Multi-Stage Rapid Drawdown

1. Introduction

When the water level at a dam drops, the stabilizing force due to the weight of the water is removed. If the dam material has low permeability and the water level drops quickly, then excess pore pressures will be slow to dissipate. This causes reduced stability in the slope. This tutorial describes how to use **Slide2** to model rapid drawdown and examine the effect on dam stability and factor of safety.

The finished product of this tutorial can be found by selecting **File > Recent Folders > Tutorials Folder > Tutorial 17 Rapid Drawdown.slmd in Slide2**.

This tutorial does not go through the process of setting up a rapid drawdown analysis. For details on how to do this, see Tutorial 13 - Rapid Drawdown in Slide2.

2. Full Reservoir - Steady State

The model is based on the Pilarcitos Dam analysis as described in Duncan, Wright and Wong (1990). The dam failed due to rapid drawdown of the water level in November 1969.

We will load a file which has been prepared for this tutorial. Go to **File > Recent Folders > Tutorials Folder** and open *Tutorial 17 Rapid Drawdown.slmd*.

Notice that the file has four groups, one without drawdown and one for each drawdown method examined in this tutorial. Compute the file.

2.1 INTERPRET

Looking at the results of the **Water Table** group, you can see that the factor of safety is 2.5 and that this is for a very small surface slip at the toe.

You can prevent **Slide2** from generating these shallow failure surfaces by going to **Surfaces > Surface Options** and selecting a minimum depth greater than 0. See the Slip Surfaces topics under Slide Interpret. Essentially, this model can be considered stable.

3. Rapid Drawdown

Go back to the Modeler and let us examine the **Project Settings** and **Material Properties** for the first drawdown analysis, Duncan Wright and Wong.

1. Go to the **Groundwater** tab of the **Project Settings**.
   Notice the **Undrained Strength Interpolation Scheme for Rapid Drawdown** section.

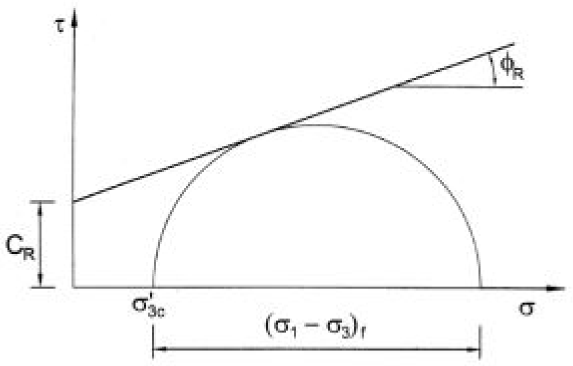
The default option is VandenBerge, Wright (2016).

2. Click **Cancel** to exit the **Project Settings**.
3. Go to the **Material Properties** dialog and click on the **Define Strength** button in the **Rapid Drawdown Parameters** section.
   For the Duncan, Wright and Wong and Lowe Karafiath methods, Cr and PhiR parameters must be entered.

The total stress R envelope is a way of representing the undrained strength of the material. It is also possible to specify a Kc = 1 envelope. For details about the meaning of these different envelopes, and their relationship to each other, see the information below.

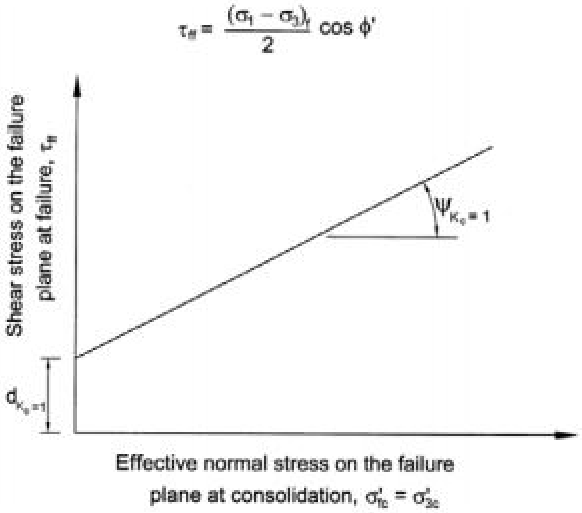
ABOUT STRENGTH ENVELOPES

For undrained material, the shear strength can be determined from isotropic consolidated undrained (IC-U) laboratory tests. The total stress R envelope can be constructed as shown below.



Where s3c' is the effective stress during (isotropic) consolidation and (s1 – s3)f is the principal stress difference at failure.

From the same laboratory test data, it is possible to construct a Kc = 1 envelope instead as shown below.



