GeoStudio Example File
High Earth Pressure Coefficient (Ko)

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Introduction

One-dimensional unloading of soil generally produces a more rapid drop of vertical effective stress than horizontal stress. Under certain circumstances, the horizontal effective stresses can actually exceed the vertical effective stresses – the horizontal stresses remain 'locked in' during unloading. Such stress conditions are described mathematically by an earth pressure coefficient at rest ($K_o = \sigma_h^{'}/\sigma_v^{'}$) that exceeds 1.0.

In general, the first step in a stress-deformation simulation using SIGMA/W is to establish the initial stress conditions. The initial stress conditions are particularly important if a more advanced constitutive model (e.g. modified Cam clay) is used in a subsequent analysis such as staged construction of an embankment.

Initial stresses can be established in SIGMA/W via an *In Situ* analysis using either the gravity activation procedure or the K_0 procedure. The horizontal stresses generated by the gravity activation method are limited to the case where the horizontal effective stresses are less than or equal to the vertical effective stresses (that is, K_o <= 1.0). The K_0 procedure can be used to establish horizontal effective stresses that exceed the vertical effective stress.

Background

The reader is referred to the book SIGMA/W reference book for a complete description of the K_0 procedure and its limitations. Some of the key points are:

1. The K_0 procedure can be used to establish the initial stresses for normally compressed or overconsolidated soils.
2. The K_0 procedure should generally be used for problems involving: a) a horizontal ground surface; b) a horizontal phreatic surface (that is, hydrostatic pore-water pressures); and c) spatially continuous and horizontal stratigraphic units.
3. SIGMA/W establishes the initial stresses by enforcing the relationship $\sigma_h^{'} = K_o \sigma_v^{'}$.

Numerical Simulation

The objective of each of the following examples is to establish the initial stresses such that the earth pressure coefficient is equal to 2.0 (except in one case). Figure 1 shows the basic finite element mesh and boundary conditions used for each example. Three different cases are analyzed:

1. Dry soil with K_0= 2.0;
2. Saturated soil with K_o = 0.5 in top half of the column and K_0= 2.0 in bottom half of the column); and
3. Partially saturated soil with K_0= 2.0.

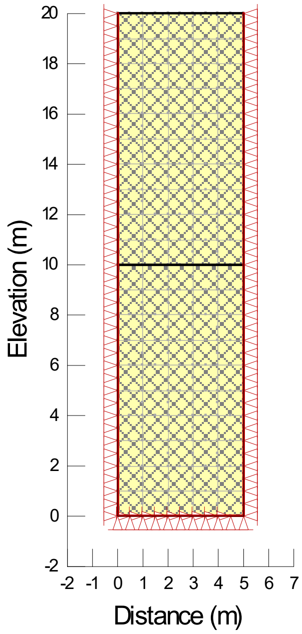

Figure 1. Finite element mesh and boundary conditions.

All of the analyses are simulated using the *In Situ* analysis type. The Analysis Tree for this Project is shown in Figure 2. The first analysis is dry, so the final pore-water pressure definition is set to ‘none’. The second and third analyses use a water table to define the final pore-water pressure conditions.

Figure 2. Analysis Tree for the Project.

The soil is defined with a unit weight of 20 kN/m^3 and a Poisson’s ratio of 0.334. Two instances of the soil have been created. On the K_0 tab, the ‘Specified’ option has been selected with $K_0 = 2$ for one of the materials, while the other material is set to ‘Calculated’ (Figure 3). In the latter case, K_0 is calculated from the effective friction angle on the ‘Basic’ tab.

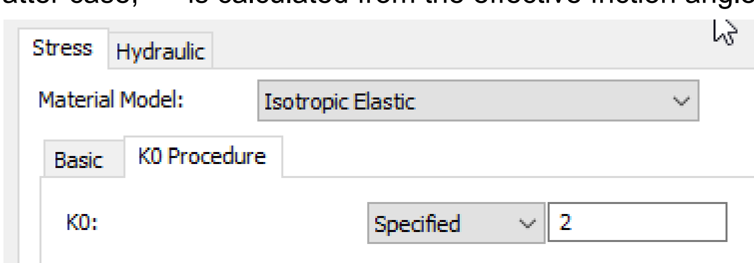

Figure 3. Example of material property definition.

Finally, it is noted that a volumetric water content function has not been defined for the soil. The influence of negative pore-water pressure in the unsaturated zone is therefore fully realized in the effective stress calculation (see Reference book).

