CUSTOMER SUPPORT NOTE

Modelling Consolidation

Note Number:	**CSN/LUSAS/1002**

This support note is issued as a guideline only.

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1. Introduction

In nonlinear geotechnical analysis, where the soil mass is represented using finite elements, it is necessary to determine whether short-term (undrained), long-term (drained), or fully coupled consolidation behaviour should be modelled. The choice between these approaches is primarily governed by the soil types represented in the model and, in particular, their permeability. Soil permeability controls the rate at which excess pore water pressures generated by excavation or construction activities dissipate.

Sandy or gravelly soils, which typically have relatively high permeability, allow excess pore water pressures to dissipate rapidly. In such cases, a drained analysis is generally appropriate.

In contrast, clay-rich soils have low permeability, so excess pore water pressures dissipate much more slowly, and it may take many years for equilibrium conditions to be reached. For such soils, it is important to determine whether short-term behaviour (immediately after construction, prior to dissipation of excess pore water pressures) or long-term behaviour (after full dissipation of excess pore water pressures) should be modelled. The appropriate choice depends on whether short-term or long-term conditions govern stability. Cuttings and excavations are generally more stable under short-term conditions due to the development of negative excess pore water pressures, whereas embankments and foundations are typically more stable under long-term conditions, once excess pore water pressures have fully dissipated.

Geotechnical engineers typically assess these short-term and long-term bounds using standard single-phase continuum elements, manually switching between total stress parameters (for undrained conditions) and effective stress parameters (for drained conditions). When the soil mass is represented using two-phase continuum elements in LUSAS, this manual switching is unnecessary because the soil skeleton and pore fluid are explicitly considered. By assigning a *Drained* or *Undrained* attribute to a specific construction stage, users can calculate the corresponding long-term or short-term equilibrium state within a single static increment (or branch analysis). A transient analysis can be performed to model the progression of the consolidation process between these two limiting states.

For a consolidation analysis, it is necessary to define both the elastic properties of the soil and the properties required to represent its two-phase behaviour. A geotechnical material model that accounts for elasto-plastic behaviour can be used to capture the effect of changes in effective stress on the shear strength of the soil.

This technical note presents the results of an illustrative example. Readers are also encouraged to consult the LUSAS step-by-step geotechnical worked examples and geotechnical overview examples for further information.

2. Illustrative example

2.1 Description

The 2D plane-strain model is shown in Figure 1. The fully saturated clay layer, 45 m in depth, is modelled using two-phase plane-strain elements (quadrilateral elements with quadratic interpolation order). The groundwater table is assumed to coincide with the ground surface. The clay is modelled as an isotropic, linear-elastic, two-phase material.

A locally refined mesh is used in the central region of the model, as this area is the main focus of the analysis. The model boundaries are located sufficiently far from this region to ensure that the effects of the boundary conditions do not influence the response in the area of interest.

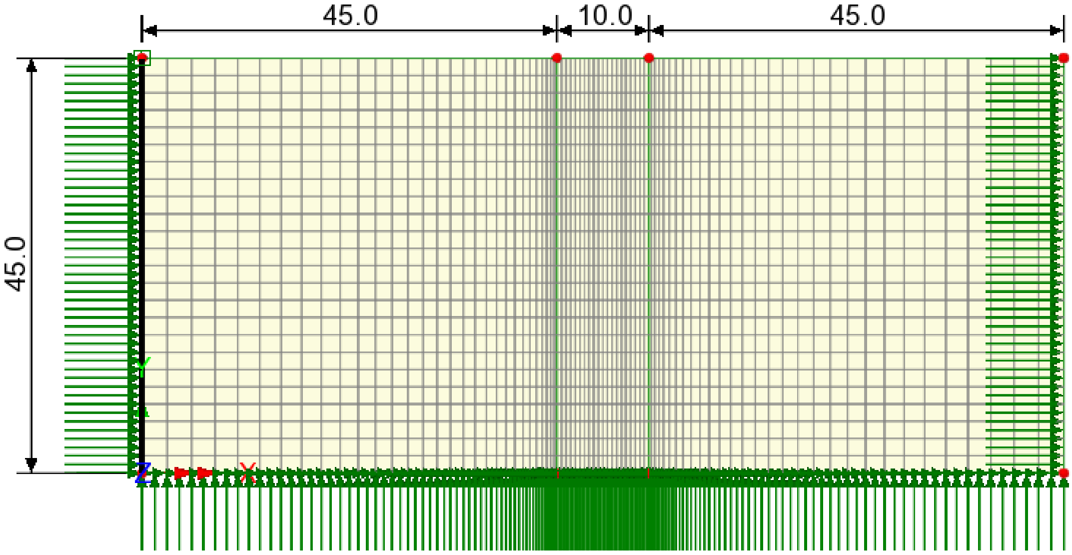

Figure 1 – 2D plane-strain model.

