Stability of Embankment Constructed on Clayey Soil Treated with Sand Columns

For LUSAS version:	21.0
For software product(s):	LUSAS Bridge plus or LUSAS Civil&Structural plus
With product option(s):	Geotechnical, Nonlinear, Dynamic

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.

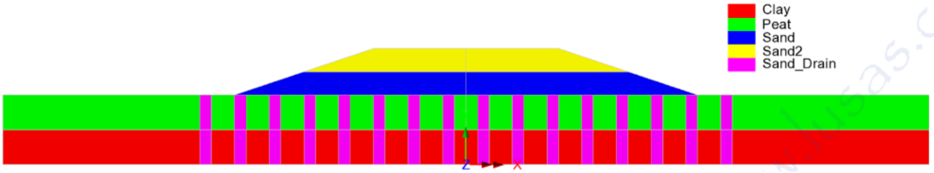


Figure 1: Embankment model

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 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.

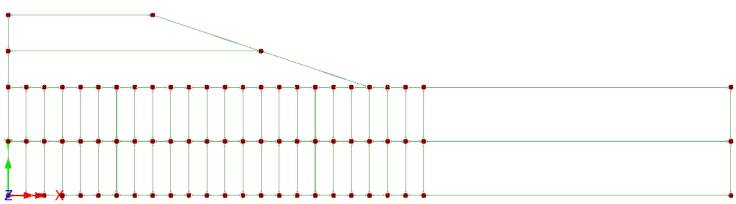


Figure 2: Embankment model

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.

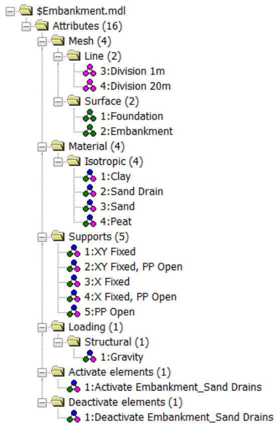


Figure 3: Model Attributes

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.

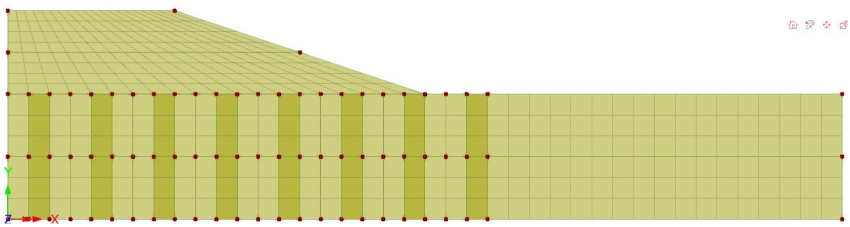


Figure 4: Model Meshing

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

Layer	Soil grain density	Young's modulus, E	Poisson's ratio, ν	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	-

