Stability of Embankment Constructed on Clayey Soil Treated with Sand Columns

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Problem Description

This chapter analyses the construction of a 4m high embankment built on clay soil. The embankment, constructed in stages, rests on two layers of clay and peat, each 3m thick. Sand drains are employed to speed up the soil consolidation process. The water table is at ground level. The entire model is illustrated in Figure 1.



Figure 1: Embankment model

The embankment is built in two stages over a period of fourteen days. The first layer is constructed over two days. The soil is then allowed to consolidate for a further ten days

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before a second layer is added, again over two days. Finally, the soil is allowed to consolidate until the maximum excess pore water pressure falls below 0.5kPa.

Keywords

Consolidation, Sand Columns, Settlement.

Associated Files

Associated files can be downloaded from the user area of the LUSAS website.



• embankment.lvb carries out automated modelling of the example.

- Use File > New to create a new model of a suitable name in a chosen location.
- Use File > Script > Run Script to open the lvb file named above that was downloaded and placed in a folder of your choosing.

Objectives

Calculating the change of excess pore water pressure and settlement over time.

Preparing the Model Features

The user has to create a new model, set the Analysis category as 2D, and specify the model units as kN,m,t,s,C. The **Time Scale** is set to **Days**. It is sufficient to simulate half of the model based on the symmetry we have.

Feature Geometry

The model can be created through point and line features which are subsequently converted into surfaces. It is good practice to use the commands **Copy** and **Sweep** to reduce considerably the time needed to develop the model. The user has to ensure proper connection between surfaces and avoid any unintentional overlapping. Figure 2 shows the surfaces used to define this problem. The water table lies at the ground surface.



Figure 2: Embankment model

Preparing the Model Attributes

Model attributes (mesh, material, geometric properties, etc.) are defined and assigned to the model. Figure 3 shows the attributes of model.



Defining the Mesh

The foundation, comprising sand and peat layers, is meshed using plane strain two phase, quadrilateral, quadratic elements (QPN8P), whereas the embankment is meshed with plane strain, quadrilateral, quadratic elements (QPN8) as illustrated in figure 4.



Defining the Materials

An isotropic nonlinear material utilising the Modified Mohr-Coulomb failure surface will be used for the soil. The initial stress state in the soil is defined by the coefficient of lateral earth pressure, K_0 . All material properties are listed in table 1. Figures 5 and 6 give the two-phase properties for the relevant materials. Dilation is zero and the Rankine cut off prevents tensile stresses developing in the soil.

Table 1: material properties

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Layer	Soil grain density	Young's modulus, E	Poisson's ratio, v	Angle of friction, φ	Cohesion, c	K_0
Peat	1.143 t/m ³	350 kPa	0.35	20°	5 kPa	0.658
Clay	2.143 t/m ³	1.0E3 kPa	0.33	24°	2 kPa	0.593
Sand	1.6 t/m ³	3.0E3 kPa	0.3	30°	1 kPa	0.5
Sand drain	2.67 t/m ³	80.0E3 kPa	0.3	35°	10 kPa	-

		Value	Eully saturated		Value
Bartially caturated	Bulk modulus of fluid phase	2.2E6	O Particity social deed	Bulk modulus of fluid phase	2,2E6
) Parualiy saturawu	Porosity of medium	0.3	Partially saturated	Porosity of medium	0.3
Water content fraction	Hydraulic conductivity in global X direction	2.0E-3	Water content fraction	Hydraulic conductivity in global X direction	0.1E-3
Saturation	Hydraulic conductivity in global Y direction	1.0E-3	Saturation	Hydraulic conductivity in global Y direction	0.1E-3
Antoine Million and Artistan	Hydraulic conductivity in global Z direction	2.0E-3	0	Hydraulic conductivity in global Z direction	0.1E-3
braining/niling curve definition	Density of fluid	1.0	Draining/filling curve definition	Density of fluid	10
Absolute value Define maximum suction pressure Define maximum cavitation pressure Incompressible solid phase			Absolute value Define maximum suction pressure Define maximum contribution pressure Define maximum contribution pressure		
Incompressible solid phase			Zincompressible solid phase		

