EXCAVATION AND DEWATERING

INTRODUCTION

This example involves the dry construction of an excavation. The excavation is supported by concrete diaphragm walls. The walls are tied back by pre-stressed ground anchors. The Hardening Soil model is used to model the soil behaviour. Special attention is focused on the output, which provides us insight in the soil behaviour and its interaction with structural elements. It is noted that the dry excavation involves a groundwater flow calculation to generate the new water pressure distribution.

INPUT

The excavation is 20 m wide and 10 m deep. 15 m long concrete diaphragm walls of 0.35 m thickness are used to retain the surrounding soil. Two rows of ground anchors are used at each wall to support the walls. The upper anchor has a total length of 14.5 m and an inclination of 33.7^o (2:3). The lower anchor is 10 m long and is installed at an angle of 45^o. The excavation is symmetric so only one half of the problem needs to be modelled.

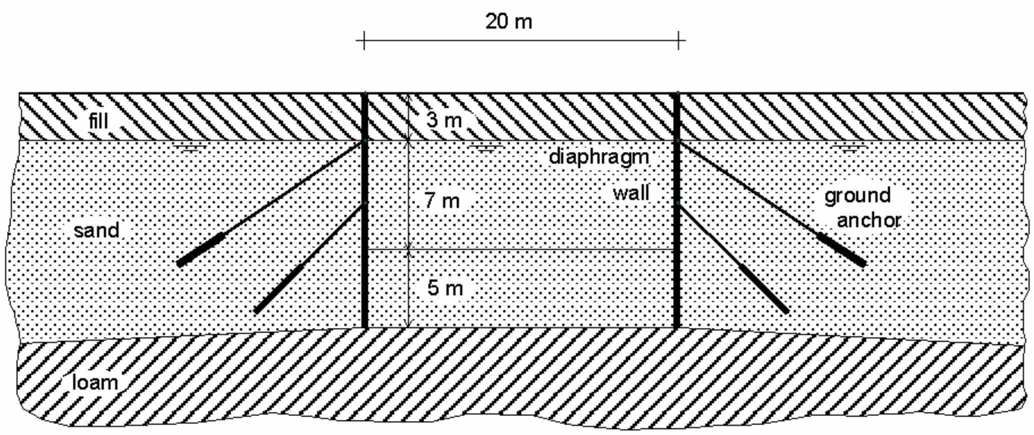


Figure 1: Excavation supported by tie back walls

The relevant part of the soil consists of three distinct layers. From the ground surface to a depth of 3 m there is a fill of relatively loose fine sandy soil. Underneath the fill, down to a minimum depth of 15 m, there is a more or less homogeneous layer consisting of dense well graded sand. This layer is particular suitable for the installation of the ground anchors. In the initial situation there is a horizontal phreatic level at 3 m below the ground surface, (i.e. at the base of the fill layer) Below the sand layer there is a loam layer which extends to large depth.

Geometry model

The symmetric problem can be modelled with a geometry model of 32 m width and 20 m depth. The proposed geometry model is given in figure 2. A ground anchor can be modelled by a combination of a node-to-node anchor and a geogrid (yellow line). The geogrid simulates the grout body whereas the node-to-node anchor simulates the anchor rod. The diaphragm wall is modelled as a plate. The interfaces around the plate are used to model soil-structure interaction effects. They are extended under the wall for 1.0 m to allow for sufficient flexibility and accurate reaction forces. Interfaces should not be used around the geogrids that represent the grout body. In general, it is a good habit to extend interfaces around corners of structures in order to allow for sufficient freedom of deformation and to obtain a more accurate stress distribution. When doing so, make sure that the extended part of the interface is always turned off in the water conditions mode.