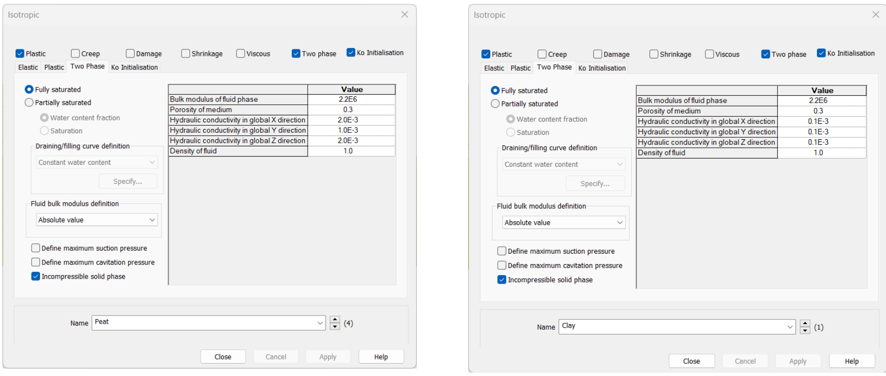


Figure 5: Two-phase properties for clay and peat layers

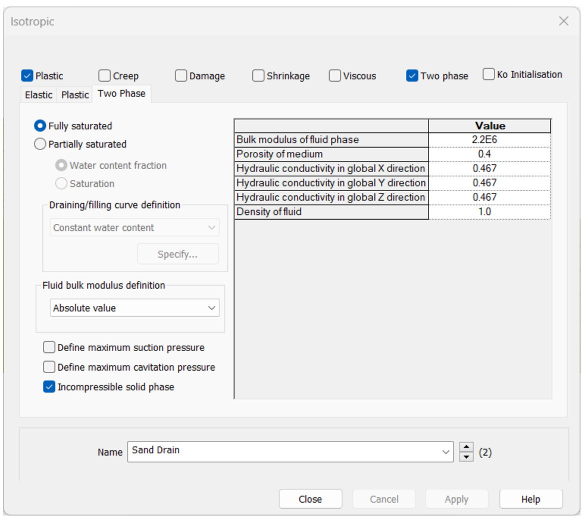


Figure 6: Two-phase properties for sand drains

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.

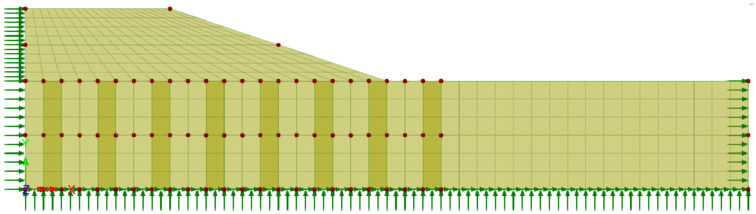


Figure 7: Boundary conditions at initial stage

- 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.

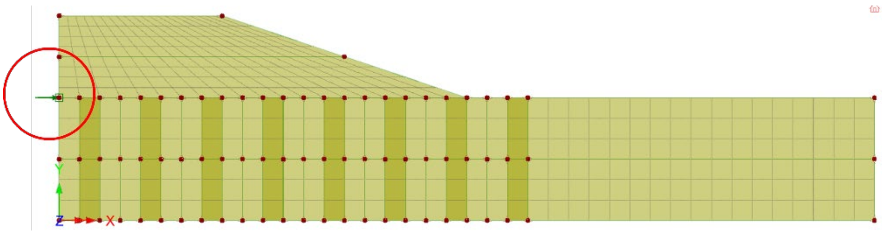


Figure 8: Boundary conditions at initial stage

- 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).

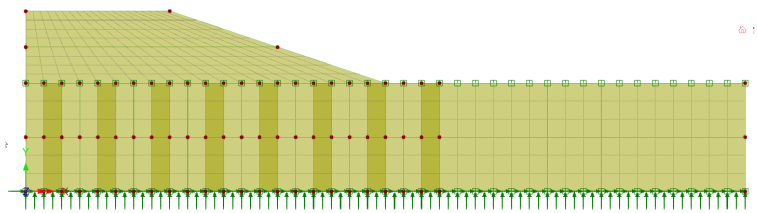


Figure 9: Boundary conditions at embankment construction stage

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.

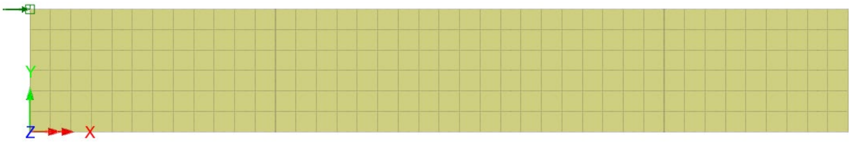


Figure 10: Initial stage (analysis 1)

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.

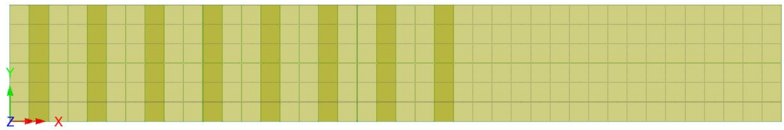


Figure 11: Installing of Sand Drains Stage (analysis 1)

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.

