

Developer's Tip

3D Tunnel Simulation Using the Material Softening Method in *Phase²*

*“How do I simulate the three-dimensional advance of a tunnel using *Phase²*? How do I get the proper deformation prior to support installation?”*

There are a variety of different methods for simulating the deformation that takes place prior to support installation. A preferred method, often used by Dr. Evert Hoek, is the “material softening” approach.

The material softening method can be implemented as follows:

- 1) First, create a staged model in which the modulus of the excavation material is successively reduced, until the material is excavated. This allows you to construct a “ground reaction curve”, which is a plot of the boundary displacement (convergence), versus the material modulus at each stage. See Figure 1.

Note: The modulus is reduced by assigning a new material at each stage, where each material has a successively lower modulus. To download a *Phase²* example file, click [phase2 material softening.zip](#) and open the ground reaction.fea file.

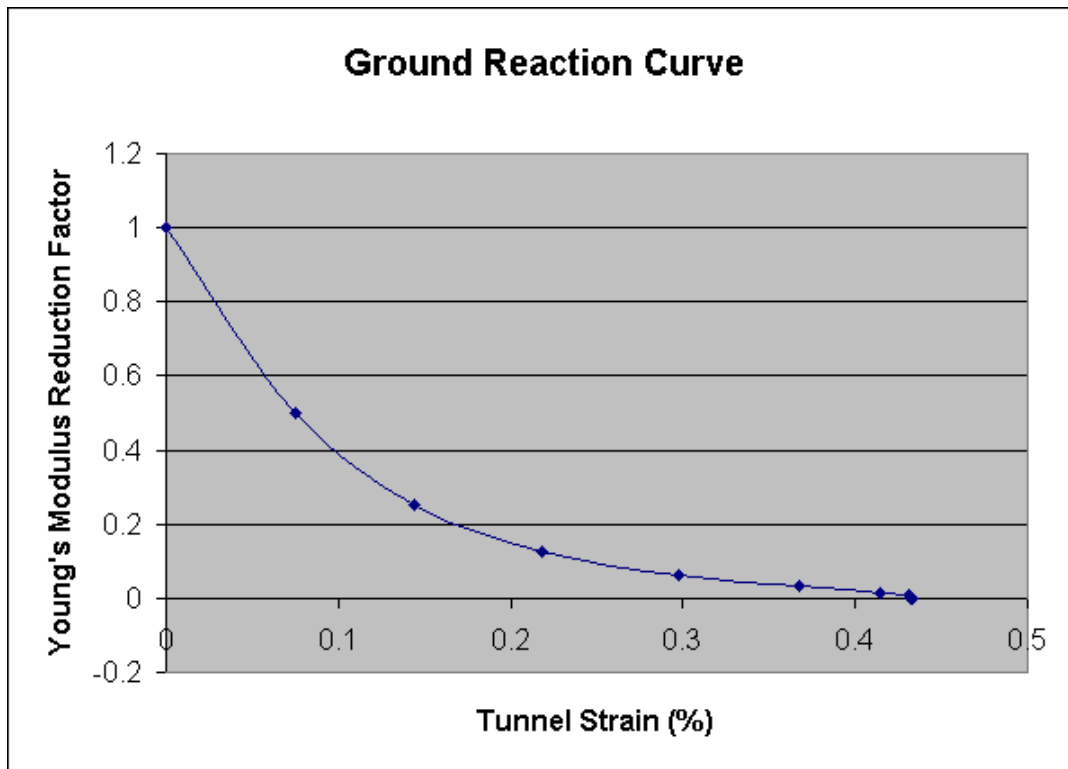


Figure 1: Ground reaction curve obtained using staged material softening (modulus reduction).

- 2) The second step is to determine the amount of deformation which is to be allowed, prior to support installation. This can come from a number of sources including:
 - i) a simple axisymmetric model of your tunnel
 - ii) closed form and empirical formulas as exist in our [RocSupport](#) program
 - iii) observation and experience.

- 3) The third step is to use the ground reaction curve (from step 1), and the tunnel convergence (from step 2), to determine the required material modulus that gives the desired convergence at support installation. Now you can create a staged excavation, with one stage used for the softening and the next stage used for the support installation. See Figure 2. To download a *Phase*² file, click [phase2_material_softening.zip](#) and open the support_installation.fea file.

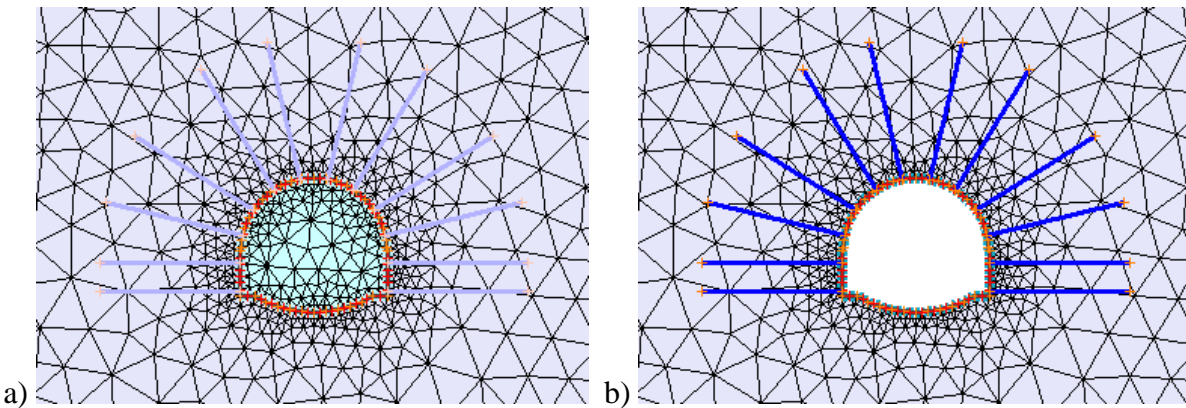


Figure 2: (a) intermediate stage -- excavation material with reduced modulus
 (b) final stage -- excavation material is removed, and support is installed

Other Methods

Other methods of simulating 3D tunnel advance, which can be achieved with *Phase*²:

- A number of customers use the load splitting feature of *Phase*². Load splitting allows you to "split" the field stress induced load between any stages of the model, rather than applying the entire load in the first stage. This allows the user to gradually apply the field stress load, as excavation progresses.
- Another approach is to apply a set of tractions (pressures) on the excavation boundary and reduce their magnitude until you get the desired closure. The only problem with this is that for non-hydrostatic stress fields, the manual calculation of the normal and shear tractions on the boundary can be difficult and time-consuming, especially for complex geometries.
- An alternative approach to the material softening method, can be found on the [Phase² Advanced Tutorials](#) page. With this method, the modulus of the material is staged using reduction factors, and the material stress is initialized as required with the custom load split option. The results of this method are identical to the method presented in this developer's tip – only the modeling procedure is different.

Related Articles

A paper published in the Canadian Geotechnical Conference in 2003 that demonstrates the usage of material softening in designing support systems can be found at [Tunnel Support Design.pdf](#).