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GeoStudio Example File
Hoek-Brown Analytical Solution Comparison

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Introduction

Stresses and displacements are determined numerically for the case of a pressurized cylindrical hole in an infinite Hoek-Brown material subjected to an isotropic in situ stress field. The analytical solution for this problem is provided by Carranza-Torres and Fairhurst (1999) for associated and nonassociated plastic flow with zero dilation. The nonassociated flow, zero dilation results are presented here. The problem tests the Hoek-Brown model with applied field stresses in plane-strain conditions imposed in Sigma/W. The closed-form equations are not repeated here; the reader referred to the Carranza-Torres and Fairhurst paper.

The material is assigned the following properties:

Young's modulus (E)	5.5 GPa
Poisson's ratio (ν)	0.25
m_b	1.7
s	0.0039
a	0.5
σ_{ci}	30 MPa

Numerical Simulation

For modelling purposes, the problem is defined by the domain sketched in Figure 1. The model is subjected to an isotropic in situ stress field of magnitude $\sigma_0 = 30$ MPa and contains a hole of radius $b = 2$ m that has an internal pressure of $p_i = 5$ MPa. The model takes advantage of quarter symmetry. In the analytical solution, infinite boundaries are assumed but in the Sigma/W model the external boundaries are placed at 40 m from the hole centre.

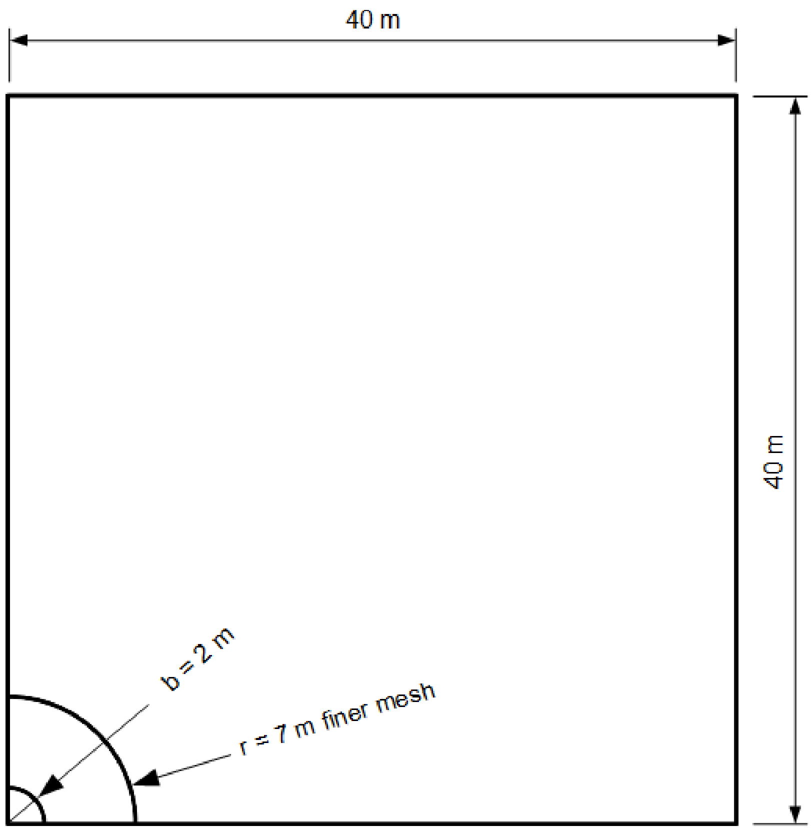

Figure 1. Model geometry.

The GeoStudio configuration for this model is shown in Figure 2. The 3D geometry tools were used to construct the geometry and a vertical section was cut through the 3D model for the 2D plane strain geometry. An artificial radius=7 m circle was introduced into the model to create a more finely discretized area of the model near to the excavation.