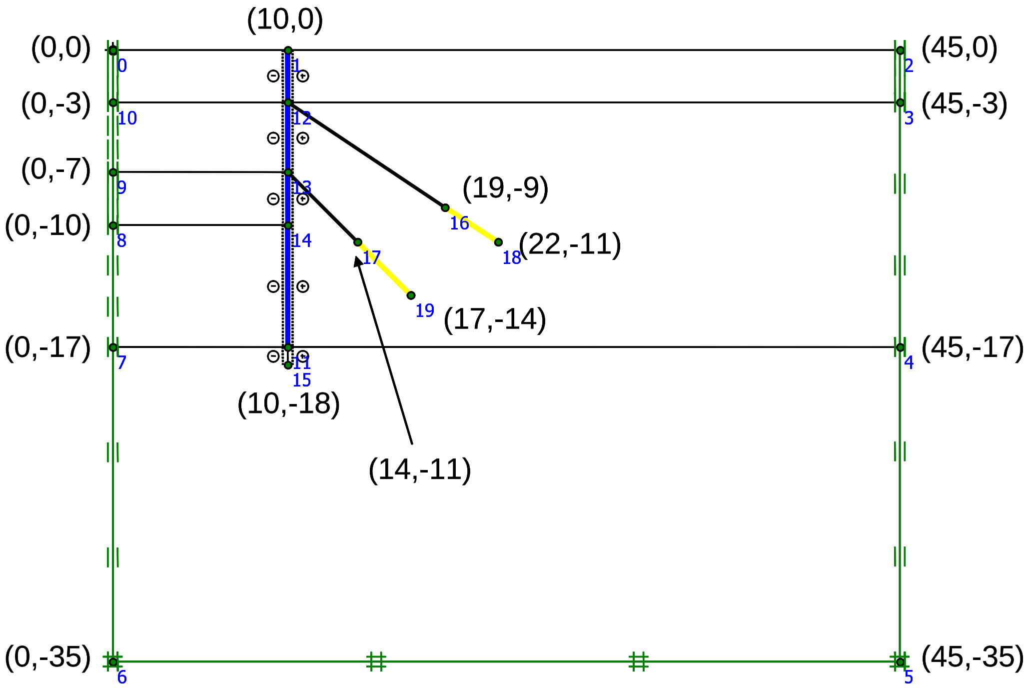


Figure 2: Geometry model of building pit

Material properties

The soil consists of three distinct layers. The parameters of the different layers are shown in table 1. The interfaces around the wall will be left impermeable in order to block the flow through it. Since the interfaces in the loam layer below the wall (the extended part of the interfaces) do not influence the soil behaviour, therefore their strength is not reduced and the permeability must be changed to permeable. This will be achieved during the definition of the staged construction phases.

Table 1: . Soil and interface properties.

Parameter	**Symbol**	**Fill**	**Sand**	**Loam**	**Unit**
Material model	Material model	HSsmall	HSsmall	HSsmall	
Drainage type	Drainage type	Drained	Drained	Drained	
Unsaturated soil weight	γ_{unsat}	16.0	17.0	17.0	kN/m^3
Saturated soil weight	γ_{sat}	20.0	20.0	19.0	kN/m^3
Reference secant stiffness from triaxial test	E_{50}^{ref}	$20.5 \cdot 10^3$	$38.5 \cdot 10^3$	$20.0 \cdot 10^3$	kN/m^2
Reference tangent stiffness from oedometer test	E_{oed}^{ref}	$20.5 \cdot 10^3$	$35.0 \cdot 10^3$	$20.0 \cdot 10^3$	kN/m^2
Reference unloading/reloading stiffness	E_{ur}^{ref}	$61.5 \cdot 10^3$	$115.5 \cdot 10^3$	$60.0 \cdot 10^3$	kN/m^2
Power for stress-dependent stiffness	m	0.5	0.5	0.7	–
Cohesion	c’	1.0	1.0	8.0	kN/m^2
Friction angle	φ'	30.0	34.0	29.0	^{o}
Dilatancy angle	ψ'	0.0	4.0	0.0	^{o}
Threshold shear strain	$\gamma_{0.7}$	$1.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	–
Reference small-strain shear modulus	G_0^{ref}	$180.0 \cdot 10^3$	$350.0 \cdot 10^3$	$180.0 \cdot 10^3$	kN/m^2
Advanced parameters		Default	Default	Default	
Horizontal permeability	k_x	1.0	0.5	0.1	m/day
Vertical permeability	k_y	1.0	0.5	0.1	m/day
Interface strength reduction	R_{inter}	0.65	0.7	Rigid	–
Coefficient for initial horizontal stress	K_0	Automatic	Automatic	Automatic	–