Figure 5: Two-phase properties for clay and peat layers

Fully saturated			Value
Partially saturated		Bulk modulus of fluid phase	2.2E6
buturuteu		Porosity of medium	0.4
Water conter	nt fraction	Hydraulic conductivity in global X direction	0.467
Saturation		Hydraulic conductivity in global Y direction	0.467
Draining/filling ou	nue definition	Hydraulic conductivity in global Z direction	0.467
praining/filling cu	ive definition	Density of fluid	1.0
Absolute value Define maximum Define maximum Incompressible	n suction pressure n cavitation pressure solid phase		
Absolute value Define maximum Define maximum Incompressible	m suction pressure n cavitation pressure solid phase		

Figure 6: Two-phase properties for sand drains

Defining the Supports

• The model is restrained in X and Y directions at its base and in the X direction for the lateral sides as shown in the figure 7. These conditions are activated at the initial stage as explained in the following paragraph.



• To establish the position of the water table, the pore pressure is set to **Open** and the X-direction restrained at point 101 (Figure 8). These conditions are activated during the first stage as well.



• During construction of the embankment, the pore pressures from the hydrostatic pressure distribution established in the initial phase are fixed at the top and bottom of the foundation by setting the pore pressure to **Open** (Figure 9).



Defining the Loads

Gravity load is applied via the command Attributes > Loading > Body Force.

Defining Other Attributes

Deactivate and Activate attributes are employed to simulate the construction of the embankment and sand drains as we demonstrate in the following paragraphs.

Running the Analysis

We are considering the following analyses and stages.

Analysis 1 > Initial Phase

This stage establishes the initial stress and water pressure distributions with gravity acting as a load and the model being restricted from movement at the base and sides as shown in figures 7 and 8. During this stage, the embankment and sand columns are turned off through the **Deactivate** command (Figure 10).

Nonlinear analysis control properties are defined for this phase, all the parameters are left at their default values.

Note: To simulate real-life practice, when installing the sand drains, it is necessary to switch materials following the same procedure outlined in the "Bearing Capacity of Shallow Foundation" example.



Figure 10: Initial stage (analysis 1)

Analysis 1 > Installation of Sand Drains

The material for sand drains is activated to simulate the installation process, while the clay and peat materials occupying the same location as the sand drains are deactivated (Figure 11).

Nonlinear analysis control properties are defined for this phase, all the parameters are left at their default values.



Figure 11: Installing of Sand Drains Stage (analysis 1)

Analysis 2 > Construction of 1st layer of Embankment

In analysis 2, we first create a Load Curve by the command **Analysis2 (right click)** > **New** > **Load Curve**. Using load curves, we can assign the gravity load gradually over time. In this regard three load curves are created as follows (Figure 12):

- Gravity is assigned to the foundation layers from Time day 0 to day 1E6.
- Gravity is increased from 0 on day 0 to 1 on day 2 to model the construction of the first layer of embankment over two days. It then remains constant until the end of the analysis.
- Gravity is increased from 0 on day 12 to 1 on day 14 to model the construction of the second layer of embankment over two days. It then remains constant until the end of the analysis.



Figure 12: Load curves used in analysis 2

In this stage, the first layer of the embankment is built up using the command Activate. The excess pore water freely dissipates through the upper and lower boundary of the foundation layers (Figure 13).



Nonlinear analysis control properties are set as shown in figure 14. The total time is set to 2 days with a starting time step is 0.001 days. Automatic time stepping is used for this stage, and in fact for the other stages as well, with a target change in pore water pressure per step of 1 kPa.

ncrementation		Solution strategy		Advanced Time Step Parameters	
Nonlinear		Same as previous loadcase			
Incrementation	Manual \checkmark	Max number of iterations	12	Time step increment restriction factor	1.0
Starting load factor	0.1	Residual force norm	0.1	Minimum time step	0.0
Nax change in load factor	0.0	Incremental displacement norm	1.0	Minimum ume step	0.0
Nax total load factor	1.0		Advanced	Maximum time step	100.0
Adjust load based on co	invergence			Target change in pore water pressure per step	1.0
Iterations per increment	4	Same as previous loadcase		Target change in saturation per step	0.0
	Advanced	Output file	1		
Time domain	Two Dhaee	Plot file	1	Termination value of excess pore water pressure	0.0
loitial time step	1.05-2	Restart file	0	Termination rate of change of pore water pressure	0.0
Total remonse time	2.0	Max number of saved restarts	0	Termination rate of change of saturation	0.0
Automatic time stanning		Log file	1		
Automatic une stepping	Advanced	History file	1	Integration factor beta	1.0
		Save a restart at the end of this	control		
ommon to all				Allow step reductions	_
Max time steps o	r increments 0			Maximum step reductions	5