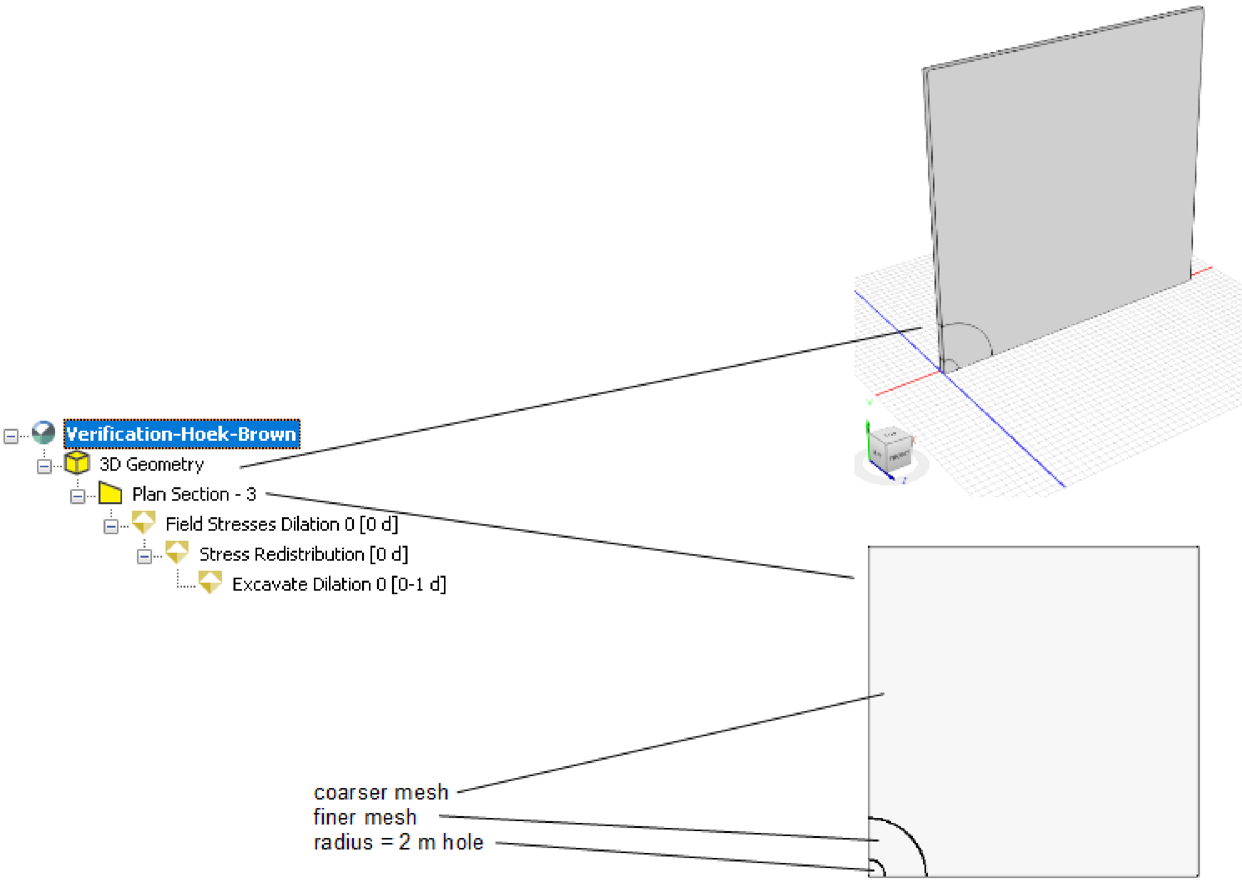

Figure 2. GeoStudio analysis tree, 3D geometry, and vertical cross section through the 3D geometry.

Figure 3 shows the In Situ analysis of the GeoStudio model. In the Define Project options, an In Situ analysis is selected with the Field Stresses method. The entire model, including the yet to be excavated circular opening, are assigned Hoek-Brown material. This analysis method allows a user defined constant stress field (see Define→Field Stresses in the GeoStudio menu) to be applied to the model. Field stresses are applied to the model through Draw→Field Stresses. Areas where field stresses have been applied are shown cross-hatched in red. X-extent model boundaries are fixed in the x-direction and y-extent model boundaries are fixed in the y-direction.