The properties of the concrete diaphragm wall are entered in a material set of the *plate* type. The concrete has a Young's modulus of 35 GPa and the wall is 0.35 m thick. The properties are listed in table 2.

Table 2: Properties of the diaphragm wall

Parameter	**Symbol**	**Diaphragm wall**	**Unit**
Material type	Material type		
Axial stiffness	EA	$1.2 \cdot 10^7$	kN/m
Flexural stiffness	EI	$1.2 \cdot 10^5$	$kN/m^2/m$
Weight	w	8.3	$kN/m/m$
Poisson's ratio	ν	0.15	–

For the properties of the ground anchors, two material data sets are needed: One of the Anchor type (anchor rod) and one of the Geogrid type (grout body). The Anchor data set contains the properties of the anchor rod and the Geogrid data set contains the properties of the grout body. The data are listed in tables 3 and 4.

Table 3: Properties of the anchor rod

Parameter	**Symbol**	**Anchor rod**	**Unit**
Material type	Material type	Elastic	
Axial stiffness	EA	$2.5 \cdot 10^5$	kN
Spacing	L_s	2.5	m

Table 4: Property of the grout body

Parameter	**Symbol**	**Grout**	**Unit**
Material type	Material type	Elastic	
Axial stiffness	EA	$1.0 \cdot 10^5$	kN/m

Mesh generation

For the generation of the mesh it is advisable to set the *Global coarseness* parameter to *Medium*. In addition, it is expected that stress concentrations will occur around the two grout bodies and in the lower part of the wall, hence local refinements are proposed there.

After generating the mesh, continue to the calculation.

CALCULATION

The calculation consists of the initial phase and six phases.

- In the first phase the wall is constructed.
- In the second phase the first 3 m of the excavation are constructed without connection of anchors to the wall. At this depth the excavation remains dry.
- In the third phase the first anchor is installed and prestressed.
- The fourth phase involves further excavation to a depth of 7 m, including the de-watering of the excavation. This involves a groundwater flow analysis to calculate the new pore water pressure distribution, which is a part of the definition of the third calculation phase.
- In the fifth phase the second anchor is installed and prestressed.
- The sixth phase is a further excavation (and de-watering) to the final depth of 10 m.

The calculation will be done using 2 alternative methods. In the first method the water will be lowered using steady-state groundwater flow analysis. This method assumes that excavation is sufficiently slow that the flow field will reach a steady-state situation for every excavations step. For rather slow excavations in high permeable soils this is a reasonable assumption. In the second method the water will be lowered using a transient flow analysis. This method is the preferred method if the excavation is sufficiently fast that no steady-state situation will be reach during excavation.

Method 1: Steady-state groundwater flow

In this method a so-called semi-coupled analysis will be performed. This means that the groundwater flow field is generated first and used as input to the deformation analysis. In other words, the groundwater flow will have an effect on the deformations in the soil, but the deformations in the soil will not change the flow field. This assumption is reasonable if the flow field will not be disturbed by excess pore pressures resulting from undrained behaviour or by significant changes in permeability due to large deformations. In this excavation problem indeed permeabilities are high and undrained behaviour should be of little or no importance.

For this method the *Calculation mode* should be set to *Classical mode* in the *Select calculation mode* window that appears directly after opening PLAXIS Calculations. If the incorrect mode is chosen one can still change this by selecting the *Calculation mode* option from the *Tools* menu.