2.2 Analysis stages

2.2.1 Initial conditions

Initially, the soil is assumed to be in a state of rest. The pore water pressure distribution is shown in Figure 2. Under hydrostatic conditions, the maximum pore water pressure at a depth of 45 m is 441.5 kPa. The vertical effective stress distribution is presented in Figure 3.

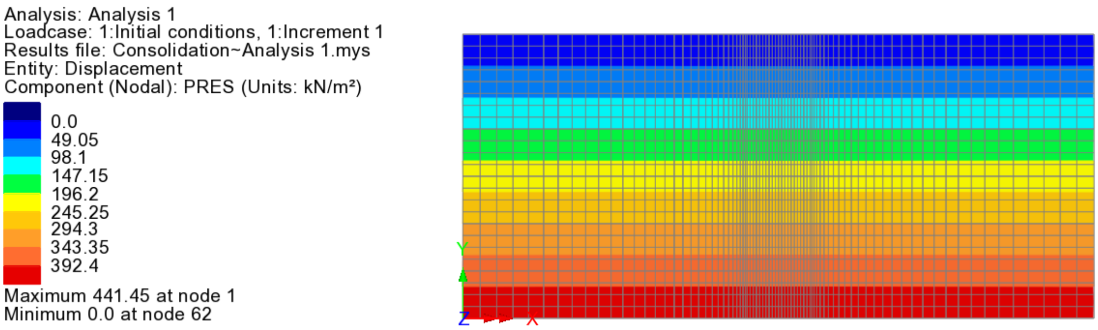

Figure 2 – Initial conditions: Pore water pressure distribution.

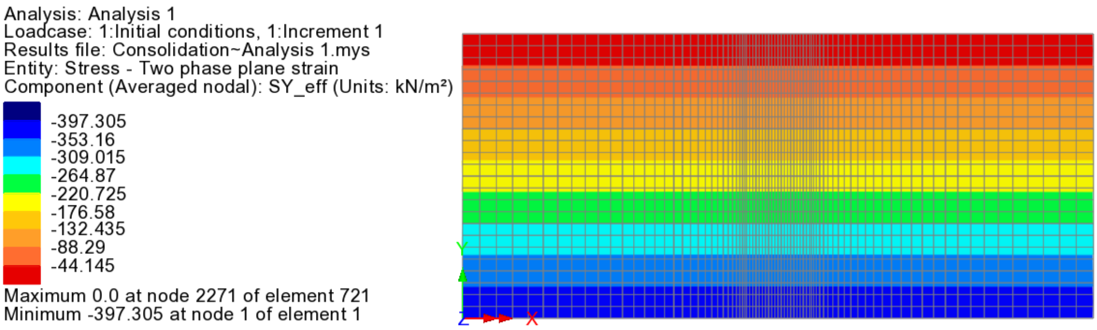

Figure 3 – Initial conditions: Vertical effective stress distribution.

2.2.2 Undrained (short-term) conditions

Under undrained (short-term) conditions, the application of a distributed load results in the pore water pressure distribution shown in Figure 4 and the vertical effective stress distribution shown in Figure 5. The soil region beneath the applied load is of particular interest, as the excess pore water pressure in this area is almost equal to the increase in total stress, while the vertical effective stresses remain almost unchanged.