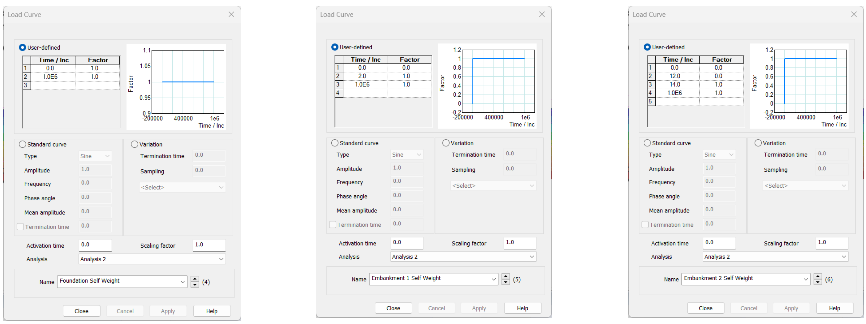


Figure 12: Load curves used in analysis 2

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).

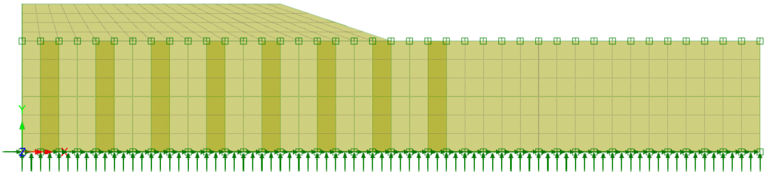


Figure 13: First layer of embankment stage (analysis 2)

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.

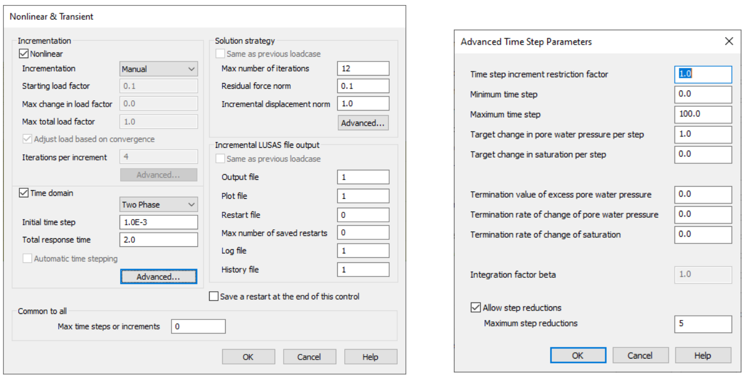


Figure 14: Nonlinear analysis control parameters

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.

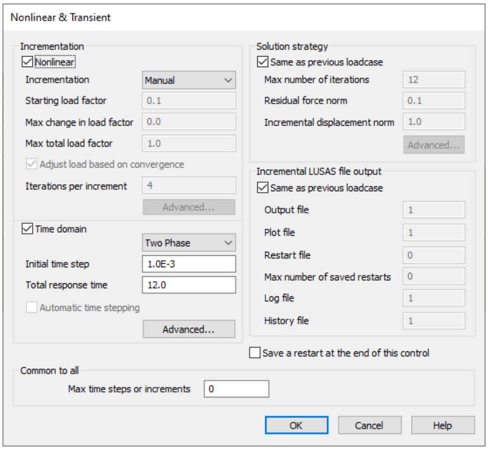


Figure 15: Nonlinear analysis control parameters

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.

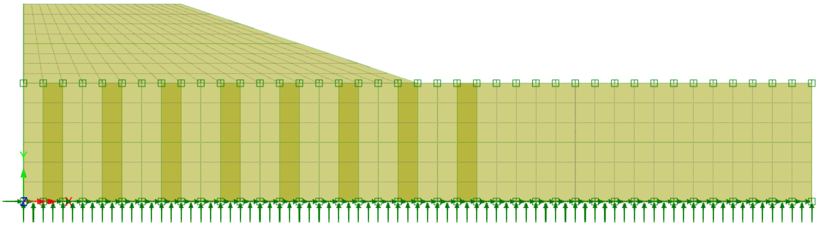


Figure 16: Second layer of embankment stage (analysis 2)