All calculation phases are defined as *Plastic* calculations of the *Staged construction* type and standard settings for all other parameters. The instructions given below are limited to a description of how the phases are defined within the Staged construction mode.

Initial phase

- Set the *Calculation type* to K_0 *procedure* for calculating the initial stresses.
- Press the *Define* button on the *Parameters* tabsheet to define the initial situation
- In *Staged construction* mode make sure that all soil is activated and all structural elements are deactivated, then continue to *Water conditions* mode.
- Draw a horizontal phreatic level from (x,y) = (-2,-3) to (20,-3), (30,-3) and (47,-3).
- Pore pressures will be generated based on this phreatic line. To do so, make sure the *Generate by phreatic level* button  is selected.
- Press the *Water pressures* button  to view the pore pressures.
- After inspecting the initial pore pressures, close the Output program and press the *Update* button to return to the Calculations program.

Phase 1: Construction of the diaphragm wall

- Construction of the diaphragm wall takes 5 days. Therefore, fill in a *Time interval* of 5 days on the *Parameters* tabsheet.
- Go to the phase definition by pressing the *Define* button on the *Parameters* tabsheet.
- In *Staged construction* mode activate the wall and the interface extensions below the wall. The interfaces along the wall are activated automatically.

Phase 2: First excavation stage

- On the *Parameters* tabsheet select the option *Reset displacements to zero* as we're not interested in the displacements caused by the installation of the wall.
- Also on the *Parameters* tabsheet, enter a construction time of 7 days in the *Time interval* field.
- Go to the phase definition by pressing the *Define* button on the *Parameters* tabsheet.
- In *Staged construction* mode deactivate the first excavation part.
- Press *Update* to return to the Calculations program.

Phase 3: Prestress first anchor

- Prestressing the first row of anchors will take 1 day, hence enter a 1 day construction time.
- In *Stage construction* mode of the phase definition activate the upper geotextile representing the grout body of the first anchor.
- Double-click on the top node-to-node anchor, the properties window for the node-to-node anchor appears.
- Select the option *Adjust prestress* and enter a 120 kN/m prestress force.
- Close the properties window and return to the Calculations program.

Phase 4: Second excavation stage and dewatering

- The second excavation stage including dewatering will take 10 days, hence enter a 10 days construction time.
- In *Staged construction* mode deactivate the second excavation stage.
- Switch to *Water conditions* mode.
- No water flow can occur through a axis of symmetry. Therefore the axis of symmetry must be a closed flow boundary. To do so, select the *Closed boundary* button  and draw a closed boundary from (x,y) = (0,0) to (0,-35). Check that the bottom of the geometry is also a closed boundary.
- During excavation the water level will be lowered. Due to high permeabilities water will be drawn from outside the excavation, hence a groundwater flow analysis has to be performed. Therefore, make sure the *Groundwater* button is set to *Groundwater flow steady state*  by clicking the down arrow and choosing the correct option.
- The groundwater head boundary conditions needed for the groundwater flow analysis can be applied in a simple manner by using the general phreatic level. In order to do so, make sure no cluster is selected (for instance by clicking completely outside the geometry so that the general phreatic line is red) and then draw a new general phreatic level from (x,y) = (-2,-7) to (20,-7), (30,-3) and (47,-3).
- Press *Update* to return to the Calculations program.

Phase 5: Prestress second anchor

- Prestressing the second row of anchors will take 1 day, hence enter a 1 day construction time.
- In *Stage construction* mode of the phase definition activate the lower geotextile representing the grout body of the second anchor.
- Double-click on the lower node-to-node anchor, the properties window for the node-to-node anchor appears.
- Select the option *Adjust prestress* and enter a 200 kN/m prestress force.
- Close the properties window and continue to *Water conditions* mode.
- The phreatic line should be still the same as in the previous calculation phase and also the option *Groundwater flow steady-state* should still be selected.
- Return to the Calculations program.

