GeoStudio Example File

Submerged Construction of an Excavation

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Introduction

This example simulates the staged construction of a submerged excavation supported by a diaphragm wall and a pre-stressed strut. The elevation of the water inside the excavation is assumed constant and commensurate with the initial water table. Deactivation of a region, which is used to simulate excavation, produces a boundary condition that removes all material (i.e. soil and water), making it necessary to apply a boundary condition to the face of the excavation to add back the water.

Numerical Simulation

Figure 1 presents the geometry and stratigraphy of the ground profile before the excavation. The geology comprises a 20 m thick clay layer overlying a 30 m thick sand deposit. The water level is located at a depth of 2 meters below the ground surface.

The analysis takes advantage of symmetry by modeling half of the excavation (i.e. 15 m width). The final excavation depth is 20 m, which is at the boundary between the two stratigraphic units. The left edge of the domain was chosen to be sufficiently far-field as to not impose an influence on the stress-strain response around the excavation.

Color	Name	Initial Void Ratio	Dilatancy Cut-off	Unit Weight (kN/m³)	Response Type	O.C. Ratio	K0nc	Lambda*	Kappa*	Effective Poisson's Ratio	E_ur Reference (kPa)	E_50 Reference (kPa)	E_oed Reference (kPa)	m Exponent	Reference Stress (kPa)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Dilation Angle (°)	Rf
	Clay (Soft Soil Model)	1		18	Undrained	1	0.5774	0.03	0.0085	0.15						1	25	0	
	Sand (Hardening Soil Model)	0.5	No	20	Drained	1	0.4701			0.2	120,000	40,000	40,000	0.5	100	0	32	2	0.9

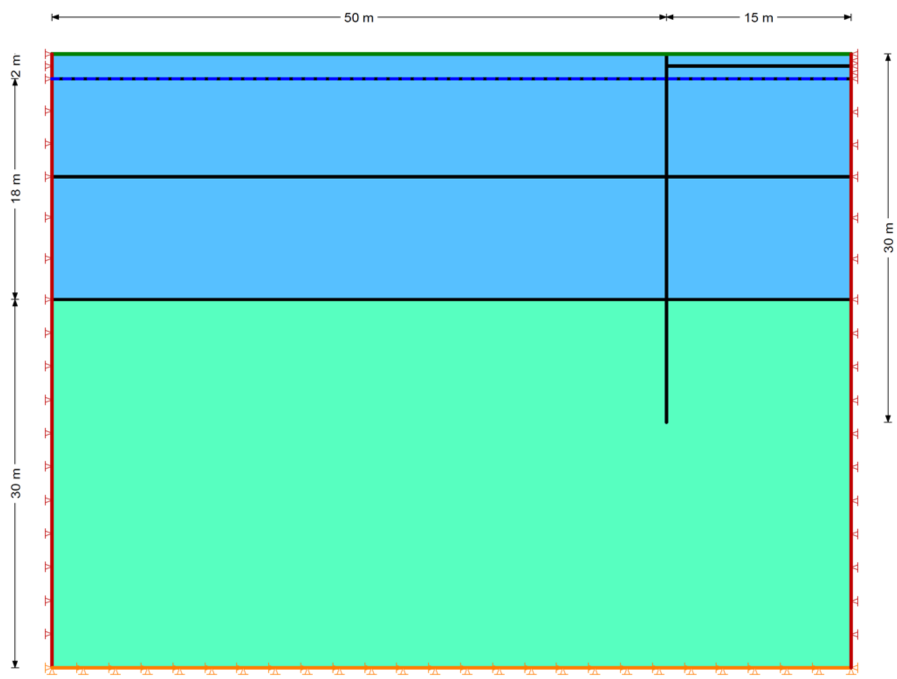

Figure 1. Geometry and stratigraphy for the submerged excavation analysis.

The table in Figure 1 displays the constitutive model and input parameters used for each material in the domain. The clay layer was represented by the Soft Soil model, while the Hardening soil model was used to represent the sand. The hydraulic properties have no influence on the solution and are therefore arbitrary.