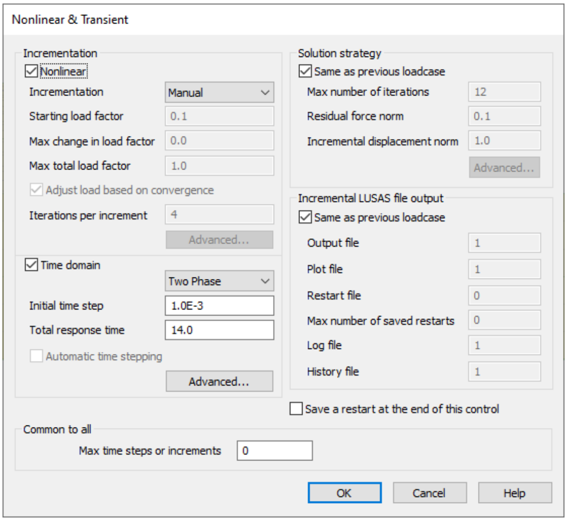


Figure 17: Nonlinear analysis control parameters

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.

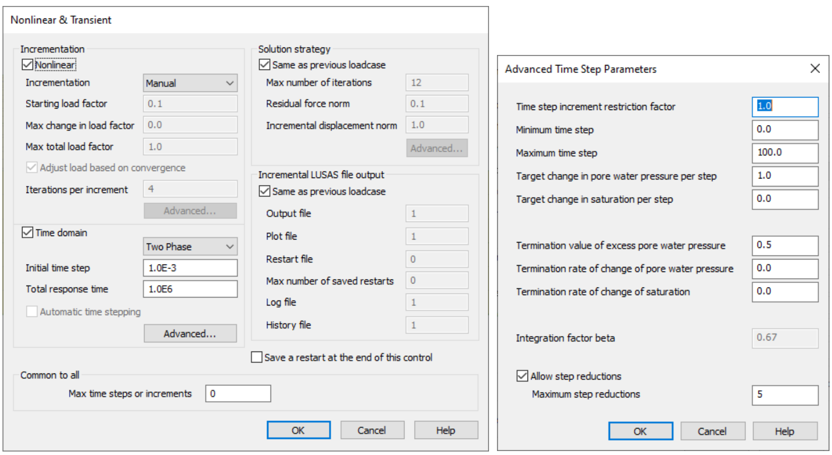


Figure 18: Nonlinear analysis control parameters

Viewing the Analysis

Analysis loadcase results are present in the Treeview.

Stress

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

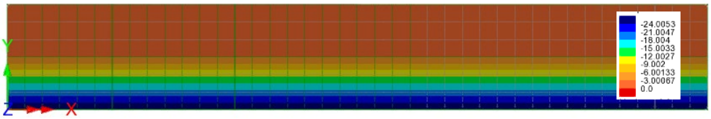
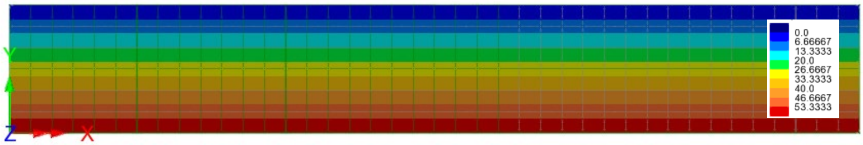


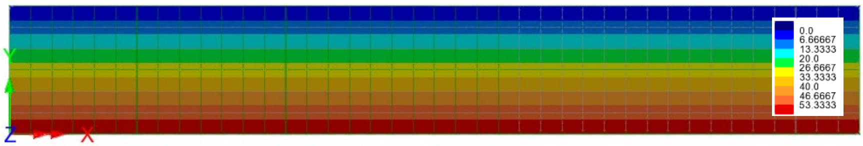
Figure 19: Effective stress at the initial stage (kN/m^2)

Pore Pressure

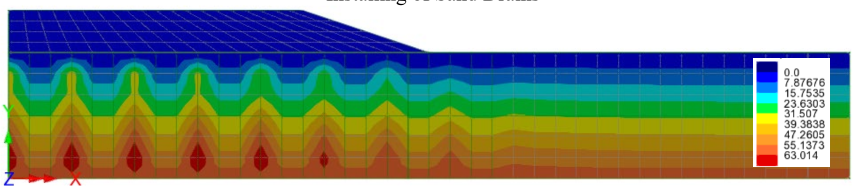
The distribution of pore pressure in different stages is shown in figure 20. It clearly illustrates the generation of the excess pore pressures and their dissipation with time/stages.