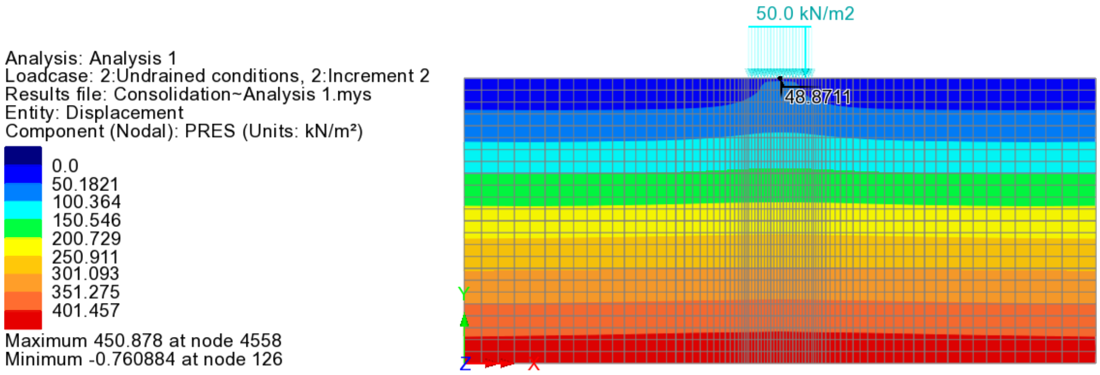

Figure 4 – Undrained conditions: Pore water pressure distribution.

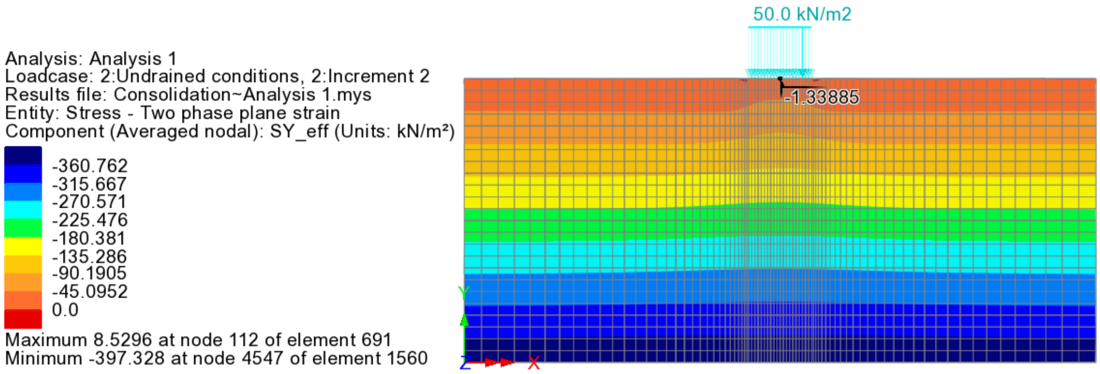

Figure 5 – Undrained conditions: Vertical effective stress distribution.

Figure 6 presents the deformed mesh plot, with the deformation shown at an exaggerated scale, together with the distribution of vertical displacement.

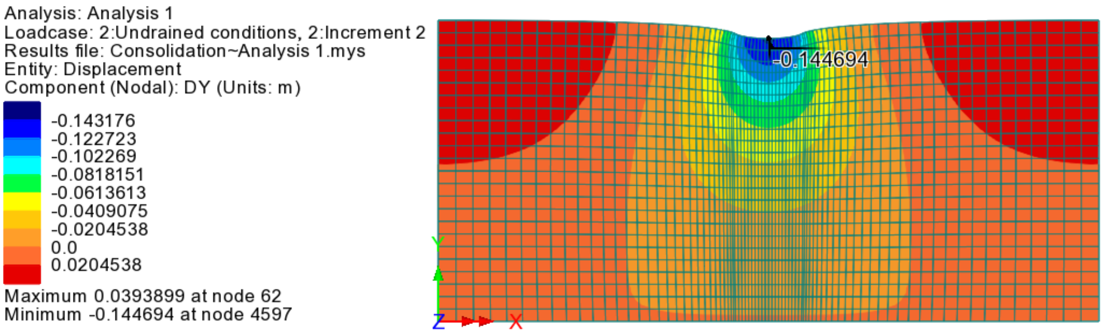

Figure 6 – Undrained conditions: Deformed mesh plot and vertical displacement distribution.

2.2.3 Drained (long-term) conditions

Once the excess pore water pressures have fully dissipated (i.e. under drained or long-term conditions), the pore water pressure distribution is identical to that of the unloaded state (see Figure 7). As shown in Figure 8, the vertical effective stresses beneath the applied load are similar in magnitude to the applied stress, indicating that the entire load is carried by the soil skeleton.

