Chapter 7

Slope Stability Analysis of a Heterogeneous Earth Dam Using SLOPE/W

7.1 Introduction

This program is part of the GeoStudio 2007 software suite and is used to evaluate the stability of sloping surfaces and determine the factor of safety (FOS) in slope design. This analysis is performed using limit equilibrium methods, including Bishop, Ordinary, and Janbu methods. In this example, the Morgenstern–Price method, which was previously described in Chapter 3, is used to evaluate slope stability.

As stated in Chapter 3, the minimum factor of safety for slope stability should be 1.0; however, in engineering design, this minimum value is typically taken as 1.5.

It is important to note that, unlike the other modules of GeoStudio, this module does not use the finite element method. One of the main features discussed in this chapter, compared with Chapter 3, is the ability of the program to evaluate slope stability under dynamic conditions. It should be noted that this capability is also available in the 2004 version of the program.

In this chapter, the analysis of a heterogeneous earth dam is described according to the following procedures:

- Evaluate the stability of the slope of a heterogeneous dam under end-of-construction conditions and determine the corresponding factor of safety.
- Evaluate the stability of the dam slope under steady-state seepage conditions and determine the corresponding factor of safety.

- Evaluate the stability of the dam slope under dynamic conditions subject to a horizontal seismic acceleration.

7.2 Project Description

Figure 7.1 shows a heterogeneous earth dam with a clay core, constructed in 10 different layers with different material properties. The parameters of these layers are presented in Table 7.1. The dam geometry is shown in Figure 7.1, and the coordinates of the points required to define its dimensions should be obtained from Table 7.2.

Table 7.1 Materials Properties

Materials		Permeability (m/s)	Cohesion (kPa)	Internal friction angle ($^\circ$)	Saturated unit weight (kN/m^3)	Moist unit weight (kN/m^3)
Core	Material #1 (UU)	10^{-8}	100	10	20.6	20
	Material #1 (CU)	10^{-8}	50	20	20.6	20
	Material #1 (CD)	10^{-8}	0	28	20.6	20
Upstream and downstream shell	Material #2	10^{-5}	0	43	22	21
	Material #3	10^{-5}	0	41	22	21
	Material #4	10^{-5}	0	39	22	21
	Material #5	10^{-5}	0	38	22	21
	Material #6	10^{-5}	0	37	22	21
Downstream shell	Material #7	10^{-3}	0	41	22	21
	Material #8	10^{-3}	0	39	22	21
	Material #9	10^{-3}	0	37	22	21
	Material #10	10^{-3}	0	36	22	21
Foundation	Material #11	10^{-4}	300	35	26.5	26
	Material #12	10^{-4}	350	55	26.5	26

Table 7.2 Coordinates of the points shown in the model

Point	Coordinate x	Coordinate y
C_{10}	158	40
C_{11}	178	42
C_{12}	210	42
C_{13}	236	42
C_{14}	248	48
D_1	132	54
D_2	155	54
D_3	170	57
D_4	185	56
D_5	213	55
D_6	233	55
D_7	257	54
D_8	300	54
E_1	137	76
E_2	150	76
F_1	140	92
F_2	147	92
G_1	141	98
G_1	146	98
H_1	141	103
H_2	147	103

Point	Coordinate x	Coordinate y
A_1	0	0
A_2	300	0
B_1	0	40
B_2	91	39
B_3	101	30
B_4	125	30
B_5	128	28
B_6	160	28
B_7	163	30
B_8	237	30
B_9	257	40
B_{10}	300	40
C_1	0	52
C_2	30	52
C_3	50	52
C_4	66	52
C_5	91	52
C_6	101	42
C_7	111	42
C_8	125	42
C_9	130	40

As indicated by the given coordinates, the dam crest is 6 *m* wide. For the dam shown, the stability of the earth-dam slopes is to be evaluated under the following conditions:

(a) Evaluate the static stability of the left slope and determine the factor of safety at the end of construction and before reservoir impoundment. In this case, the moisture content of the dam's clay core should be introduced into the analysis using the parameter R_u, as shown in Figure 7.2.

(b) Evaluate the static stability of the left slope after reservoir impoundment under steady-state seepage conditions, with the reservoir water level reaching 95 *m* above the foundation base elevation.