Phase 6: Third excavation stage and dewatering

- The third excavation stage including dewatering will take 7 days, hence enter a 7 days construction time.
- In *Staged construction* mode deactivate the third excavation stage.
- Switch to *Water conditions* mode.
- Check that both the axis of symmetry and the bottom of the model are closed boundaries.
- Make sure the *Groundwater* button is set to *Groundwater flow steady-state* .
- Draw a new general phreatic level from (x,y) = (-2,-10) to (20,-10), (30,-3) and (47,-3).

Nodes for load displacement curves

Select some nodes for load displacement curves, for instance the top of the wall at (x,y) = (10,0) and the middle of the excavation bottom at final depth at (x.y) = (0, -10).

Now start the calculation.

Method 2: Transient groundwater flow

In this method a fully coupled analysis will be performed. This analysis couples transient groundwater flow, consolidation and deformations implying that the groundwater flow field, development and dissipation of excess pore pressures and deformation are calculated simultaneously all influencing each other. This type of analysis should be performed if developement of excess pore pressures is expected influencing the flow field or when significant changes in permeability due to large deformations are likely to occur. In this excavation problem the main reason to use this analysis is to take into account that the flow field will not reach a steady-state during excavations. The addidional effects of coupling the flow field with undrained behaviour will probably be small as this project deals with high permeabilities. Note that a fully coupled analysis requires that the calculation type is *Consolidation*.

It is possible to re-use the project made for the calculation using the method of steady-state analysis:

- In PLAXIS Calculation save the project under a different name
- From the menu *Tools* select the option *Calculation mode*. In the window that now appears select *Advanced mode*.
- Change the calculation phases according to the description below. Note that only the changes relative to the steady-state calculation method are mentioned.

Initial phase

- No changes have to be made

Phase 1: Construction of the diaphragm wall

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.

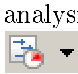
Phase 2: First excavation stage

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.

Phase 3: Prestress first anchor

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.

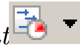
Phase 4: Second excavation stage and dewatering

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.
- Define the staged construction phase and switch to *Water conditions* mode.
- During excavation the water level will be lowered. However, due to the short construction time it's unlikely that the flow field will be steady state and therefore a transient groundwater flow analysis will be done. Therefore, make sure the *Groundwater* button is set to *Groundwater flow transient*  by clicking the down arrow and choosing the correct option. The phreatic level remains unchanged.
- Return to the Calculations program.

Phase 5: Prestress second anchor

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.
- Define the staged construction phase and switch to *Water conditions* mode.

Though the phreatic level in the excavation doesn't change, the flow field is not steady-state yet outside the excavation. Therefore this phase needs transient flow analysis without making further changes.

- Make sure the option *Groundwater flow transient*  is selected.
- Return to the Calculations program.

Phase 6: Third excavation stage and dewatering

- Set the calculation type to *Consolidation* on the *Parameters* tabsheet.
- Also on the *Parameters* tabsheet, set the number of *Additional steps* to 500.
- Define the staged construction phase and switch to *Water conditions* mode.
- Make sure the *Groundwater* button is set to *Groundwater flow transient* .
- Return to the Calculations program.

Start the calculation

OUTPUT

Figure 3 gives the total displacements for the final phase for both the calculation with steady-state groundwater flow and the transient groundwater flow.

The excavation using steady-state flow gives a maximum displacements of about 24 mm while excavation using transient flow gives a maximum displacement of about 23 mm.