Figure 2 presents the Analysis Tree for the GeoStudio Project. An In Situ analysis was conducted using the K0 procedure to establish the initial stresses and pore-water pressures in the ground. The subsequent five analyses in the tree capture the construction history for the submerged excavation. Each construction stage is modeled using a Load/Deformation analysis to capture the stress-strain response of the system. The time duration for each analysis is set to 1 day; however, this is irrelevant in a Load/Deformation analysis. More importantly, each stage of the analysis is simulated in one load step. The construction sequence starts with the application of a 5 kPa stress boundary condition as a surcharge and the installation of the diaphragm wall (Phase 1). The chronology then follows a pattern of excavating the first layer of the clayey soil (Phase 2), installation of a strut (Phase 3), and excavating the second and third submerged layers (Phases 4 and 5). Each analysis forms the Parent for the subsequent Child analysis, establishing the initial stress and pore-water pressure conditions.

Figure 2. Analysis tree in the GeoStudio project.

Figure 3 presents the boundary conditions and strut location for the model domain before starting two submerged excavations. The left and right vertical edges of the domain are constrained in the x-direction, while the lower boundary is fixed in the x and y directions (see Figure 1). The strut is pinned on the right edge. The excavation stages are modeled by deactivating a region, which is discussed in more detail subsequently.

The diaphragm wall is modeled using a structural beam. A typical modulus for a concrete diaphragm wall was assumed (30 GPa). The cross-sectional area and moment of inertia are set to 0.25 m^2 and 0.033 m^4, respectively. The interaction of the diaphragm wall with the surrounding soils were simulated by defining the interface materials. The stiffness parameters of the interface materials are set to be identical to the corresponding soils and an interface reduction factor of 0.5 and 0.67 was applied on the strength parameters of the clayey and sandy soils, respectively. The strength parameters of the interface materials have been compared with the corresponding main materials in Table 1.

Strut installation is modeled independently from the excavation stage because the strut is pre-stressed after installation. Defining a pre-axial force (i.e., a pre-stress) for a structural bar automatically produces a force boundary condition applied to the endpoints of the structure. The strut is modeled using a structural bar element with the elastic modulus of 100 GPa and the cross-sectional area of 0.02 m^2. The pre-axial force in the strut is set to 100 kN. The pre-axial forces are positive to model compression and therefore a lateral load acting against the wall. The spacing of the struts in the out-of-plane direction was assumed to be 5 m.