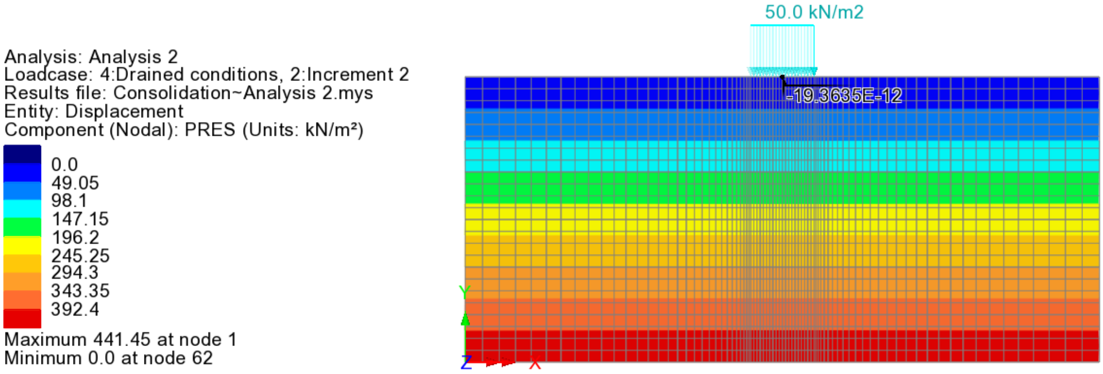

Figure 7 – Drained conditions: Pore water pressure distribution.

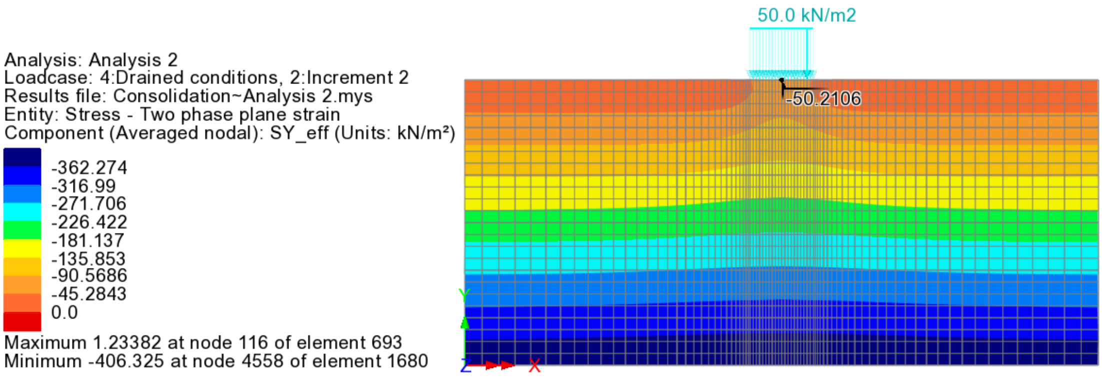

Figure 8 – Drained conditions: Vertical effective stress distribution.

Figure 9 presents the deformed mesh plot, with the deformation shown at an exaggerated scale, together with the distribution of vertical displacement.

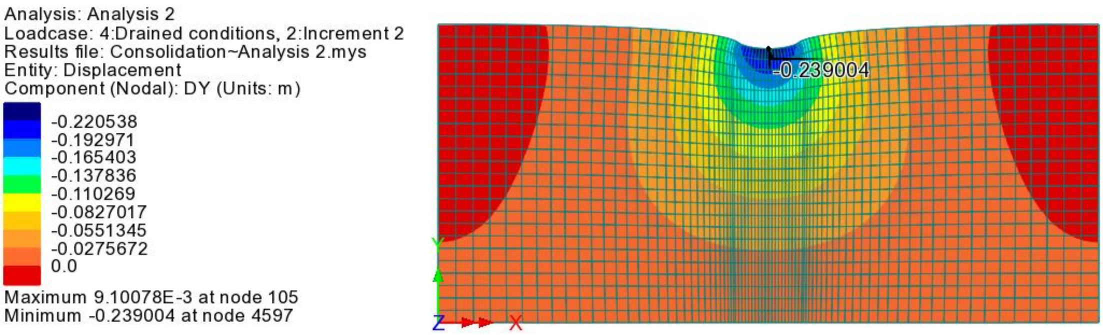

Figure 9 – Drained conditions: Deformed mesh plot and vertical displacement distribution.

2.2.4 Consolidation

The results of the time-dependent consolidation analysis are presented in Figure 10, Figure 11, and Figure 12. Water is permitted to flow through the ground surface nodes (drainage boundaries), allowing excess pore water pressures to dissipate gradually.

Figure 10 (node at X = 50 m, Y = 45 m): At t = 0 (undrained conditions), the application of the distributed load generates excess pore water pressures. As time progresses, the excess pore water pressures gradually dissipate. At the end of the consolidation process (drained conditions), the excess pore water pressures have fully dissipated.