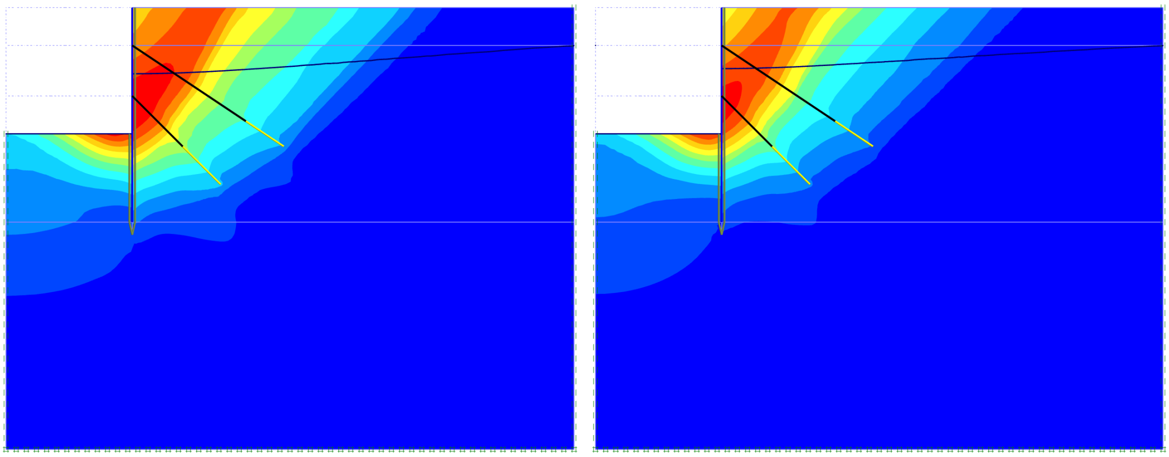


Figure 3: Total displacements for the steady state flow analysis (left) and the transient flow analyis (right)

Figure 4 shows the vertical displacements for the final phase for both calculations. For the displacements behind the wall the excavation using steady-state analysis clearly gives more vertical displacements over a larger distance from the excavation than the excavation with transient flow.

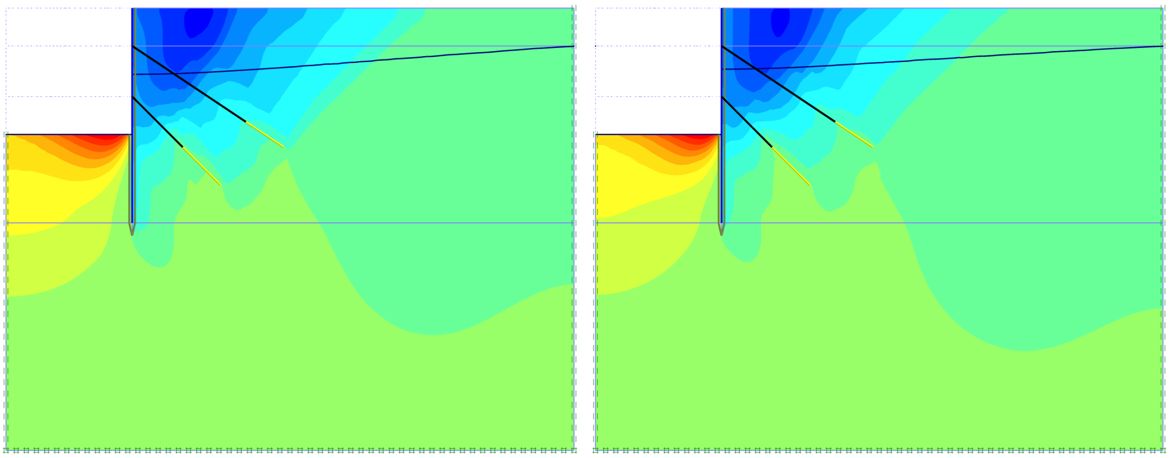


Figure 4: Vertical displacements for the steady state flow analysis (left) and the transient flow analyis (right)

The extreme bending moments are about -165 kNm/m and 75 kNm/m for the excavation using steady-state groundwater flow analysis while the extremen bending moments for the excavation using transient groundwater flow are about -170 kNm/m and 95 kNm/m.