(c) Evaluate the dynamic stability of the right slope and determine the factor of safety at the end of construction and before reservoir impoundment, assuming a horizontal seismic acceleration of 0.15. In this case, the moisture content of the dam's clay core should likewise be introduced into the analysis using the parameter R_u, as shown in Figure 7.2. It should be noted that the properties of the dam core are provided for three conditions: (1) Unconsolidated-

Undrained (UU), (2) Consolidated- Undrained (CU), and (3) Consolidated -Drained (CD). The required parameters should be selected from these sets according to the conditions of each analysis.

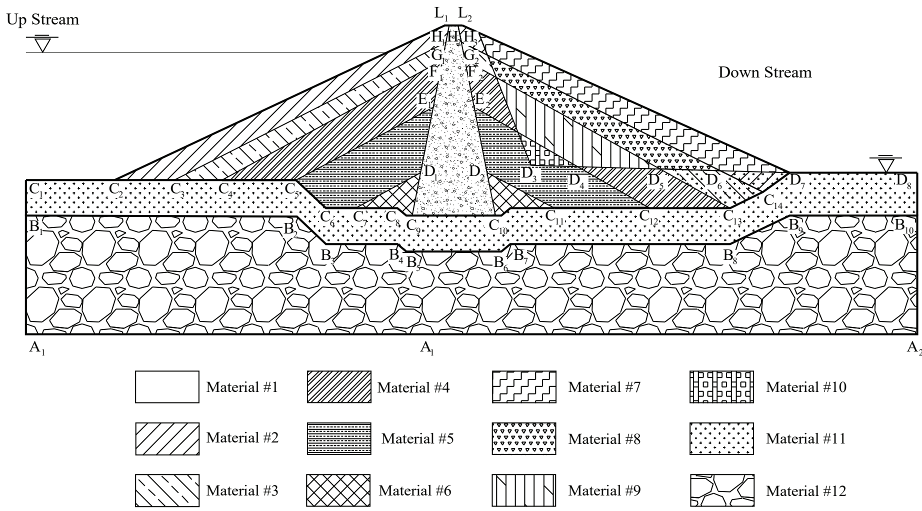

Figure 7.1 Cross-section of a heterogeneous earth dam with different layers and a clay core

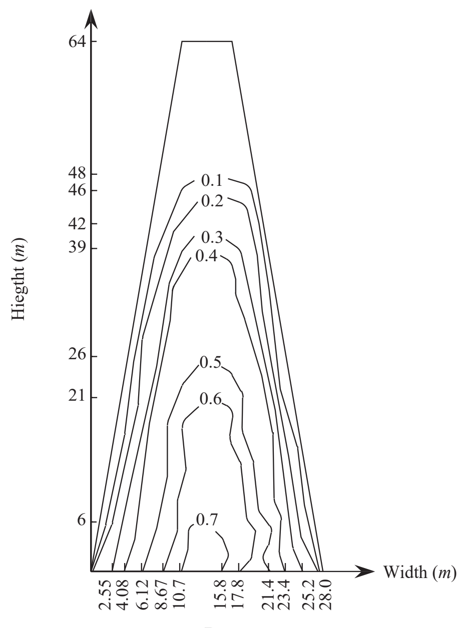

Figure 7.2 Values of R_u at the end of construction

7.3 Modeling the Project in SLOPE/W

After launching GeoStudio 2007, the dialog box shown in Figure 7.3 appears. After selecting **SLOPE**, an **Analysis Settings** dialog box opens. Click **Cancel** to open the **SLOPE/W** program window, as shown in Figure 7.4. It should be noted that, in this chapter, the first part of the project is initially evaluated in full, and the modeling procedure is explained step by step. The other two parts of the project are then described in the subsequent subsections.

