameters for the embankment are as in Table 1.

γ	E	φ	ψ	c	ν	Tensile strength
kN/m³	kPa	°	°	kPa	-	kPa
20,0	40000	38	0	1,0	0,3	0,0

Table 1: Material parameters for embankment problem

The domain analysed was 60 m wide and 36 m deep. Boundary conditions implied are such that the lateral boundary is restrained horizontally or no movement allowed in x- direction except in y-direction. At bottom boundary no movement is allowed in x and y directions. For the case of consolidation analysis, lateral boundary is closed and the bottom boundary is opened in order to allow the flow of water. Open and close boundary conditions are similar to the concept of drained condition in the laboratory test. The soft soils layers will be modelled as an undrained type material in order to have excess pore pressure during the construction stage. In this condition the volumetric strain, e_v will remain unchanged. The water table is specified at horizontal line 2 m below the ground surface. The unit weight of water has been set to 10 kN/m³.

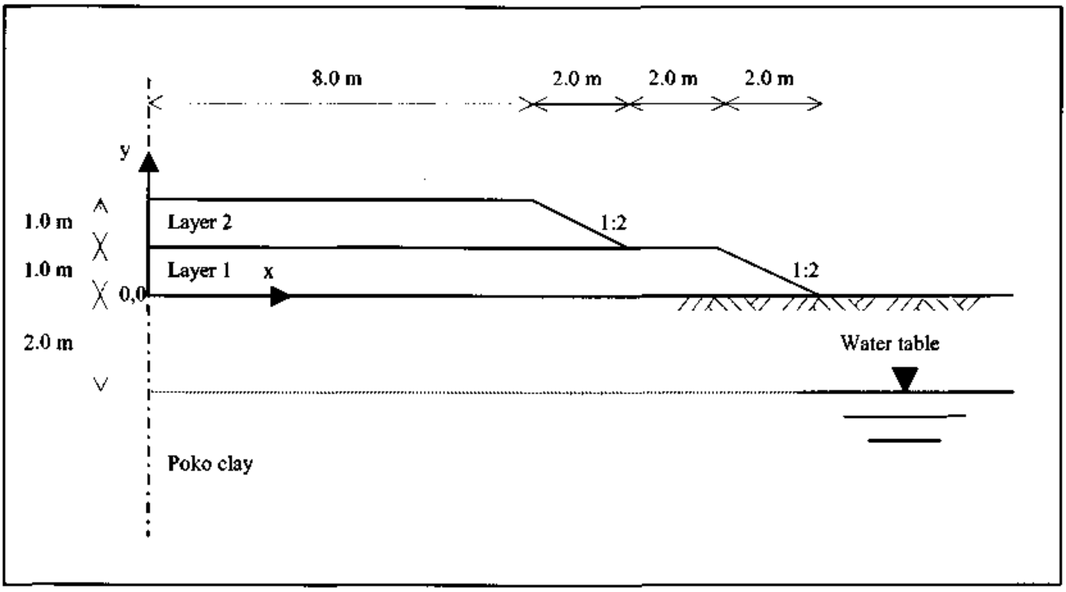


Figure 4. Geometry of embankment problem.

Physical and Mechnical properties of Poko clay are listed in table 2 and 3 respectively.

Material	Unit	Value
Clay size fraction	(%)	75- 77
Organic content	(%)	1
Specific Gravity		2.74 – 2.75
Water Content	(%)	80
Liquid Limit	(%)	80
Plasticity Index	(%)	50
Undrained Shear Strength (from vane test)	kPa	20

Table 2. Properties of Poko Clay.

κ	0.03	κ*	0.01
λ	0.71	λ*	0.24
$\lambda_{intrinsic}$	0.26 (remoulded sample)		
$c_{\alpha e}$	0.02	μ*	0.0087
e_o	2.1		
M	1.2 (for triaxial compression)		
ν	0.2		
ψ	0°		
c	1 kPa		
γ_{sat}	15 kN/m		
k_f	1 x 10^{-9} m/ sec		
sensitivity	15		

Table 3. Input parameter for Poko Clay.

Result and discussion

Finite element discritisation.

The results of embankment simulations may be categorised into two parts. In the first part, the results are presented after the construction phase and in the second part it is presented after the consolidation analysis phase.

During finite element simulation the problems were analysed using plain strain conditions and a 6-nodes triangular element have been applied. The tolerance equilibrium error was set as a default of 0.01. In the finite element discretisation for the embankment problem 1271 nodes, 600 element and 1800 stress points were applied.

Embankment after construction.

Figure 5 shows the deformed mesh after applying both layers on top of the Poko clay. Figure 6a shows the surface settlement trough from the centreline. MSS model shows the largest settlements after application of two layers of embankment. At this stage, comparison between SSC and MLC models does not show much difference as compared with these between SS and MSS. At the distance of 15 meters from the centreline, the clay seems to move upward due to the lateral pressure from the embankment and the condition of the soft soil itself. All of models gave the same pattern for the settlement.