The Field Stress analysis does not account for gravitational effects and unit weight of defined materials is ignored. The model is in equilibrium with the applied and initial stresses and boundary conditions. As a result, solving this step does not require iterations. In more advanced analyses, especially when using a plastic material, the model may not be in equilibrium for a number of reasons, such as field stress magnitudes exceeding material strength or inappropriate boundary conditions. In cases where plastic material is used, such as this, it is advisable to run a Stress Redistribution analysis using the Stress Correction method immediately following the In Situ Field Stress Analysis. The Stress Correction analysis should be checked for yielding conditions (Figure 4). It is advisable to start from a well defined stress state with field stresses, where the model remains in the elastic state.

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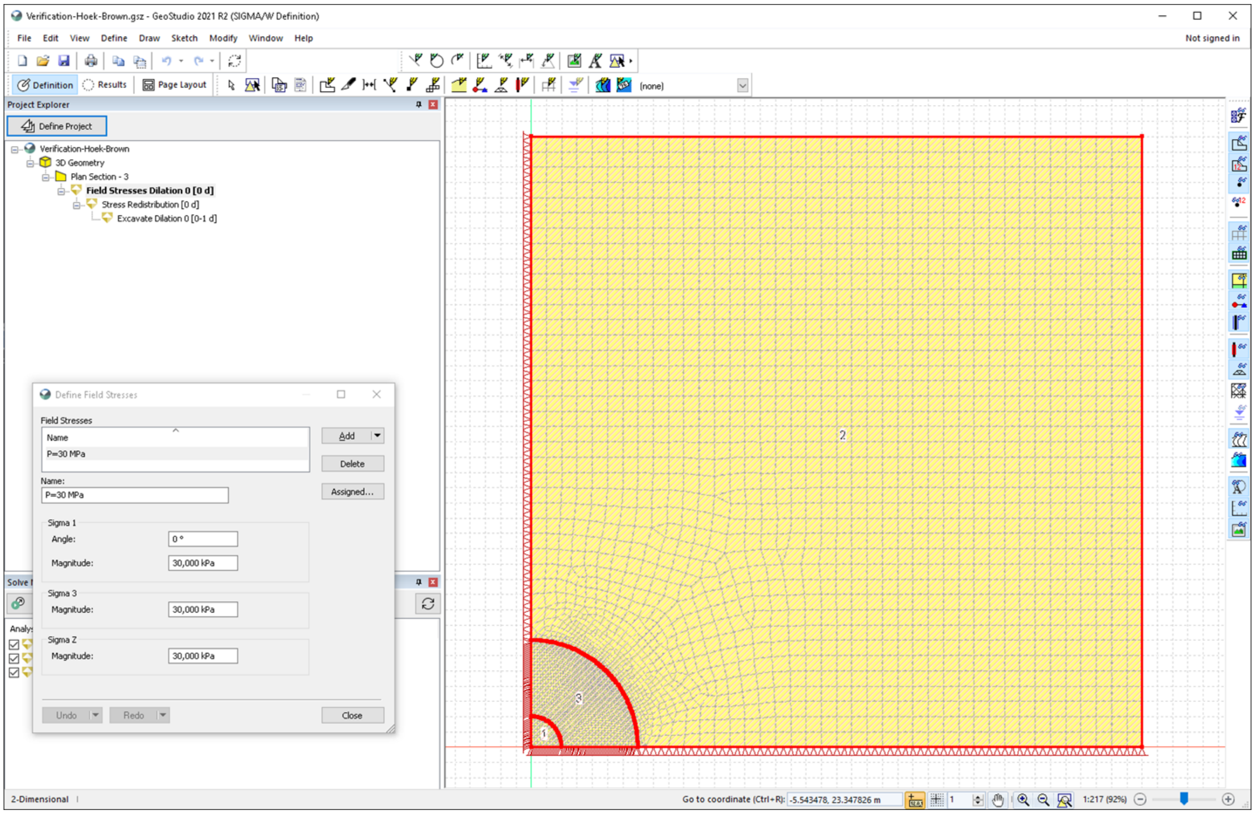

Figure 3. Field Stress definition, model mesh, and boundary conditions for In Situ analysis.