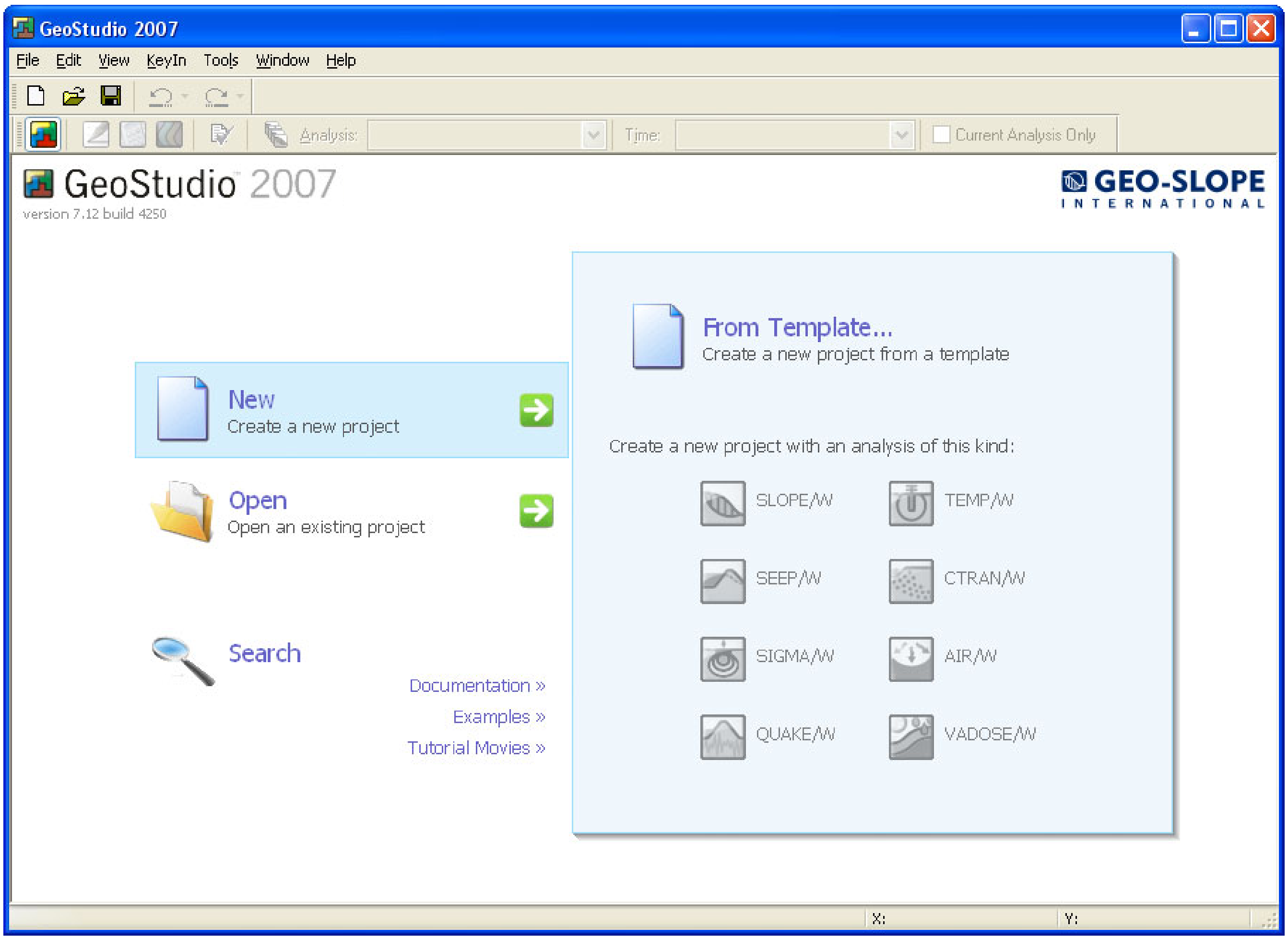

Figure 7.3 Dialog box for selecting the analysis type at program startup

To begin working with the software, the initial settings including the workspace, scale, axes, and grids must first be configured. These settings are accessed through the **Set** and **View** menus, as described in the following sections.

