High Earth Pressure Coefficient K_0

1 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 $K_0 = \sigma_h' / \sigma_v'$ 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 (e.g. staged construction of an embankment).

Initial stresses can be established in SIGMA/W using an 'Insitu' type analysis; however, the horizontal stresses generated by this method are limited to the case where the horizontal effective stresses are less than or equal to the vertical effective stresses (that is, $K_0 <= 1.0$). Problems involving $K_0 > 1.0$ require the K_0 - procedure be used during the insitu analysis.

2 Feature Highlights

GeoStudio feature highlights include using the K_0-procedure to establish initial stresses.

3 Fundamentals

The reader is referred to the book SIGMA/W: An Engineering Methodology 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. The K_0 procedure overrides the initial stresses established by the insitu method for a particular region only when a value of K_0 is specified in the material properties definition.
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 $\sigma_h' = K_0 \sigma_v'$ in the saturated zone and $\sigma_h = K_0 \sigma_v$ in the unsaturated zone. In other words, the earth pressure coefficient at rest K_0 is applied to the total, not effective, stress components in the unsaturated zone.

4 Examples

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 $K_0 = 0.5$ in top half of the column and $K_0 = 2.0$ in bottom half of the column);

(3) Partially saturated soil with $K_0 = 2.0$.

The soil and water are assumed to have unit weights of 20 kN/m^3 of 10 kN/m^3, respectively (regardless of saturation state).

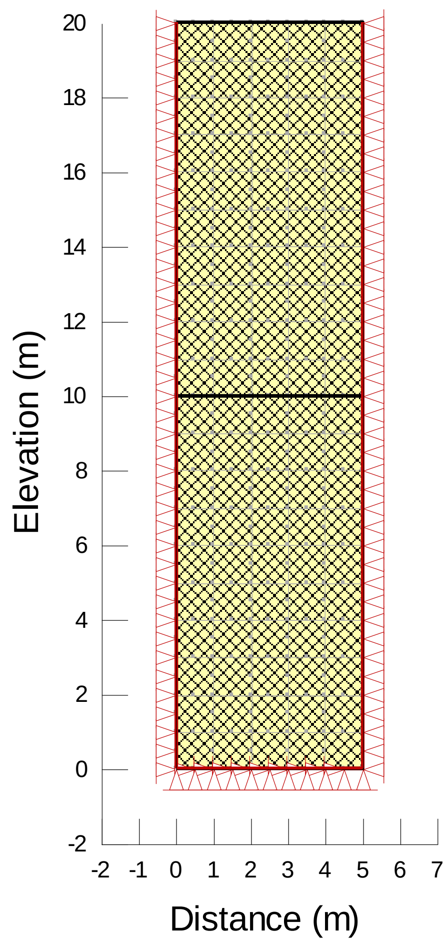

Figure 1 Finite element mesh and boundary conditions

As noted, SIGMA/W uses the K_0-procedure as part of an insitu analysis only if a value of K_0 is specified for a material (Figure 2).

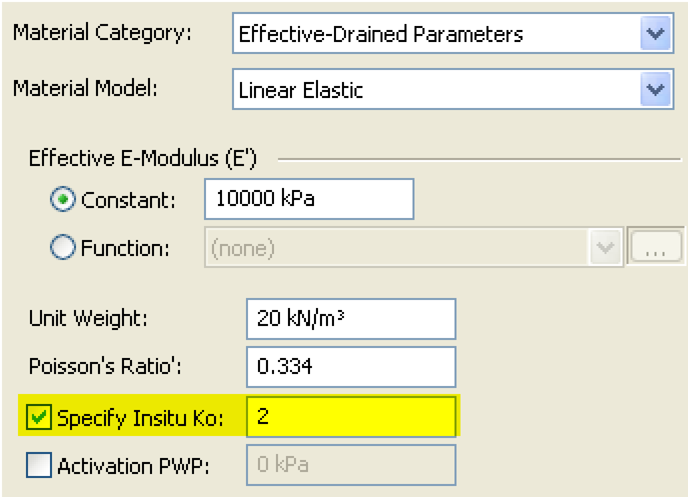

Figure 2 Example of material property definition for making use of the K_0 procedure

4.1 Case 1: Dry Soil Profile

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. Figure 3 shows the SIGMA/W computed total stresses. As verification, consider the hand calculated stresses at the bottom of the column:

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

$$\sigma_h = \sigma_h' = K_0 \sigma_v' = 2.0(400) = 800 \text{ kPa}$$

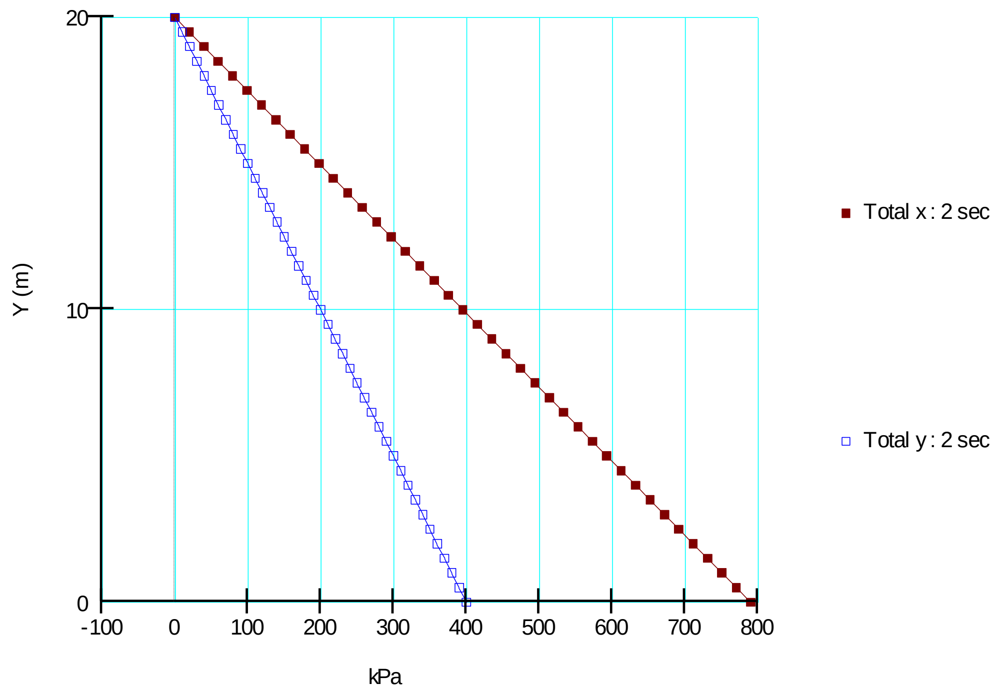

Figure 3 total vertical (y) and horizontal (x) stresses

4.2 Case 2: Saturated Soil Profile: K_0 = 0.5 overlying K_0 = 2

The objective of this example 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, no value is input for K_0. In other words, the stresses in the upper half of the column should be computed in accordance with Poisson's ratio, which was specified as 0.334 (which should generate $K_0 = 0.5$).

Figure 4 shows the computed total and effective stresses. As verification, consider the hand calculated stresses at an elevation of 15 m (depth of 5 m):

$$u = \gamma_w z_i = 10(5) = 50 \text{ kPa}$$

$$\sigma'_v = \sum(\gamma_i h_i - u) = 20(5) - 50 = 50 \text{ kPa}$$

$$\sigma'_h = K_0 \sigma'_v = 0.5(50) = 25 \text{ kPa}$$

$$\sigma_v = \sigma'_v + u = 50 + 50 = 100 \text{ kPa}$$

$$\sigma_h = \sigma'_h + u = 25 + 50 = 75 \text{ kPa}$$

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

$$u = \gamma_w z_i = 10(20) = 200 \text{ kPa}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(20) - 200 = 200 \text{ kPa}$$