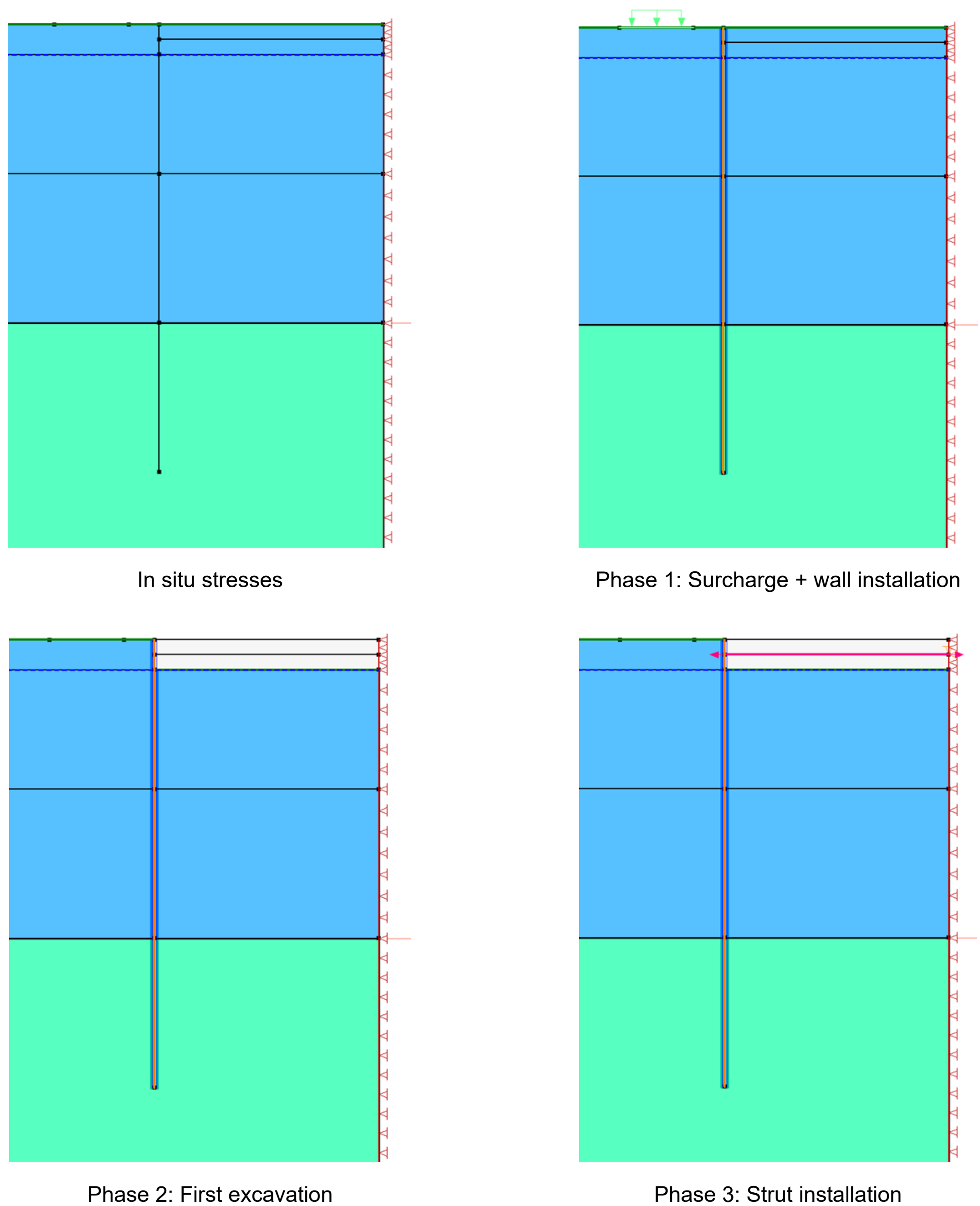

Figure 3. Boundary conditions and strut location before submerged excavations.

Table 1. Strength properties used for interface materials.

Color	Name	Stress Material Model	K0nc	Effective Cohesion (kPa)	Effective Friction Angle (°)	Dilation Angle (°)
	Clay - Interface	Soft Soil	0.773	0.5	13.12	0
	Clay (Soft Soil Model)	Soft Soil	0.5774	1	25	0
	Sand - Interface	Hardening Soil	0.6138	0	22.72	1.34
	Sand (Hardening Soil Model)	Hardening Soil	0.4701	0	32	2

Material deactivation involves determining the reaction forces acting on boundaries of regions that are to be deactivated (excavated). When a region becomes deactivated, opposing reaction forces are applied as boundary conditions to the adjacent active region boundaries. The total stresses from the Parent analysis (i.e. initial conditions) are used to calculate the reaction forces. As a result, the boundary forces represent excavation of the soil and water within the excavation; however, in this case the excavation is assumed submerged.

Figure 4 illustrates the boundary condition that is required to add back the water in the two stages of submerged excavation. A *Stress/Strain* boundary condition of the type *Hydrostatic Pressure* was applied on the excavation base and vertical face. The hydrostatic pressure, which acts normal to the surface, is calculated from the input unit weight of water (9.807 kN/m^3) and water elevation (y = 18 m). Notice that the boundary condition need only be applied once to the faces exposed by the excavation.