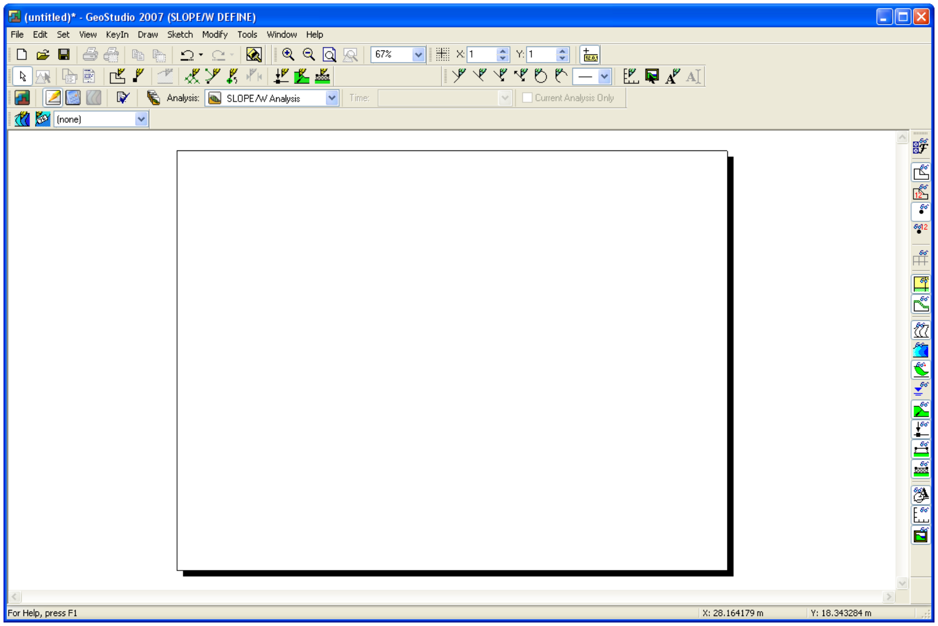

Figure 7.4 SLOPE/W program window

7.3.1 View Configuration Tools

7.3.1.1 Set Menu Settings

The **Set** menu and its available options are shown in Figure 7.5.

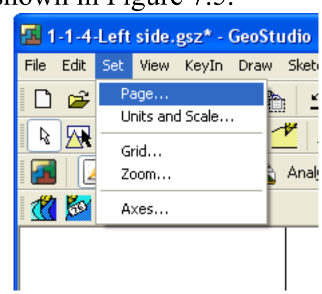

Figure 7.5 Set menu

7.3.1.1.1 Page Display Settings

Using this menu, the page on which the model is displayed can be configured according to the dimensions of the model. The width and height of the display page can also be specified in inches or millimeters (Figure 7.6).

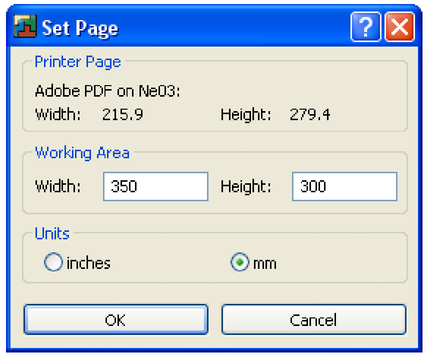

Figure 7.6 Page window

7.3.1.1.2 Display and Unit Settings in the Units and Scale Menu

In this menu, the user specifies the desired model scale. In this project, a scale of **1200** is selected in both the horizontal and vertical directions. The **unit weight of water** and **atmospheric pressure** must also be specified in the lower section of the dialog box (Figure 7.7).

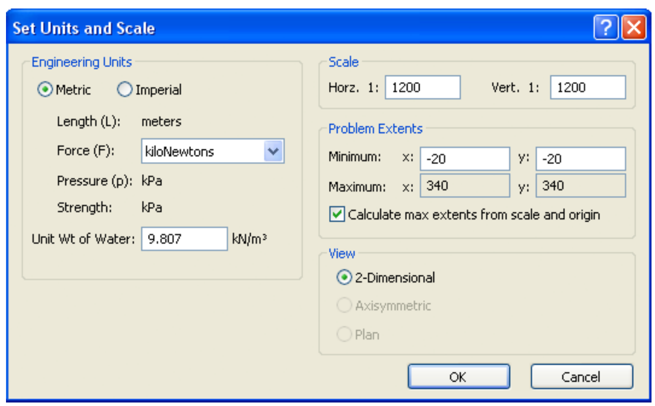

Figure 7.7 Units and Scale window

7.3.1.1.3 Grid Settings

In this dialog box, the grid spacing, which serves as a useful aid in model construction, is specified. As an initial setting, the grid spacing can be set to 1 unit. The **Display Grid** and **Snap to Grid** options are also enabled to facilitate the modeling process (Figure 7.8). Activating these options enables the software to display the grid and facilitates the alignment of model geometry with the grid.

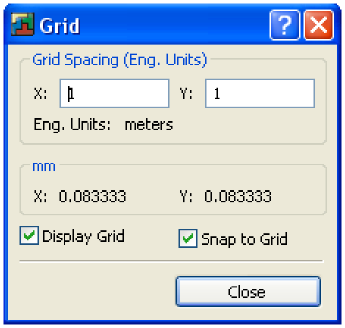

Figure 7.8 Grid window

7.3.1.1.4 Coordinate Axes Settings in the Axes Menu

In this dialog box, the coordinate axes are configured, and their dimensions and numerical ranges are specified in the software (Figure 7.9).

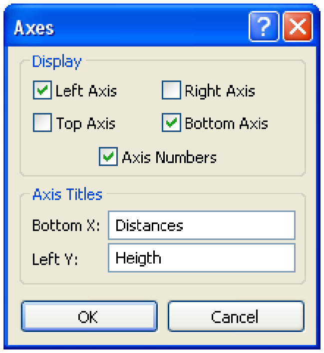

Figure 7.9 Axes window

The **Set Axes Size** dialog box is shown in Figure 7.10.