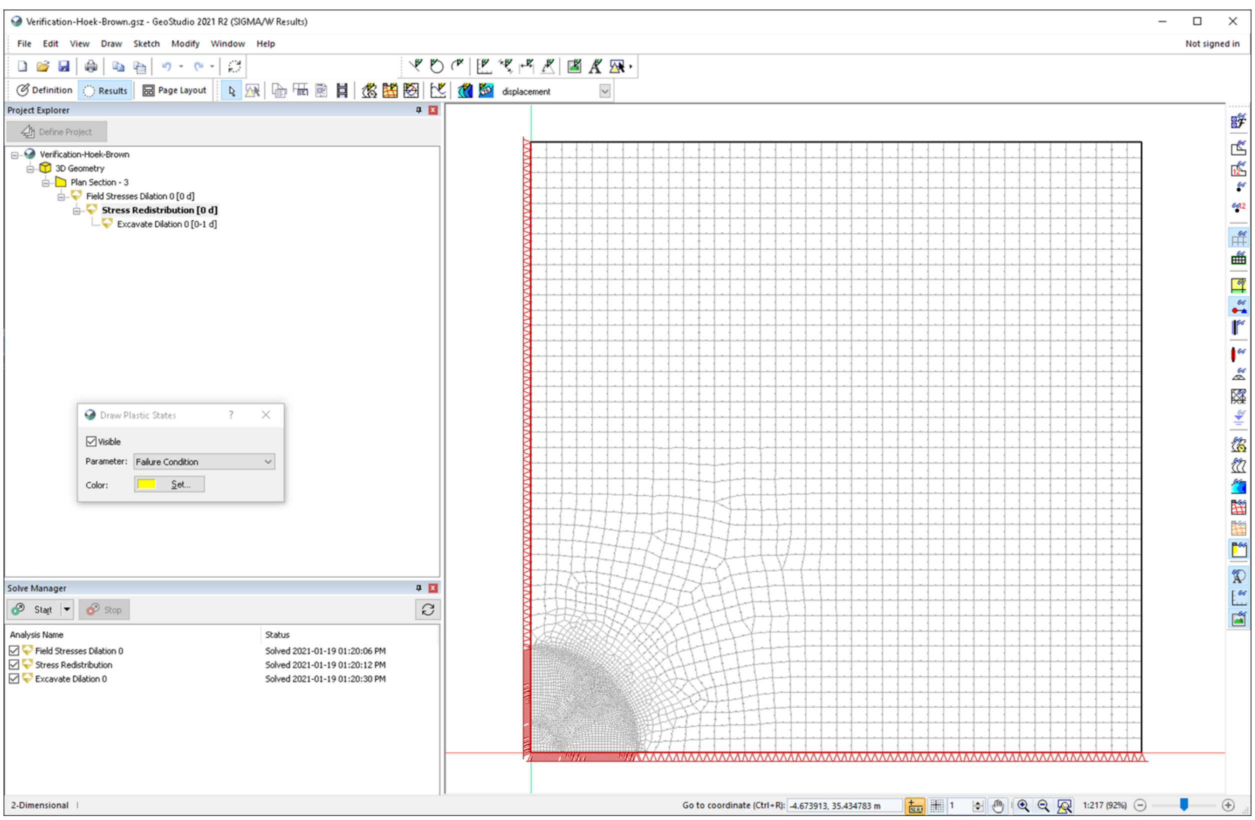

Figure 4. Stress Redistribution analysis and checking for yielded areas in the model.

A Load/Deformation analysis is run after the Stress Redistribution analysis, Figure 5 . The material in the circular opening is removed (the Hoek-Brown material is unassigned) and a pressure boundary condition (normal stress of $p_i = 5$ MPa) is assigned to the interior of the circular opening prior to solving. The material deforms according to the load imbalance.