Figure 11 (node at X = 50 m, Y = 45 m): At t = 0 (undrained conditions), the applied load is carried almost entirely by the pore water. As time progresses, an increasing proportion of the load is transferred to the soil skeleton. At the end of the consolidation process (drained conditions), the vertical effective stress reaches -50 kPa, which is equal to the applied stress.

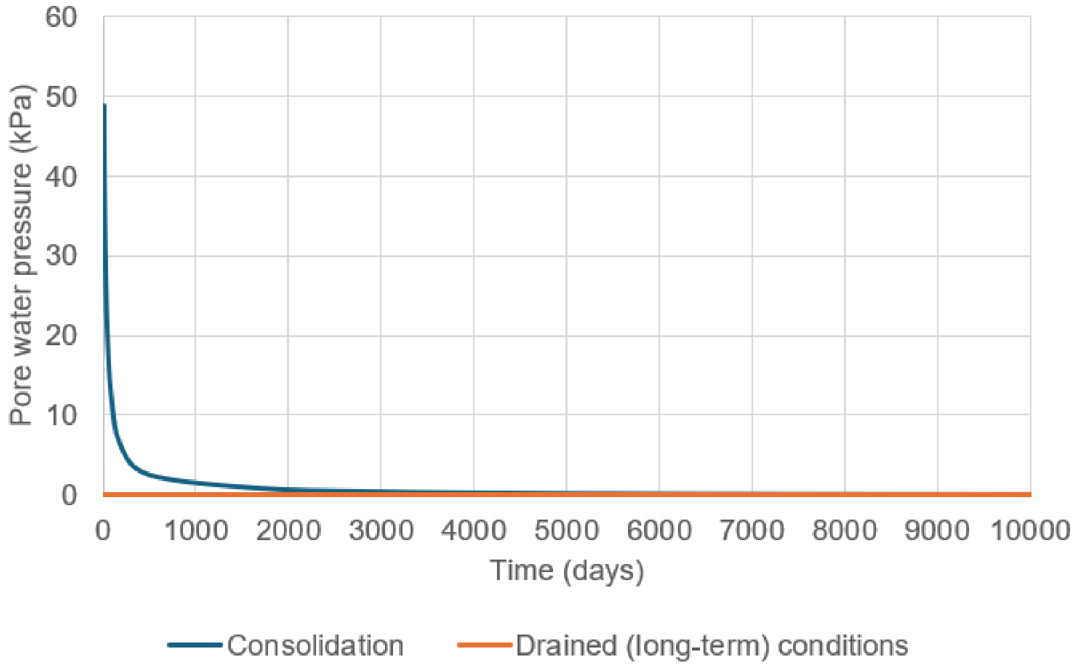

Figure 10 – Consolidation: Pore water pressure–time graph.