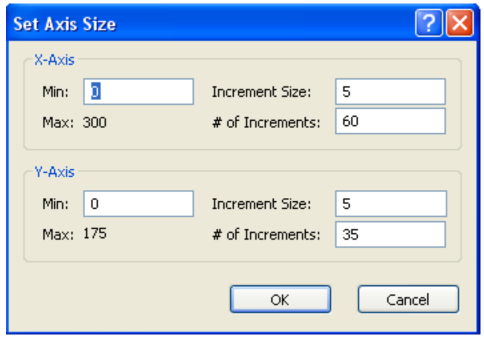

Figure 7.10 Set Axis Size window

Finally, after completing the software display settings, the program environment is ready for model construction and analysis setup, as shown in Figure 7.11.

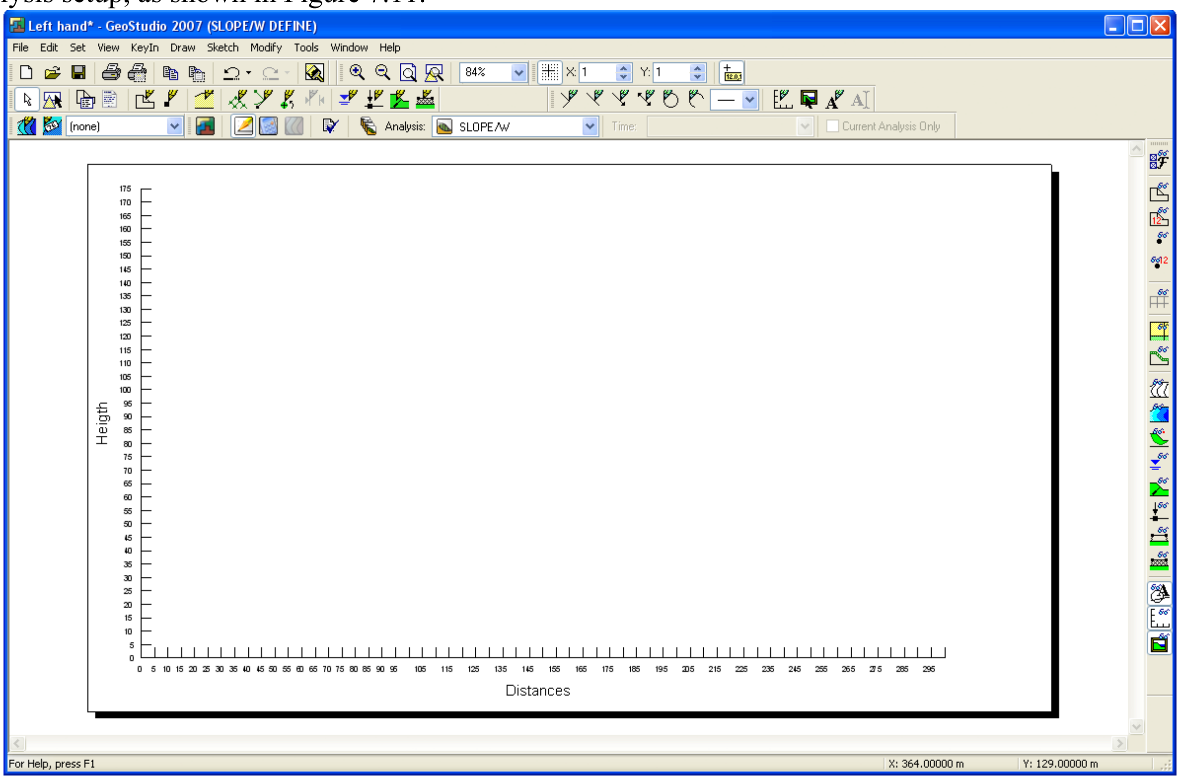

Figure 7.11 Program environment for model drawing

7.3.1.2 View Menu Display Settings

The **View** menu and its available options are shown in Figure 7.12. Through the **Preferences** dialog box in this menu, the display or non-display of **elements, regions, points**, and other model components can be configured according to the user's requirements (Figure 7.13).