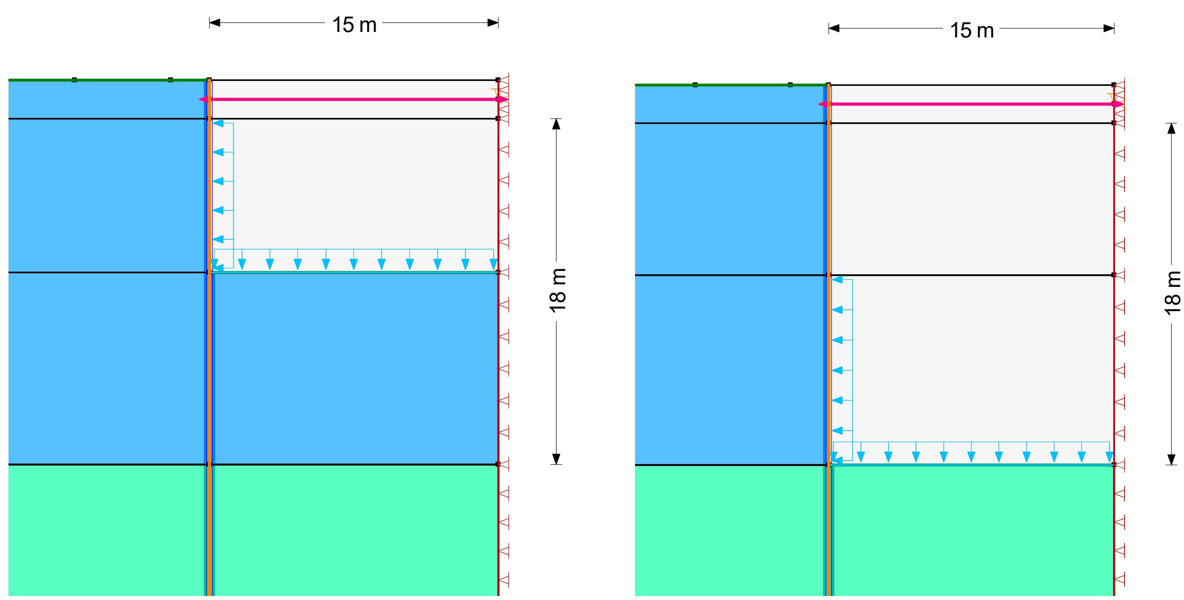

Figure 4. Boundary conditions of submerged excavation phases

Results and Discussion

Figure 5 presents the vertical total stress at the excavation center line (i.e., the right edge of the domain). Figure 6 shows the vertical stress contours at the end of the excavation. According to Figure 5, unloading of the marine clay reduces the total stress across the centerline of the excavation. For instance, at the final level of the excavation (i.e., y = 0), the total stress is reduced to about 180 kPa at the end of the last stage, which is about equal to a hydrostatic pressure calculated as 18 m multiplied by about 10 kPa/m (i.e. 10 kN/m^3).

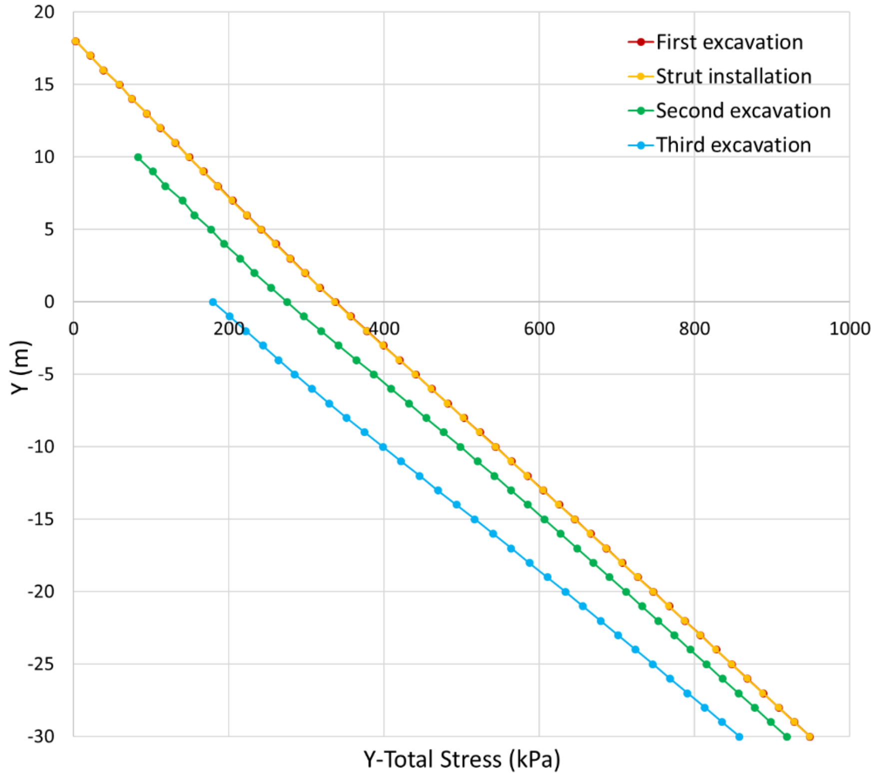

Figure 5. Vertical total stress profile at the excavation center line.