Results and Discussion

The simplest and most instructive case for establishing high K_0 conditions is to consider a dry soil because the effective and total stresses are equal (Analysis 1). Figure 4 shows the SIGMA/W computed total stresses for this analysis. As verification, consider the hand calculated stresses at the bottom of the column:

$$\sigma_v = \sigma_v' = \sum(\gamma_i h_i - u) = 20(20) - 0 = 400\ kPa \quad \text{Equation 1}$$

$$\sigma_h = \sigma_h' = K_o \sigma_v' = 2.0(400) = 800\ kPa \quad \text{Equation 2}$$

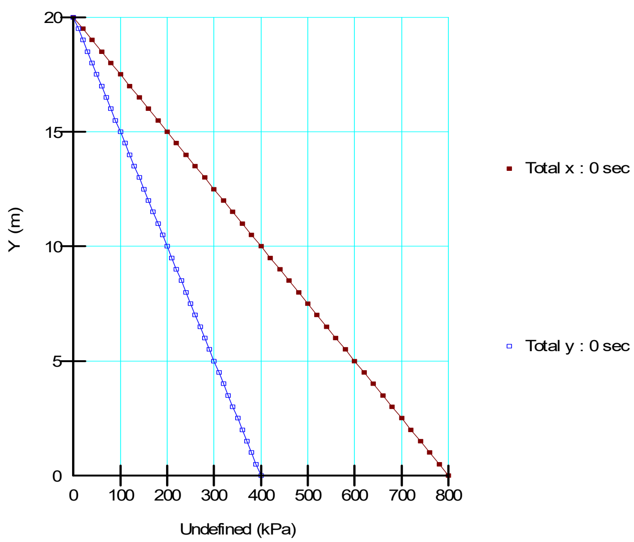

Figure 4. Total vertical (y) and horizontal (x) stresses.

The objective of the second analysis (saturated soil) is to establish K_0 = 2 in the lower half of a 10 m saturated soil column; consequently, a K_0 value is specified for the material assigned to the lower region. The upper 10 m is assumed normally compressed; consequently, the K_0 value is automatically calculated from the frictional properties of the soil (K_0 = 0.5).

Figure 5 shows the computed total and effective stresses. As verification, consider the hand calculated stresses at an elevation of 15 m (depth of 5 m):

$$u = \gamma_i z_i = 9.807(5) = 49.035\ kPa \quad \text{Equation 3}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(5) - 49.035 = 50.965\ kPa \quad \text{Equation 4}$$

$$\sigma_h' = K_o \sigma_v' = 0.5(50) = 25.4825\ kPa \quad \text{Equation 5}$$

$$\sigma_v = \sigma_v' + u = 50.965 + 49.035 = 100\ kPa \quad \text{Equation 6}$$

$$\sigma_h = \sigma_h' + u = 25.4825 + 50.965 = 74.5175\ kPa \quad \text{Equation 7}$$

The calculations of the effective and total stresses at the bottom of the profile are:

$$u = \gamma_i z_i = 9.807(20) = 196.14\ kPa \quad \text{Equation 8}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(20) - 196.14 = 203.86\ kPa \quad \text{Equation 9}$$

$$\sigma_h' = K_o \sigma_v' = 2.0(203.86) = 407.72\ kPa \quad \text{Equation 10}$$

$$\sigma_v = \sigma_v' + u = 203.86 + 196.14 = 400\ kPa \quad \text{Equation 11}$$

$$\sigma_h = \sigma_h' + u = 407.72 + 196.14 = 603.86\ kPa \quad \text{Equation 12}$$

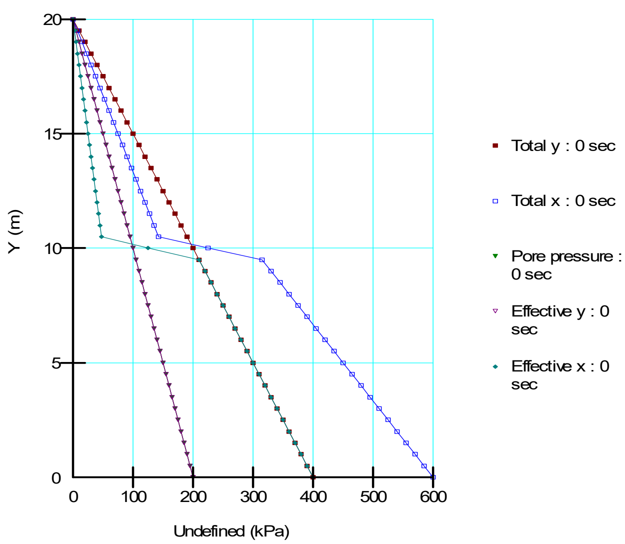

Figure 5. Total and effective vertical (y) and horizontal (x) stresses and pore-water pressure.