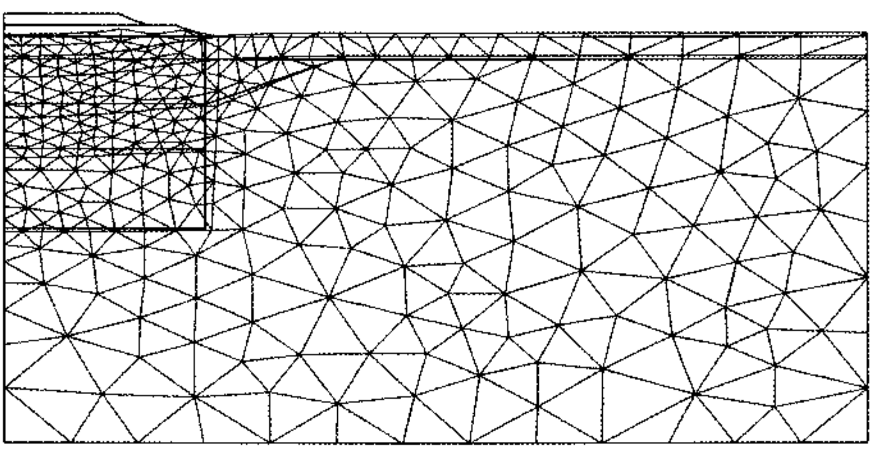


Figure 5. Deformed mesh after construction of embankment for Soft Soil Model

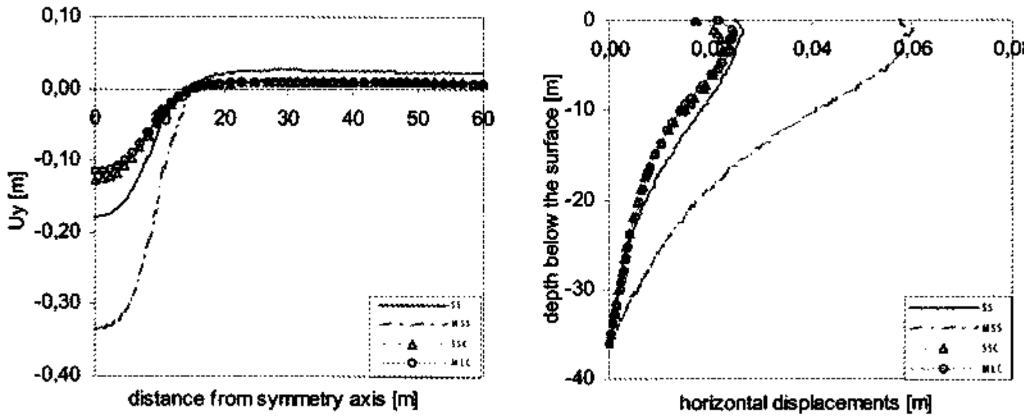


Figure 6. a) Surface settlement trough and b) Horizontal displacement at x=8m after construction

When we look at the horizontal displacement measured at a distance of 8 meters from the centreline, MSS model gave again the largest displacement caused by a lateral movement of soft clay, nearly 0.06m. The horizontal displacements decrease with the depth. Initially, the loading from the embankment is taken up mostly by the pore water pressure and due to that reason we do not expect that the soft soil will displace very much. The SS, SSC and MLC models did not show any big movement during the early stages. It is shown in Figure 6b.

Embankment after Consolidation.

After 100 years of consolidation, the results are compared again. Surface settlements, horizontal displacements occurred in the vertical profile at the distance of 8 meters from the symmetry line are presented. Figure 7 shows the deformed mesh after 100 years of consolidation scaled up to 4 times from the true scale.