These two different envelopes are related through the following equations:

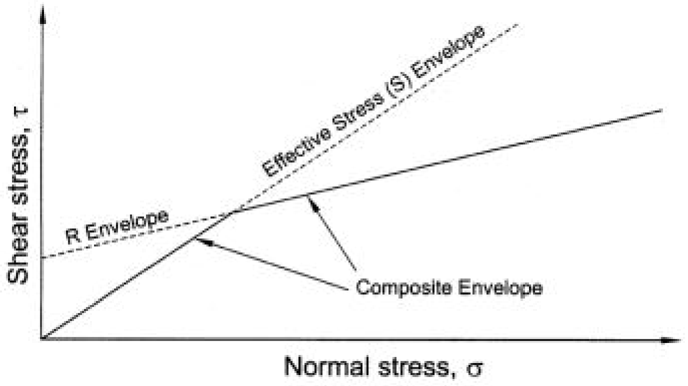
$$d_{k_c=1} = c_r \left(\frac{\cos\phi_r \cos\phi'}{1 - \sin\phi_r} \right)$$

$$\psi_{k_c=1} = \tan^{-1} \left(\frac{\sin\phi_r \cos\phi'}{1 - \sin\phi_r} \right)$$

Where φ′ is the undrained friction angle.

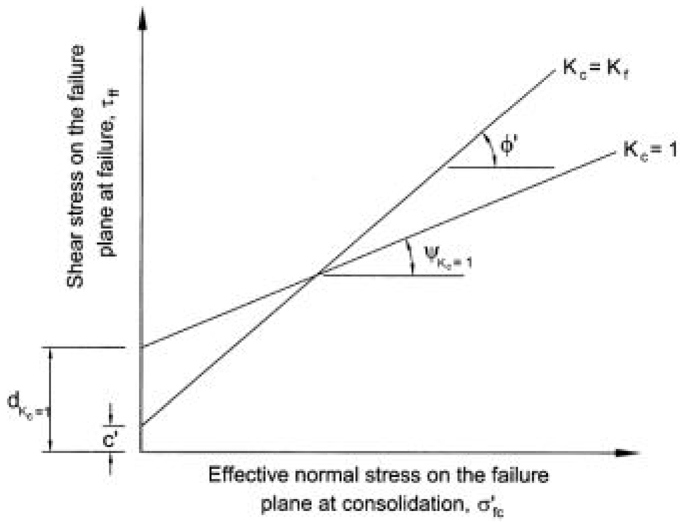
Army Corps Method

To perform the limit equilibrium analysis, the Army Corps method requires the R envelope. If the Kc = 1 envelope is entered instead, then it is converted using the above equations. The R envelope is then combined with the effective stress envelope to avoid relying on elevated shear strengths that result from negative pore pressures. The composite envelope is shown below.