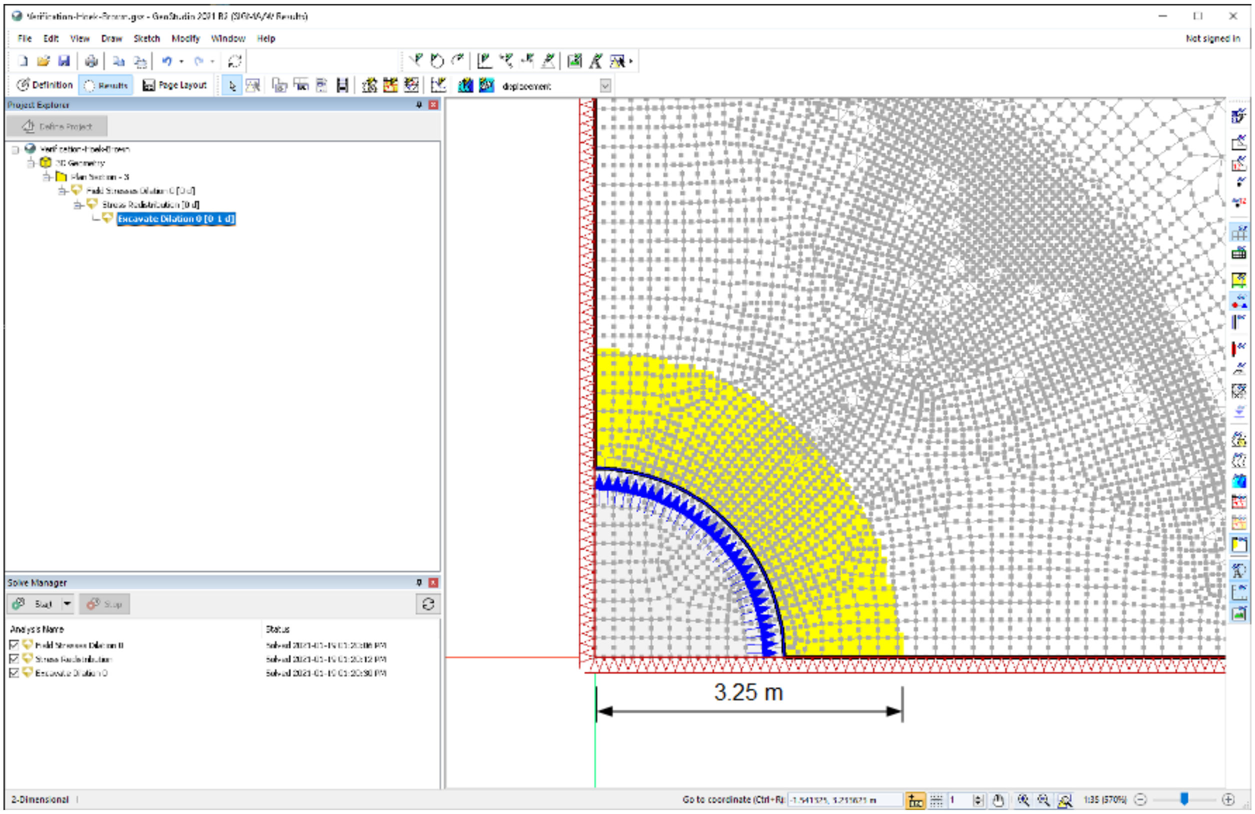

Figure 5. Load/Deformation analysis showing yielded area in yellow.

Results and Discussion

Displacements and stresses along a radial line were extracted from the GeoStudio model and processed by a Python script to compare with analytical results (Figure 6 and Figure 7). The analytical yield zone extent is 3.25 m (yellow area in Figure 5).

In the graphs below, displacements are normalized to the hole radius b and stresses are normalized to the uniaxial compressive strength of the intact rock, σ_{ci}. The match with analytical results, including the yield extent, is good, and the error can be made arbitrarily small by using a finer discretization and moving the model boundaries further out.