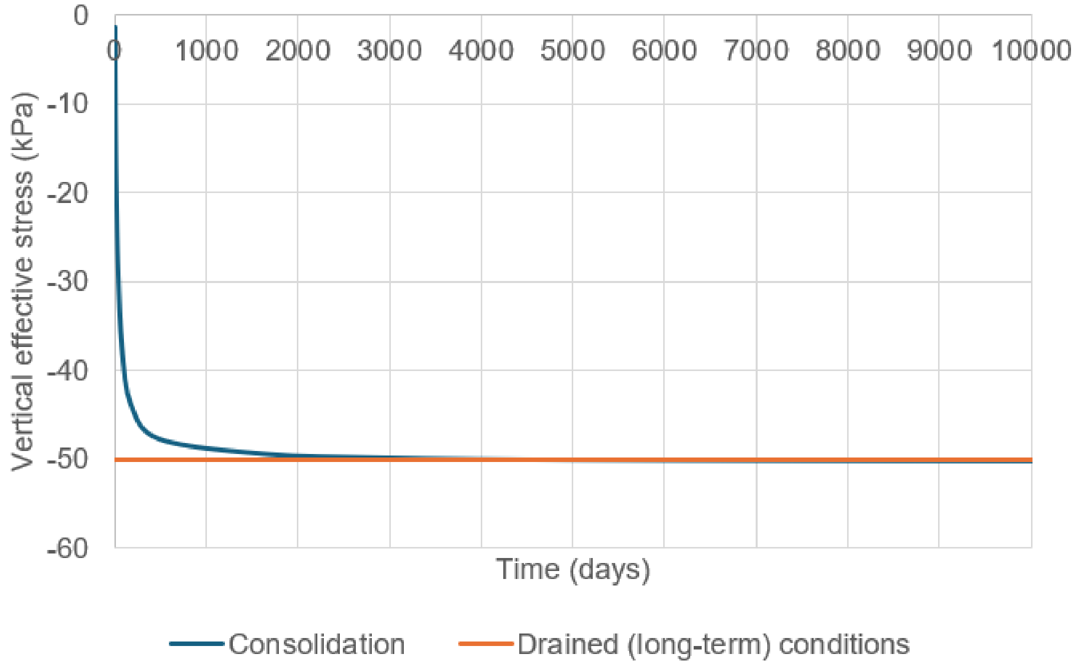

Figure 11 – Consolidation: Vertical effective stress–time graph.

As shown in Figure 12, the long-term (drained) vertical deflection is much greater than the short-term (undrained) deflection. The difference between long-term and short-term deflections may be even more pronounced under different soil and loading conditions.

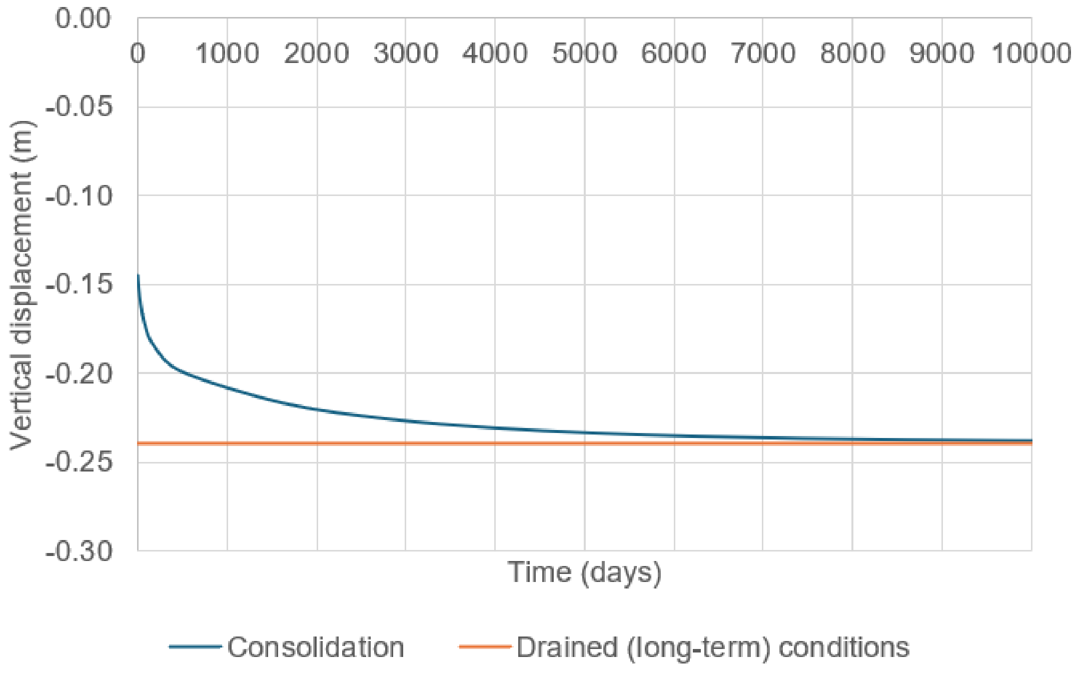

Figure 12 – Consolidation: Vertical displacement–time graph.

3. Summary

This technical note presents the results of three analyses: an undrained analysis, a drained analysis, and a consolidation analysis. The undrained and drained analyses are not time-dependent and represent the initial and final stages of the consolidation process, respectively. In contrast, the consolidation analysis is time-dependent and captures the complete consolidation process, including changes in pore water pressure, effective stress, and settlement.

For a consolidation analysis, it is necessary to define both the elastic properties of the soil and the properties required to represent its two-phase behaviour. A geotechnical material model that accounts for elasto-plastic behaviour can be used to capture the effect of changes in effective stress on the shear strength of the soil.

By tracking changes in pore water pressure, effective stress, and settlement over time, engineers can evaluate both the serviceability of a structure, in terms of the magnitude and rate of settlement, and its stability, taking into account the increase in soil shear strength as excess pore water pressures dissipate.

If you have any doubts or require specific advice for your type of analysis, please contact the LUSAS Technical Support team at support@lusas.com.