Figure 6 shows the horizontal displacements of the top of the wall as a function of construction time for both the excavation using steady-state flow and transient flow.

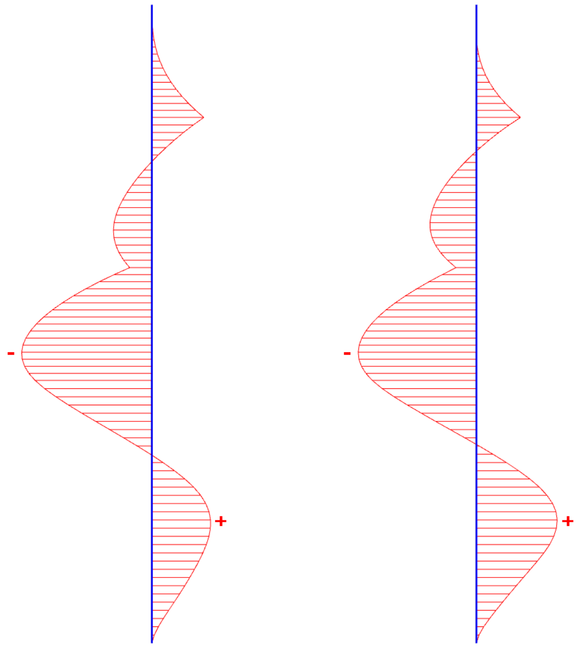


Figure 5: Bending moments in the wall for the steady state flow analysis (left) and the transient flow analyis (right)

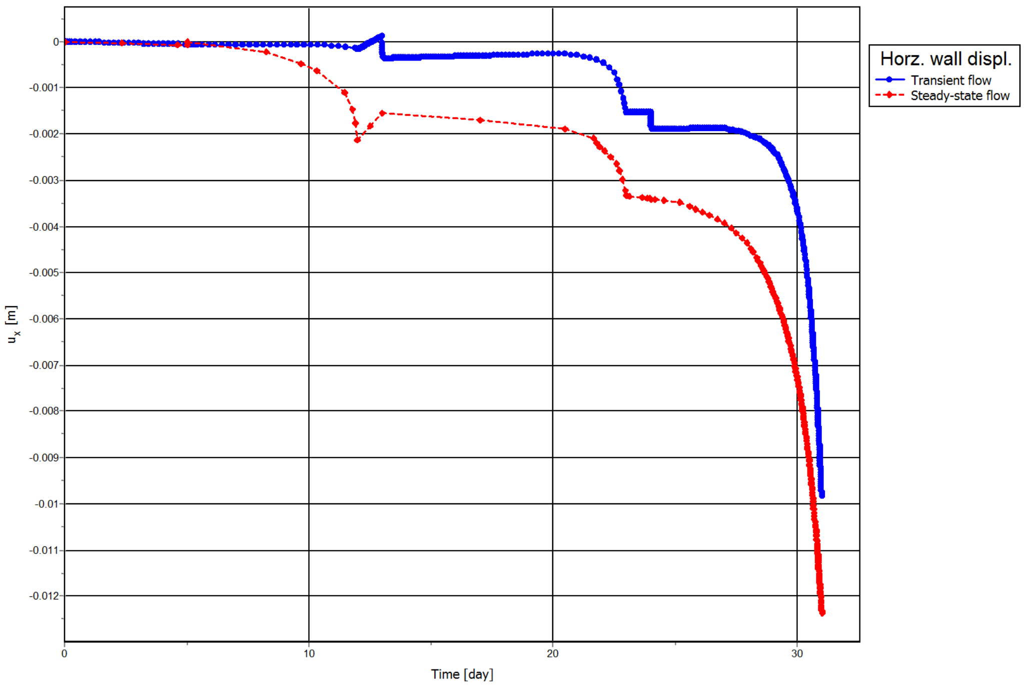


Figure 6: Horizontal wall displacements for the excavation