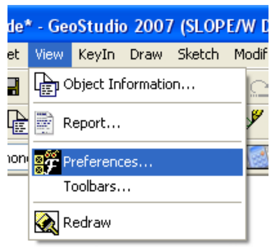

Figure 7.12 View menu

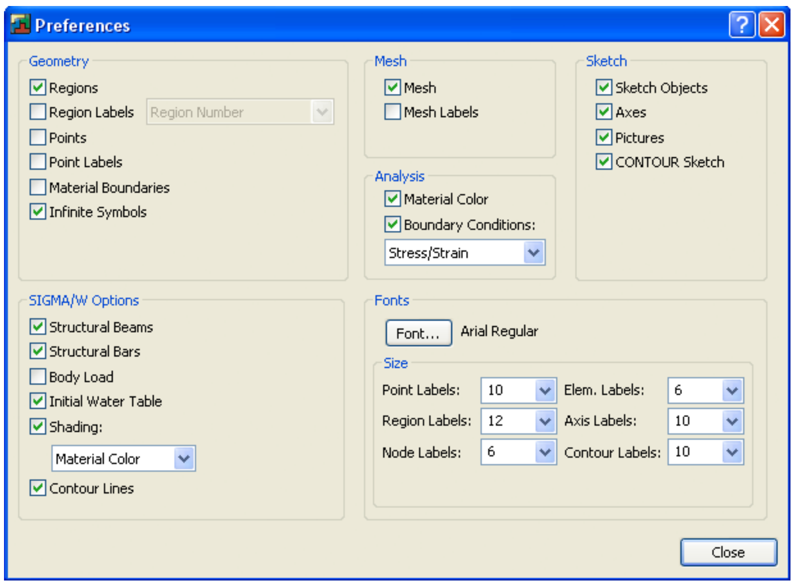

Figure 7.13 Preferences window

7.3.2 Defining Model Properties Using the KeyIn Menu

The SLOPE/W program is used to perform the slope stability analysis. In this stage, parameters such as material properties, the water table or piezometric level, analysis specifications, and other required parameters must be defined in the software, as described in the following sections.

7.3.2.1 Defining Analysis Specifications Using the Analyses Menu

By selecting this option from the menu shown in Figure 7.14, the analysis type, slope direction, and pore-water pressure conditions can be defined. The main parameters of interest in this section include the analysis method, for which the Morgenstern- Price method is selected in this project. The theoretical basis of this method was previously described in Section 3.3.1.1. The pore-water pressure condition for the first part of the project is defined using the parameter R_u .

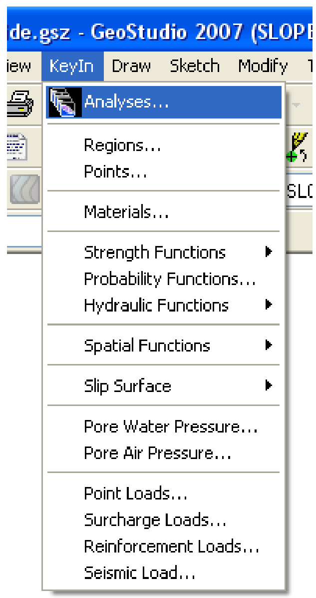

Figure 7.14 KeyIn Analyses menu

In this section, under **PWP Condition**, select the R_u option, as shown in Figure 7.15.

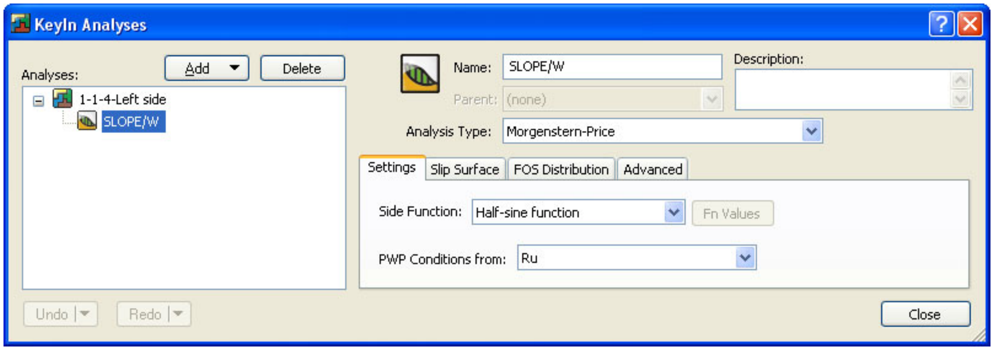

Figure 7.15 Settings tab in KeyIn Analyses window

To define the analysis settings for the slip surface, refer to the **Slip Surface** section shown in Figure 7.16. Since the slip surface being investigated in this case is the **left slope of the dam**, the **Right to Left** option is selected. The method for determining the slip surface is then set to **Grid & Radius**. It should be noted that the theoretical basis of this method was briefly presented in Section 3.3.1.2.