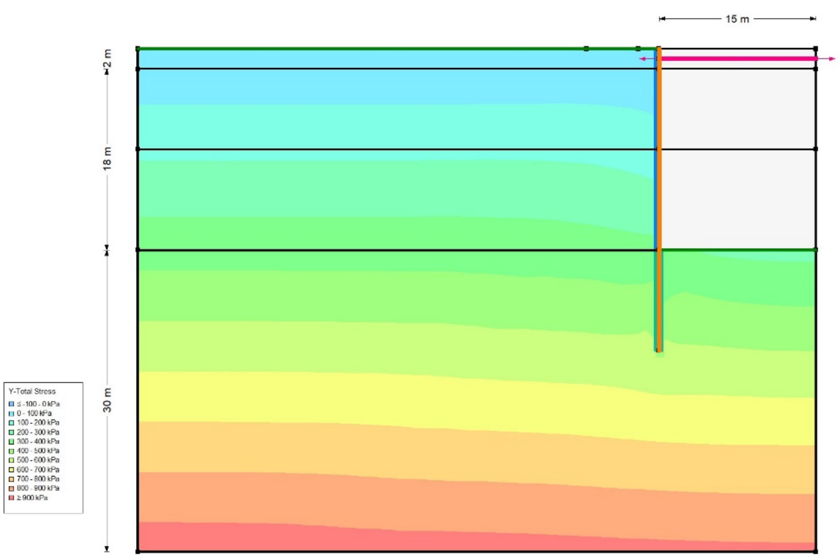

Figure 6. Vertical total stress contour at the end of excavation

The wall deflection profiles at the end of each excavation stage are presented in Figure 7. A review of the profiles from analysis-to-analysis reveals that the strut installation has a significant effect on the displacement pattern and magnitudes. In addition, the maximum deflection of the wall is about 21 mm at the end of the second excavation stage, and this deflection is increased to about 62 mm by excavating the final layer of the profile. The deformed mesh of the model as well as X-Displacement contours at the end of the excavation is shown in Figure 8. These figures indicate that the maximum final deflection occurs just below the mid-height of the wall.

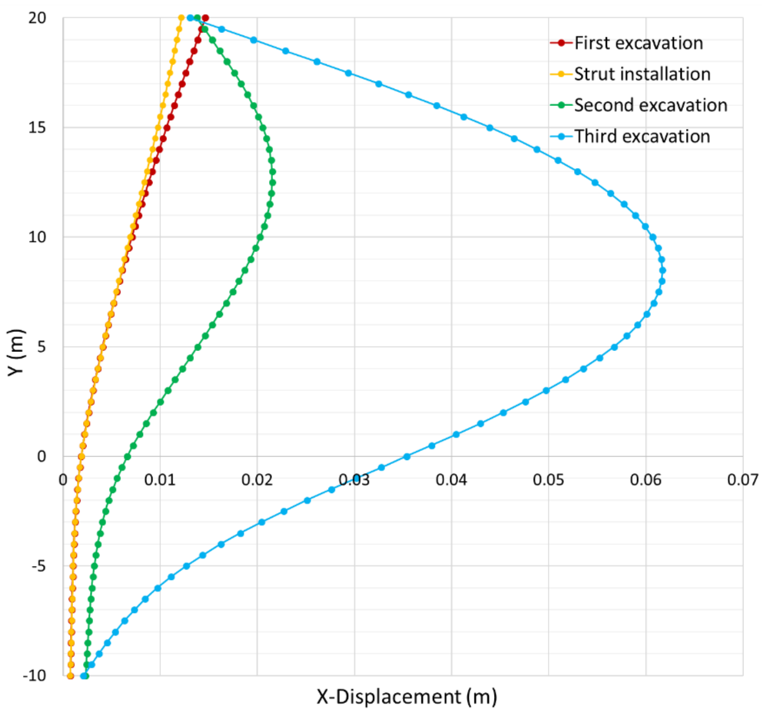

Figure 7. Deflection profiles of the diaphragm wall.

Figure 9 presents the bending moments in the diaphragm wall for each stage of the construction. The maximum bending moment is about 853 kN.m. A change in sign (+/-) for the final bending moment profile occurs near the base of the excavation. The shear force profile along the diaphragm wall at the end of each construction stage is shown in Figure 10. According to this figure, the maximum shear force, which is about 220 kN, also occurs near the base of the excavation.