The third analysis (partially saturated) illustrates the effective of negative pore-water pressure on the effective and total stress calculations. The water table is assumed to be at 10 m below ground surface. Figure 6 shows the SIGMA/W computed total and effective stresses. As verification, consider the hand calculated stresses at an elevation of 15 m (depth of 5 m):

$$u = \gamma_i z_i = -9.807(5) = -49.035\ kPa \quad \text{Equation 13}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(5) - (-49.035) = 149.035\ kPa \quad \text{Equation 14}$$

GeoStudio Example - High Earth Pressure Coefficient (Ko)

$$\sigma_h' = K_o\sigma_v' = 2.0(149.035) = 298.07\ kPa \quad \text{Equation 15}$$

$$\sigma_v = \sigma_v' + u = 149.035 + (-49.035) = 100\ kPa \quad \text{Equation 16}$$

$$\sigma_h = \sigma_h' + u = 298.07 + (-49.035) = 249.035\ kPa \quad \text{Equation 17}$$

The calculations of the effective and total stresses at the bottom of the profile are:

$$u = \gamma_i z_i = 9.807(10) = 98.07\ kPa \quad \text{Equation 18}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(20) - 98.07 = 301.93\ kPa \quad \text{Equation 19}$$

$$\sigma_h' = K_o\sigma_v' = 2.0(301.93) = 603.86\ kPa \quad \text{Equation 20}$$

$$\sigma_v = \sigma_v' + u = 301.93 + 98.07 = 400\ kPa \quad \text{Equation 21}$$

$$\sigma_h = \sigma_h' + u = 603.86 + 98.07 = 701.93\ kPa \quad \text{Equation 22}$$

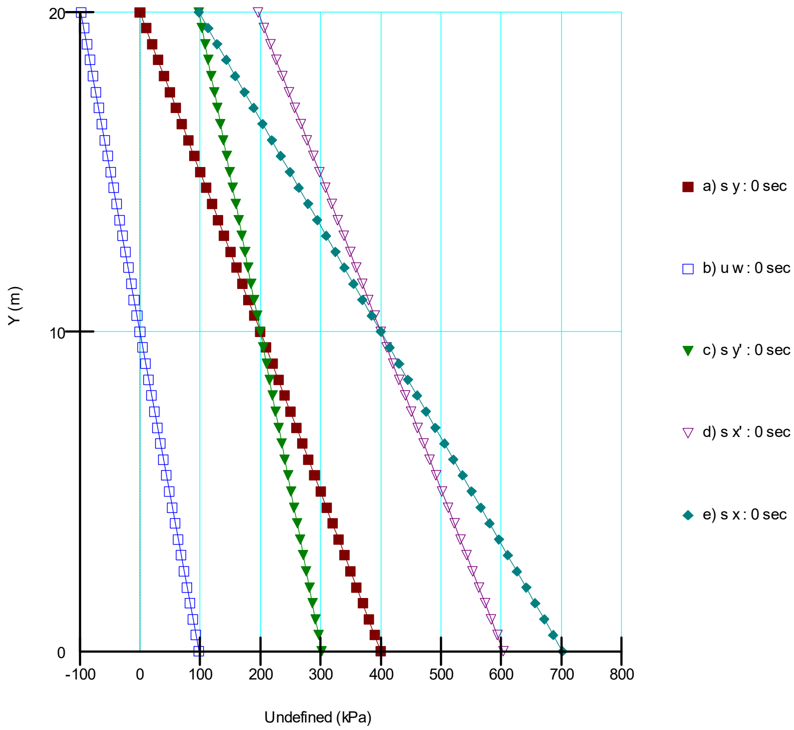

Figure 6. Total and effective vertical (y) and horizontal (x) stresses and pore-water pressure.

Summary and Conclusions

This example illustrates the use of the K_0 procedure for conducting an I*n Situ* stress analysis. The negative pore-water pressures in the unsaturated zone are fully realized in the effective stress calculation unless a volumetric water content has been defined for the material.