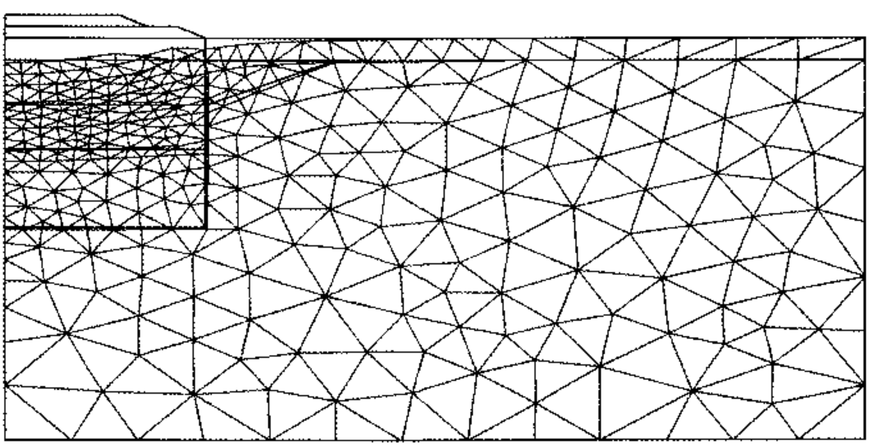
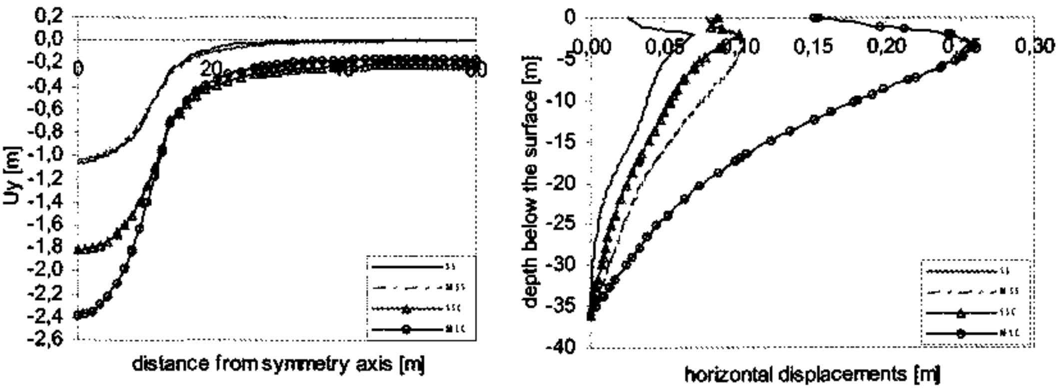


Figure 7. Deformed mesh after 100 years consolidation of embankment for Soft Soil Model.

Figure 8a shows the surface settlement after 100 years of consolidation. From the four models used, MLC model shows the largest settlements followed by the SSC model. The ground settled 0.2 m from the original surface due to the secondary compression of 70 years. SS and MSS models gained one meter settlement below the embankment. The settlements are negligible after the distance of 30 meters from the centreline.

Figure 8b shows the horizontal displacement at vertical section at the distance of 8 meters from the centreline. The highest horizontal displacement is indicated by the MLC model 0.25m compared to other three models. This is due to combination of the effects of creep and primary consolidation.



a) b)

Figure 6. a) Surface settlement trough and b) Horizontal displacement at x=8m after consolidation

The time-settlement curves for point located at the centre of the embankment's base are shown in Figure 9a. The MLC model gives the highest settlement at the end of 100 years consolidation period. The SS and MSS models bring significantly lower settlements. When we inspect settlement curves within the first 3 years of consolidation as shown in Figure 9b, it appears that the MSS model render the highest immediate settlements during the construction phase. Each models shows that the soft soil will settle continuously after 100 years of consolidation.

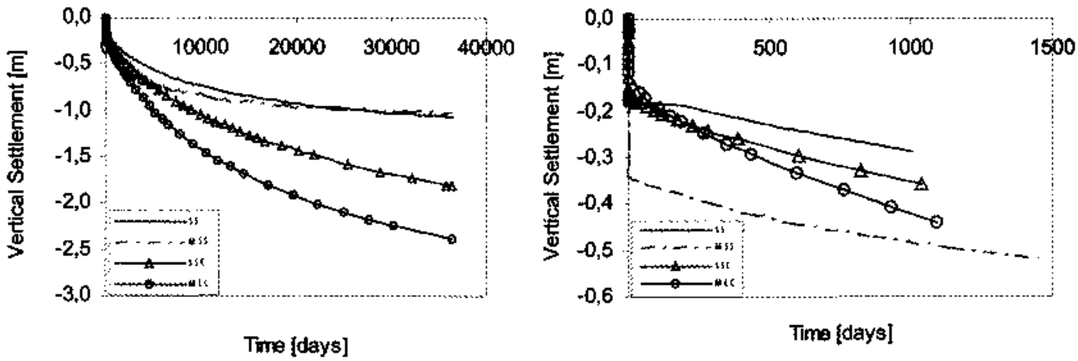


Figure 9a Figure 9b

Time settlement at the surface of centreline a) whole simulation b) within 1500 days

Conclusion.

Results of simulations of the embankment problem are presented in this report. Some of the results show significant differences between isotropic model such as SS and SSC models, and anisotropic model, which are MSS and MLC models. The main aim of this report is to see the differences between the results produced by these models.

It is obvious that SSC and MLC models show small displacements after the construction phase as the main deformation is gained during the secondary consolidation. MSS model shows higher settlements and horizontal displacements after the embankment was constructed.
Results after consolidation show that MLC and SSC models indicate the highest vertical and horizontal displacements. Viscous models (MLC and SSC) show the similar shapes of the settlement curves, like another two nonviscous models (SS and MSS), nevertheless the curves are shifted downward. MSS model indicates the highest settlements at early time of consolidation in the simulation.
The results presented here depends on given parameters.Due to simplification of parameters, thus, the results are simplified. Hence, the differences between isotropic model and anisotropic model could hardly be detected. For future next study, some improvements should be made to parameters that were ignored earlier on for simplicity.

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