Abstract
The library of material models in RS has been expanding, with more soil-specific constitutive models now included in the package. On top of the built-in constitutive models, RS has the ability to extend its material model library by using a DLL file that includes user-defined material models. The default DLL file in RS includes the “Hardening Soil” and “Hardening Soil with Small Strain Stiffness” models of PLAXIS, and the “ChSoil,” “CySoil” and “Double-Yield” models of FLAC. This article will demonstrate some applications of such models. In this article the “Softening Hardening” and the “Hardening Soil” models in RS will be used in the simulation of a deep excavation in Berlin, Germany (Nikolinakou et. al., 2011).

The “Hardening Soil” model and the “Softening Hardening” model
Three key aspects of the mechanical behaviour of soils are: the plastic deformation or yielding starts at the early stages of loading; the stiffness is proportional to the level of confinement; and, the volumetric behaviour exhibited consists of compaction followed by a possible dilation under shear loading. Considering these three features, the material models used in the following simulations utilize three respective formulations: a continuous yielding and hardening behaviour; a nonlinear elastic behaviour in which the Young’s modulus is related to the level of stress; and, an appropriate flow rule that can capture compaction and dilation of the volumetric behaviour of soils. The “Hardening Soil” and the “Softening Hardening” models will be used to simulate the behaviour of Berlin sand in the following sections.

Site Characteristics
The deep excavation studied is in the M1 pit from the VZB tunneling project in Berlin. The pit was excavated underwater to a depth of 20 metres, and supported by a diaphragm wall.
Model Setup in RS²

This RS² model includes three primary layers of sand depositions, ignoring secondary fill and organic soil. The material properties of the three layers of sands are presented in Tables 1 and 2 for the “Hardening Soil” and “Softening Hardening” models, respectively.

A 1.5 m thick diaphragm wall extends to 28.7 metres below the ground soil, and it is supported by a row of pre-tensioned tiebacks. The water table is at a depth of 2 m, and ponded water pressure is used to model underwater excavation.

![Figure 2 - Initial Stage](image1)

![Figure 3 - Final Stage Excavation](image2)

The elastic behaviour of the “Softening Hardening” model is set to match the same elastic behaviour of the “Hardening Soil” model by using its $E_{50}$ properties. The strength characteristics, including friction angle, cohesion, and tensile strength, are also the same for the two models. The hardening parameter of the “Softening Hardening” model is set so that the two material models predict very similar behaviour for Berlin sands in drained and undrained triaxial test simulations as shown in Figures 4 and 5 for Sand I. The major difference between the two models is that the “Hardening Soil” model has a cap yield surface in its formulations at a cost of having more material parameters as listed in Table 3.

Results and Discussions

The horizontal displacement of the diaphragm wall was measured after both the bolt installation and the final stage of excavation. The following compares the simulations from the RS² “Hardening Soil” model, RS² “Softening Hardening” model, the PLAXIS “Hardening Soil” model reported by Nikolinakou et. al. 2011, and the observed behaviour.

In the first case, after installing the bolt (Figure 6), the PLAXIS and RS² models are identical for the case of the “Hardening Soil” model but both give lower bound estimation compared to the observed behaviour. The “Softening Hardening” model predicts more accurate results at this stage.

![Table 1. Hardening Soil model parameters for Berlin sands](image3)
Table 2. Softening Hardening model parameters for Berlin sands

Table 3. Number of model parameters for Hardening Soil model and Softening Hardening model

Conclusion
This article serves as an effective example of finite element simulations in soils using RS². The focus was to select constitutive models that best represented the behaviour of the soils in the Berlin sand case and carry out a finite element simulation that provided accurate predictions. Through modeling the deep excavation in Berlin sand, the “Softening Hardening” and “Hardening Soil” models were shown to provide reliable predictions for the behaviour of sands.

References


Figure 5 – Comparison of simulation results using Softening Hardening and Hardening Soil models; Undrained triaxial compression test starting at confinement of 50 kPa

Figure 6 - Horizontal displacement of the diaphragm wall after tensioning the bolt

Figure 7 - Horizontal displacement of the diaphragm wall at the final excavation stage