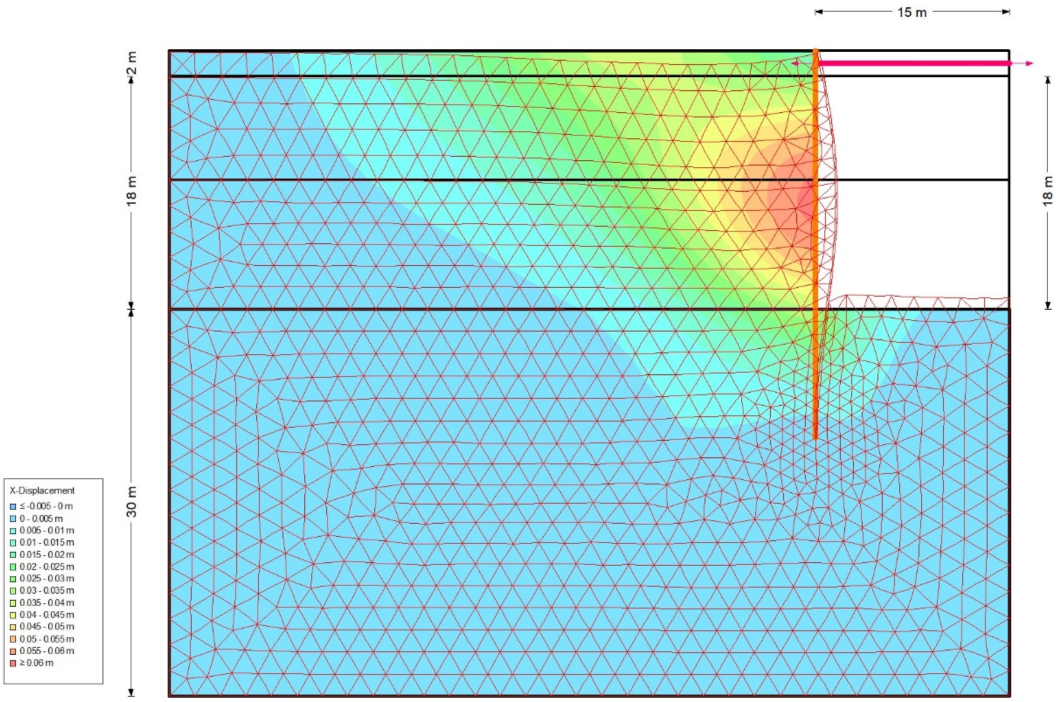

Figure 8. X-Displacement contour and the deformed mesh at the end of the excavation

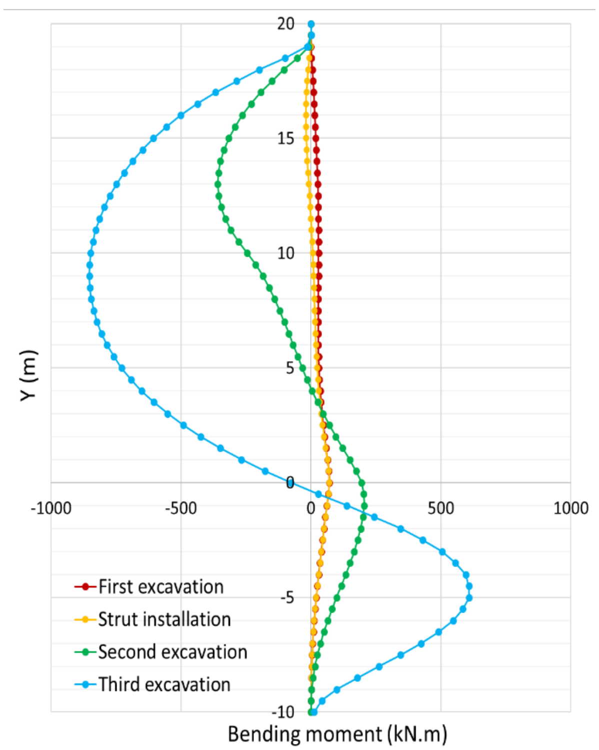

Figure 9. Wall bending moments at each stage of construction.