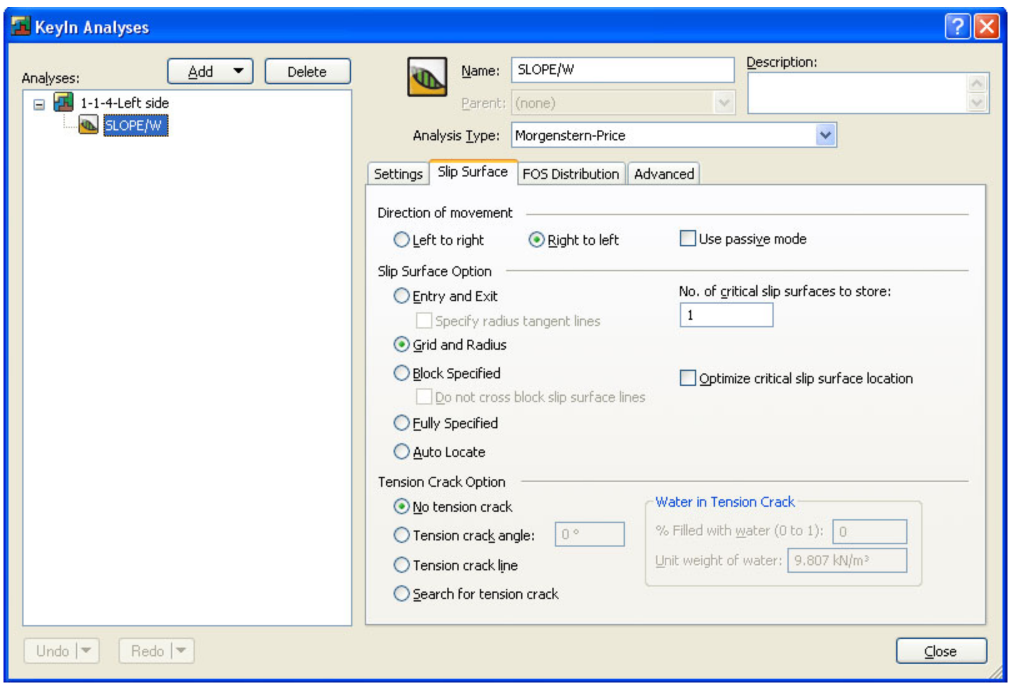

Figure 7.16 Slip Surface tab in KeyIn Analyses window

The remaining analysis settings are left at their default values, as shown by the selected options in Figures 7.17 and 7.18.