$$\sigma_h' = K_0 \sigma_v' = 2.0(200) = 400 \text{ kPa}$$

$$\sigma_v = \sigma_v' + u = 200 + 200 = 400 \text{ kPa}$$

$$\sigma_h = \sigma_h' + u = 400 + 200 = 600 \text{ kPa}$$

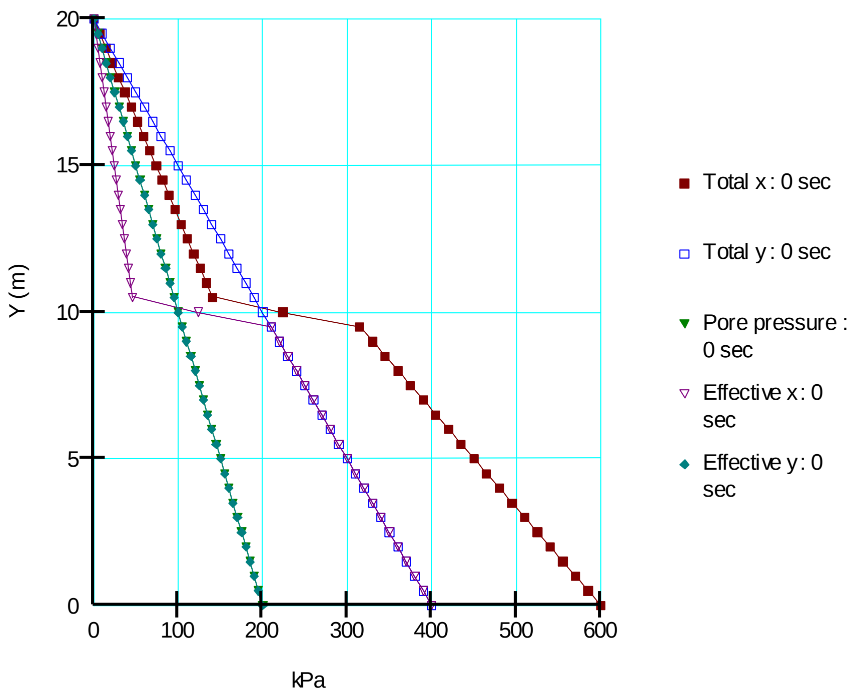

Figure 4 total and effective vertical (y) and horizontal (x) stresses and pore-water pressure.

4.3 Example: Partially Saturated Soil Profile

This example illustrates the key principle that the coefficient of earth pressure applies to the total, not effective, stresses for unsaturated soils. The objective of this example is to establish K_0 = 2 in a partially saturated soil column; consequently, a K_0 = 2 is specified for the material assigned to the lower and upper regions. The water table is assumed to be at 10 m below ground surface.

Figure 5 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):

$$u = \gamma_w z_i = -10(5) = -50 \text{ kPa}$$

$$\sigma_v = \sum(\gamma_i h_i) = 20(5) = 100 \text{ kPa}$$

$$\sigma_h = K_0 \sigma_v = 2(100) = 200 \text{ kPa}$$

$$\sigma_v' = \sigma_v - u = 100 - (-50) = 150 \text{ kPa}$$

$$\sigma_h' = \sigma_h - u = 200 - (-50) = 250 \text{ kPa}$$

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

$$u = \gamma_w z_i = 10(10) = 100 \text{ kPa}$$

$$\sigma_v' = \sum(\gamma_i h_i - u) = 20(20) - 100 = 300 \text{ kPa}$$

$$\sigma_h' = K_0 \sigma_v' = 2.0(300) = 600 \text{ kPa}$$

$$\sigma_v = \sigma_v' + u = 300 + 100 = 400 \text{ kPa}$$

$$\sigma_h = \sigma_h' + u = 600 + 100 = 700 \text{ kPa}$$

Notice also that the total vertical and horizontal stresses are 0 at the ground surface (a requirement for equilibrium).

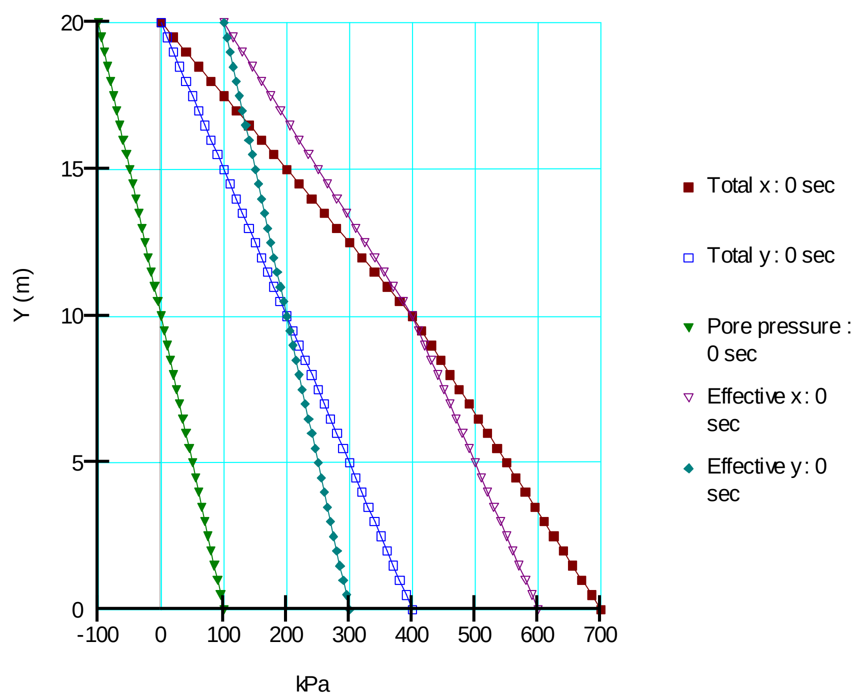

Figure 5 total and effective vertical (y) and horizontal (x) stresses and pore-water pressure.

5 Concluding Remarks

This example illustrates the use of the K_0 procedure when completing an insitu stress analysis. The limitations of the method are discussed in detail in the SIGMA/W: An Engineering Methodology book.