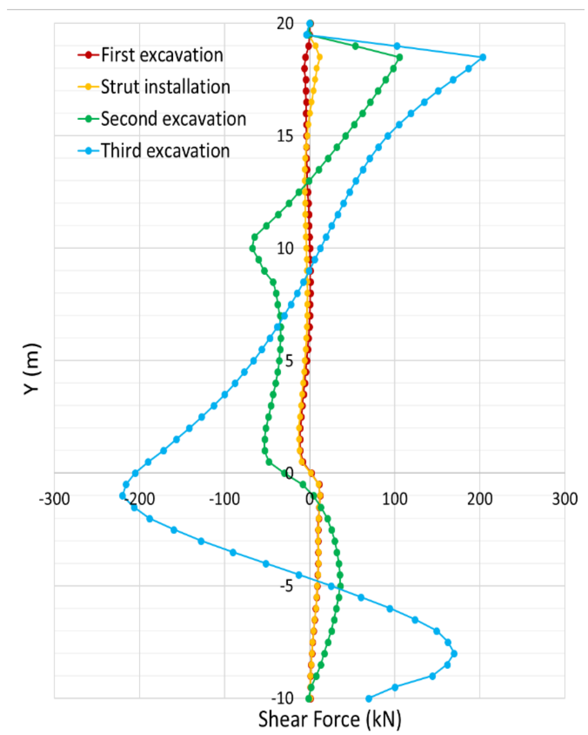

Figure 10. Wall shear force at each stage of construction.

The maximum settlement takes place some distance behind the wall and not immediately behind the wall (Figure 11). The overall displacement pattern is downward and toward the excavation. The top of the wall rotates counterclockwise, causing the ground surface to heave upwards directly adjacent to the wall. Figure 12 also shows a heaving of about 3.8 cm at the base of the excavation.

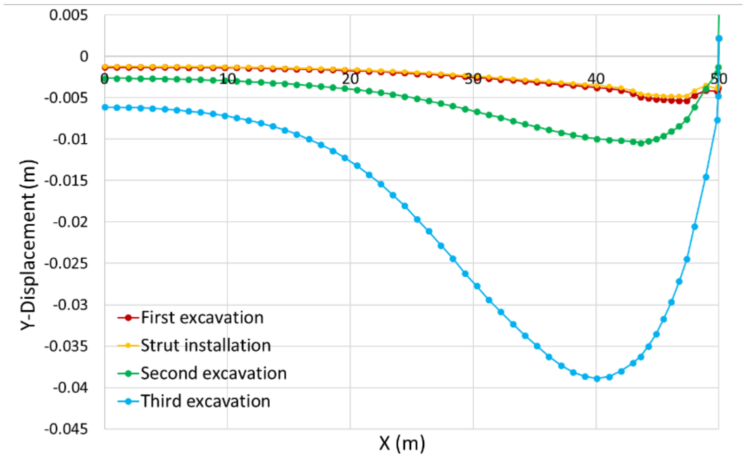

Figure 11. Surface settlement profiles.

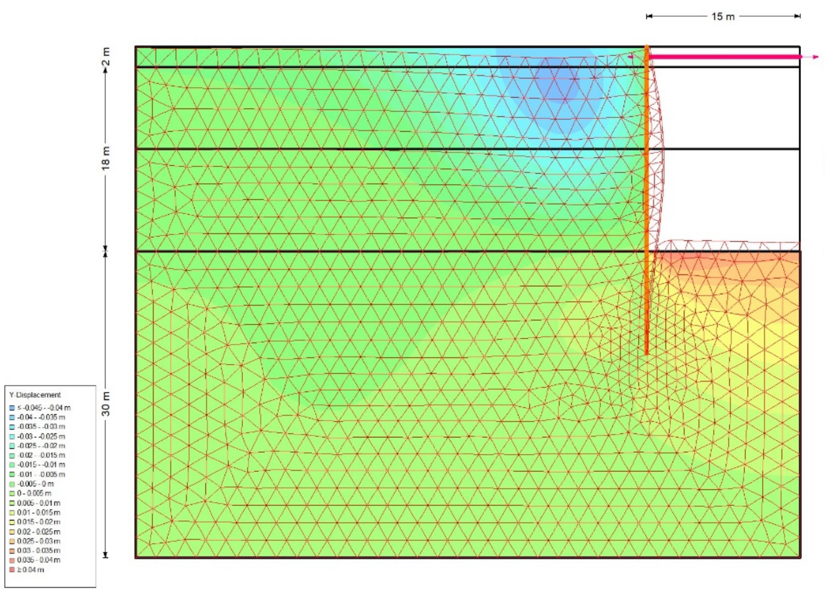

Figure 12. Y-Displacement contour and the deformed mesh at the end of the excavation

Summary and Conclusions

The example model discussed in this document demonstrates that GeoStudio can be used to model the behavior of submerged deep excavations. Deactivation of a region removes the soil and water; consequently, it is necessary to replace the water by means of a hydrostatic pressure boundary condition. The boundary condition is only applied to faces exposed by each excavation phase. In this manner, the simulation can be used to assess the soil-structure interaction of a submerged excavation.