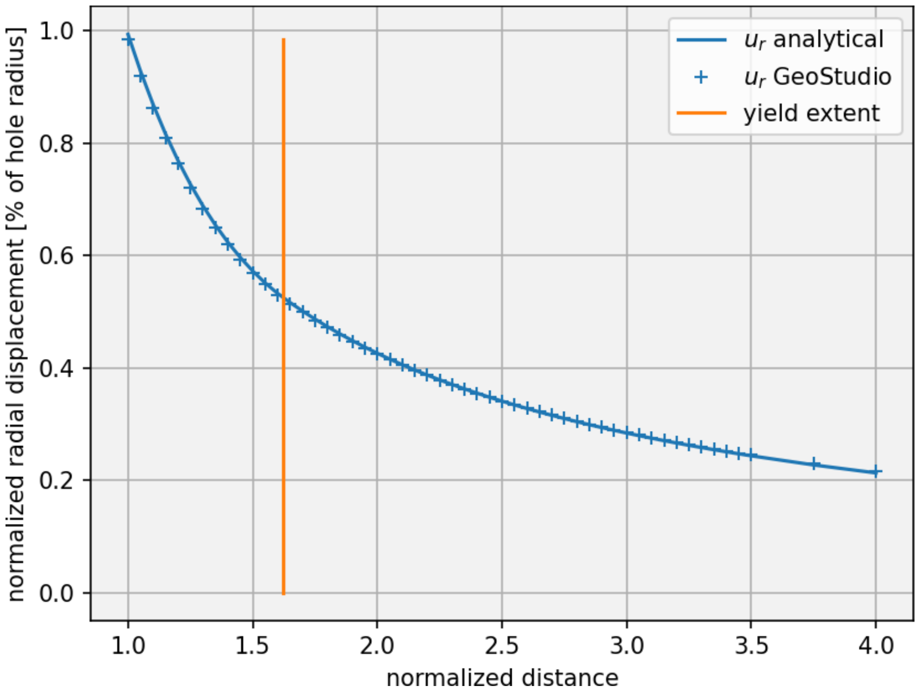

Figure 6. Normalized radial displacement versus normalized distance. Nonassociated flow, dilation = 0^o.

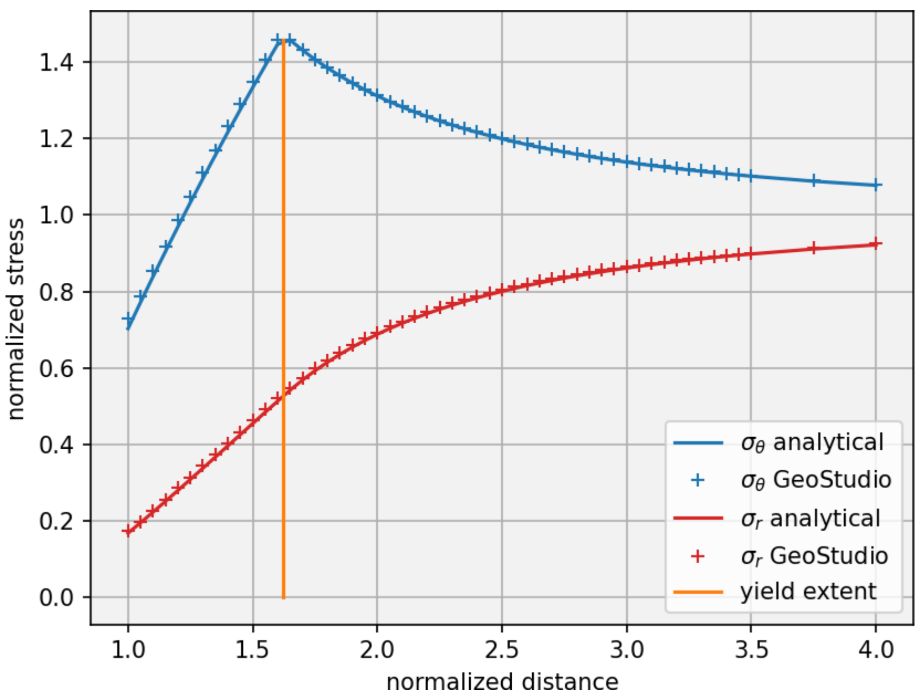

Figure 7. Normalized radial and tangential stress versus normalized distance. Nonassociated flow, dilation = 0^o.

References

C. Carranza-Torres, C. Fairhurst, The elasto-plastic response of underground excavations in rock masses that satisfy the Hoek–Brown failure criterion, International Journal of Rock Mechanics and Mining Sciences, Volume 36, Issue 6, 1999, Pages 777-809, ISSN 1365-1609, https://doi.org/10.1016/S0148-9062(99)00047-9.