Figure 14: Nonlinear analysis control parameters

Analysis 2 > Consolidation of 1st layer of Embankment

This phase allows the embankment to consolidate over 10 days. Nonlinear analysis control properties are set as shown in figure 15. As the soil is allowed to consolidate for 10 days, the total time is now set to 12 days.

ncrementation		Solution strategy	
Nonlinear		Same as previous loadcase	
Incrementation	Manual 🗸 🗸	Max number of iterations	12
Starting load factor	0.1	Residual force norm	0.1
Max change in load factor	0.0	Incremental displacement norm	1.0
Max total load factor	1.0		Advanced
Adjust load based on co	invergence	Incremental LUSAS file output	
Iterations per increment	4	Same as previous loadcase	
	Advanced	Output file	1
✓ Time domain		Plot file	1
	Two Phase 🗸 🗸	Restart file	0
Initial time step	1.0E-3		-
Total response time	12.0	Max number of saved restarts	U
Automatic time stepping		Log file	1
	Advanced	History file	1
		Save a restart at the end of this	control
Common to all			
Max time steps o	r increments 0		

Figure 15: Nonlinear analysis control parameters

Analysis 2 > Construction of 2nd layer of Embankment

The second layer of the embankment is activated (Figure 16). Nonlinear analysis control properties are set as shown in figure 17. The total time is set to 14 days.



Nonlinear		Same as previous loadcase	
Incrementation	Manual 🗸	Max number of iterations	12
Starting load factor	0.1	Residual force norm	0.1
Max change in load factor	0.0	Incremental displacement norm	1.0
Max total load factor	1.0		Advanced.
Adjust load based on a	convergence	Incremental LUSAS file output	
Iterations per increment	4	Same as previous loadcase	
	Advanced	Output file	1
Time domain		Plot file	1
	Two Phase V	Restart file	0
Initial time step	1.0E-3	Max number of saved restarts	0
Total response time	14.0	Log file	1
Automatic time stepping	Advanced	History file	1
		Save a restart at the end of this	control
Common to all			

Figure 17: Nonlinear analysis control parameters

Analysis 2 > Consolidation of 2nd layer of Embankment

At the final stage, we allow the model to stabilize until the maximum excess pore water pressure falls below 0.5 kPa to obtain the final overall settlement. Nonlinear analysis control properties are set as shown in figure 18.

ici cinci i ci		Solution strategy			
Nonlinear		Same as previous loadcase		Advanced Time Step Parameters	
Incrementation	Manual ~	Max number of iterations	12		
Starting load factor	0.1	Residual force norm	0.1	Time step increment restriction factor	1.0
Max change in load factor	0.0	Incremental displacement norm	1.0	Minimum time step	0.0
lax total load factor	1.0		Advanced	Maximum time step	100.0
Adjust load based on o	convergence	Incremental LUSAS file output		Target change in pore water pressure per step	1.0
terations per increment	4	Same as previous loadcase		Target change in saturation per step	0.0
	Advanced	Output file	1	ranget anange in batanaban per atep	
Time domain	x at	Plot file	1		0.5
	Two Phase V	Restart file	0	remination value of excess pore water pressure	0.5
nitial time step	1.0E-3		0	Termination rate of change of pore water pressure	0.0
fotal response time	1.0E6	Max number of saved restarts	0	Termination rate of change of saturation	0.0
Automatic time steppin	D	Log file	1		
	Advanced	History file	1	Integration factor beta	0.67
		Save a restart at the end of this	control	ancgrown foctor beta	0107
ommon to all			control	Allow step reductions	
Max time steps	or increments 0			Maximum step reductions	5

Figure 18: Nonlinear analysis control parameters

Viewing the Analysis

Analysis loadcase results are present in the Treeview.

Stress

The following figure 19 shows the effective stress at initial stage.



Figure 19: Effective stress at the initial stage (kN/m^2)

Pore Pressure

The distribution of pore pressure in different stages is shown in figure 20. It clearly illustrates the generation of the excess pore pressures and their dissipation with time/stages.



Consolidation



Figure 20: Pore Pressure in different stages

Settlement

Figures 21 and 22 show the settlement and pore pressure plots for node 212, with the highest settlement reaching 29 mm.



Figure 21: Settlement with time



Figure 22: Variation of pore pressure with time