Other Methods

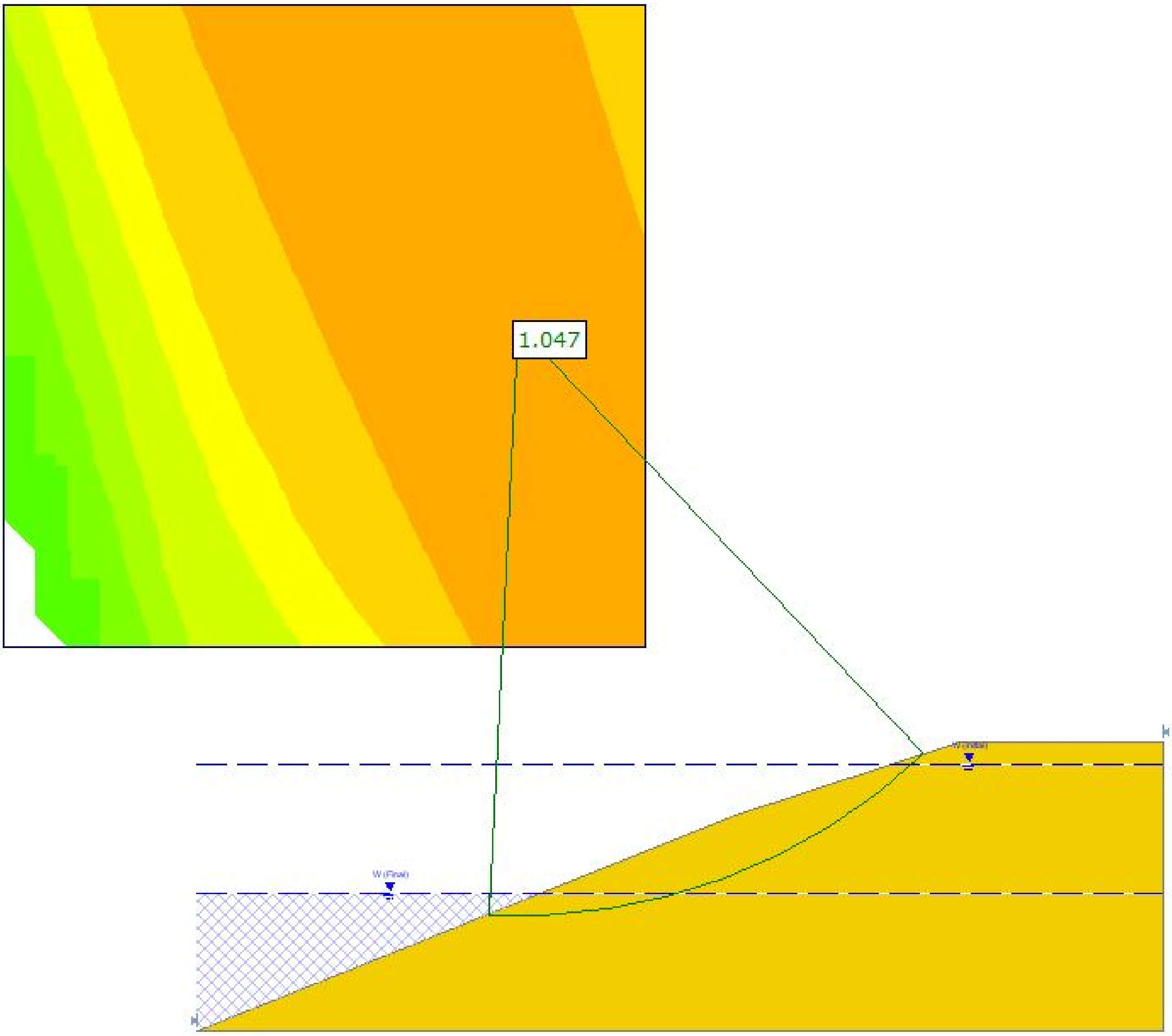
The Lowe and Karafiath (1960) and the Duncan Wright and Wong (1990) methods require the Kc = 1 envelope. If the R envelope is entered instead, then it is converted using the above equations. Kc = 1 refers to anisotropically consolidated state. To get the envelope for an anisotropically consolidated material (where Kc ≠ 1) the drained failure envelope is plotted on the same graph. The drained envelope is assumed to represent the undrained shear strength of the soil at maximum allowable Kc (i.e., the value of Kc that results in failure during consolidation). The envelope to be used in the analysis is then interpolated between the two, using the value of Kc for each slice in the limit equilibrium analysis of the slope prior to drawdown.



Once the envelope is defined, the limit equilibrium analysis is performed for the second stage (after drawdown) using the new shear strengths. In the Duncan, Wright and Wong (1990) method, a third stage of computation is also performed. In this stage, the effective stress on the bottom of each slice (after drawdown) is calculated and, if the drained shear strength is less than the undrained shear strength, the drained shear strength is used instead.

4.0 Interpret

Go back to Interpret and look at the results for Duncan, Wright and Wong.



Rapid Drawdown Method: Duncan, Wright and Wong

You can see that the factor of safety is approximately 1, corresponding to a slope failure as observed at the actual Pilarcitos dam.

The Lowe and Karafiath method is essentially the same as the Duncan, Wright and Wong method. The difference is that the Duncan, Wright and Wong method performs a third stage of calculation in which it checks if the effective stress after drawdown produces a drained strength that is less than the undrained strength. If any slices are found for which this is the case, then the drained strength is substituted and the analysis is rerun. Click OK to close the dialog.

You can see that the factor of safety for the Lowe and Karafiath method is 1.051. This is slightly higher than the value of 1.047 obtained with the Duncan, Wright and Wong method. This indicates that some of the slices must have had lower drained strengths than undrained strengths. Therefore the third stage of analysis in the Duncan, Wright and Wong method resulted in a slightly lower factor of safety.

The Army Corps method uses a different failure envelope than the other methods. However, we did not need to change the material properties since **Slide2** automatically performs any required conversions.

The factor of safety for the Army Corps method is 0.822 – significantly lower than the other methods. This agrees with the general belief that the Army Corps method gives results that are too conservative.

This concludes the tutorial.

5. Additional Exercise

Instead of using the R envelope, try entering a Kc = 1 envelope instead. If you specify d = 64 lb/ft2 and ψ = 24.4°, you should get the same results.

6. References

Corps of Engineers, 1970. Engineering and Design – Stability of Earth and Rock Fill Dams, Engineering Manual, EM 1110-2-1902. Department of the U.S. Army, Corps of Engineers, Office of the Chief of Engineers.

Duncan, J.M., Wright, S.G. and Wong, K.A., 1990. Slope Stability during Rapid Drawdown, Proceedings of H. Bolton Seed Memorial Symposium. Vol. 2.

Lowe, J and Karafiath, L., 1960. Stability of Earth Dams Upon Drawdown, Proceedings of 1st PanAm Conference on Soil Mechanic and Foundation Engineering. Mexico City, Vol 2.