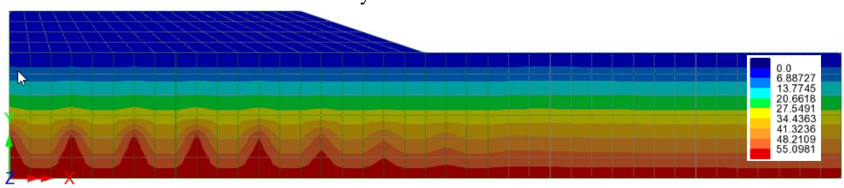
Initial Phase



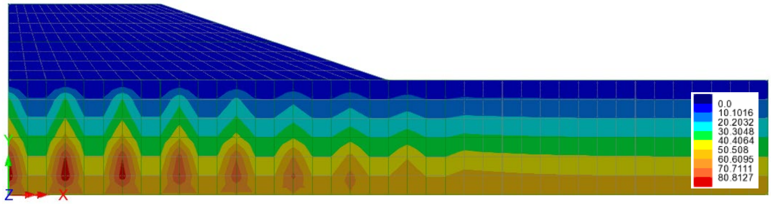
Installing of Sand Drains



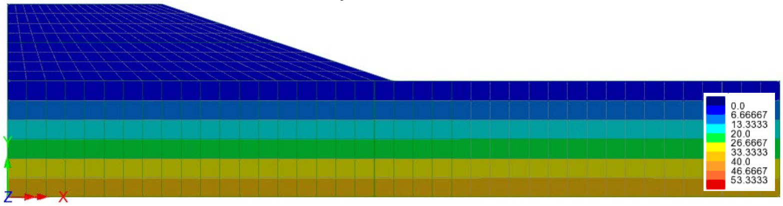
First Layer of the embankment



Consolidation



Second Layer of the embankment

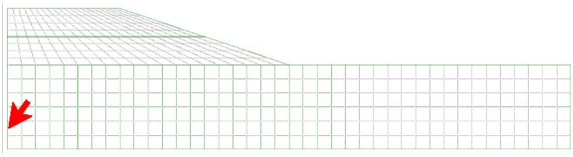


Consolidation

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.



Location of node 212

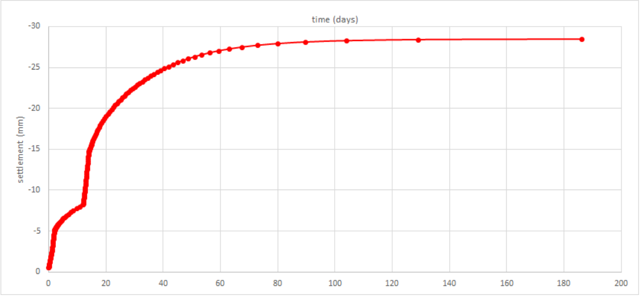


Figure 21: Settlement with time

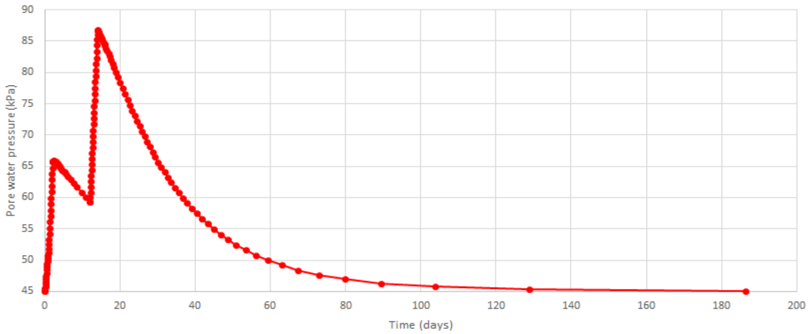


Figure 22: Variation of pore pressure with time