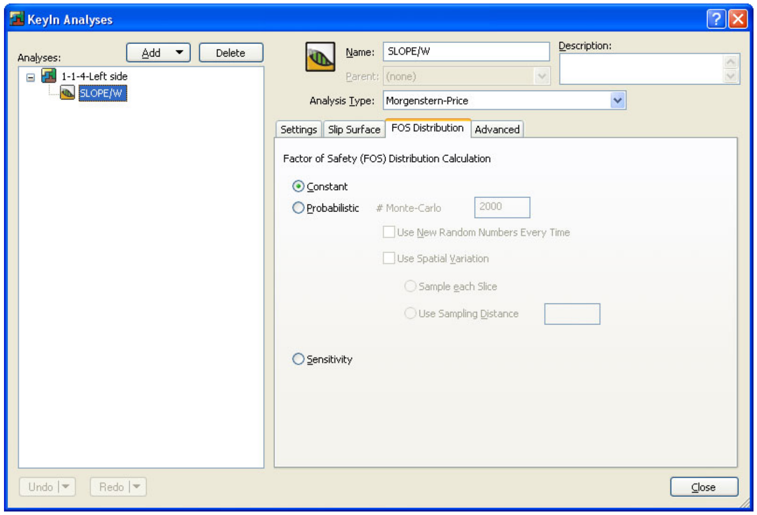

Figure 7.17 FOS Distribution tab in KeyIn Analyses window

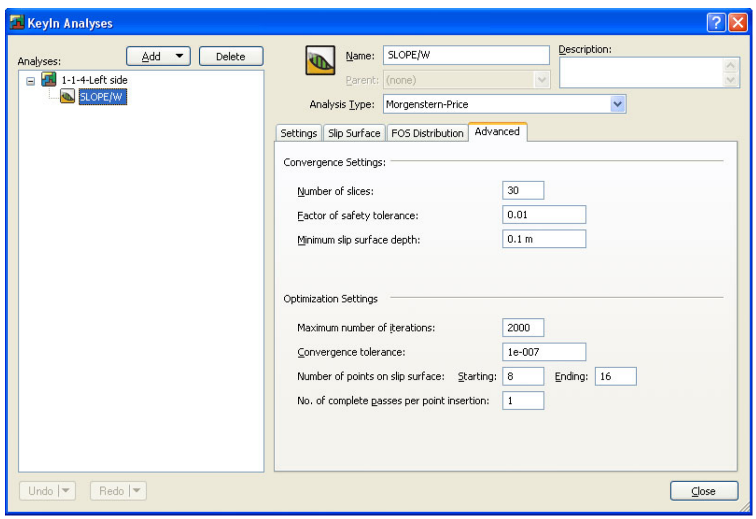

Figure 7.18 Advanced tab in KeyIn Analyses window

7.3.2.2 Defining Material Properties Using the Material Properties Menu

In this section, the material properties, including the constitutive model and geotechnical parameters, are defined using the **KeyIn** menu shown in Figure 7.14. The constitutive models available in the software were briefly described in Section 3.4.1.1, and the same explanations are sufficient for this chapter.

As shown in Figure 7.19, the constitutive model selected for this project is the Mohr- Coulomb model. According to Table 7.1, 12 types of materials are defined for this project. The parameters for Soil Type 1, however, are provided for three conditions: UU, CU, and CD.

Based on the discussion in Section 3.3.3, since the end-of-construction condition governs this part of the problem, the Unconsolidated- Undrained (UU) parameters should be used.

Therefore, as the first step, 15 material types must effectively be defined in the software. However, it should be noted that only one of the three parameter sets for Soil Type 1 should be appropriately selected, according to the conditions of the problem, and assigned to the dam core.

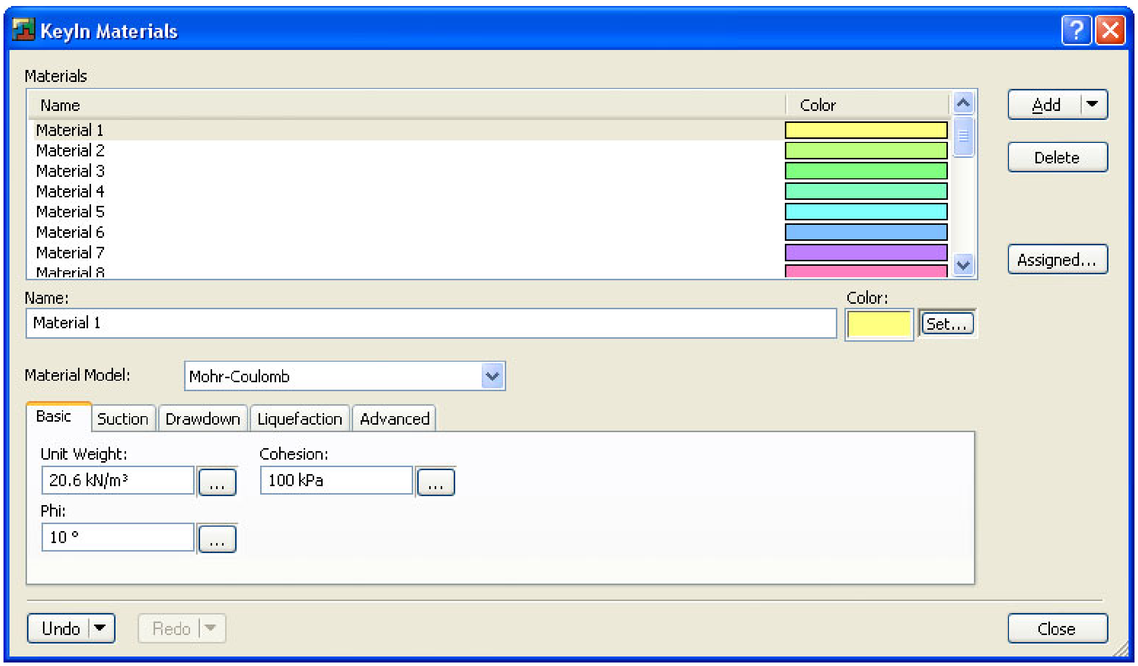

Figure 7.19 KeyIn Materials window and Basic tab