

ReActiv

Version 1.7

User Manual

REINFORCED SLOPE DESIGN

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Chapter 1

Introduction

Welcome to ReActiv®, the reinforced slope design program. ReActiv is an interactive program that helps you to design reinforced slopes in a variety of different soil types, using reinforced soil or soil nails.

This chapter of the *ReActiv User Manual* outlines the contents of this book, explains the conventions that are used herein, and tells you what to do if you need help using the program.

About this book

This *User Manual* is divided into the following chapters:

- Chapter 1 *Introduction*
- Chapter 2 *Installing and running ReActiv*
- Chapter 3 *Overview*
- Chapter 4 *Tutorial: worked example 1*
- Chapter 5 *Tutorial: worked example 2*
- Chapter 6 *Tutorial: worked example 3*
- Chapter 7 *Calculating mechanisms*
- Chapter 8 *Calculating the required reinforcement*
- Chapter 9 *Background theory and assumptions*
- Chapter 10 *Proceeding to a final design*
- Chapter 11 *Comparisons with published results*
- Chapter 12 *Further examples*
- Chapter 13 *Soil Classification System*

Conventions

To help you locate and interpret information easily, the *ReActiv User Manual* uses the following typographical conventions.

This	Represents
Bold	Items on a menu or in a list-box; the text on a button or next to an edit control; or the label of a group box.
Item1 > Item2	An item on a cascading menu. Item1 is the name of an option on the main menu bar (such as File or Window); and Item2 is the name of an option on the cascading menu that appears when you select Item1 (such as New or Open). Thus, File > New represents the New command from the File menu.
<i>italic</i>	<p>Placeholders for information you must provide. For example, if you are asked to type <i>filename</i>, you should type the actual name for a file instead of the word shown in italics.</p> <p>Italic type also signals a new term. An explanation immediately follows the italicized term.</p>
monospaced	Anything you must type on the keyboard.
CAPITALS	Directory names, filenames, and acronyms.
KEY1+KEY2	An instruction to press and hold down key 1 before pressing key 2. For example, "ALT+ESC" means press and hold down the ALT key before pressing the ESC key. Then release both keys.
KEY1, KEY2	An instruction to press and release key 1 before pressing key 2. For example, "ALT, F" means press and release the ALT key before pressing and releasing the F key.

Where to go for help

Your first source of help and information should be this manual and the ReActiv's extensive help system.

ReActiv's help system

ReActiv's help system contains detailed information about all aspects of the program. Help appears in a separate window with its own controls. Help topics that explain how to accomplish a task appear in windows that you can leave displayed while you follow the procedure.

To open the help system:

- Press F1
- Click the **Help** button in any dialog box
- Choose a command from the **Help** menu

If you need assistance with using the help system, choose the **How To Use Help** command from the **Help** menu.

Tooltips

If you pause while passing the mouse pointer over an object, such as a toolbar button, ReActiv displays the name of that object. This feature, called *tooltips*, makes it easier for you to identify what you see and to find what you need.

Technical support

Technical support for ReActiv is available direct from Geocentrix or through your local distributor. If you require technical support, please contact Geocentrix by any of these means:

Voice: +44 (0)1737 373963
Fax: +44 (0)1737 373980
Email: support@geocentrix.co.uk
Web: www.geocentrix.co.uk

Please be at your computer and have your licence number ready when you call.

Alternatively, you can write to the following address:

ReActiv Technical Support
Geocentrix Ltd
Scenic House
54 Wilmot Way
Banstead
Surrey
SM7 2PY
United Kingdom

Please quote your licence number on all correspondence.

Sales and marketing information

For sales and marketing information about ReActiv, please contact ReActiv Sales on the same numbers as above.

Chapter 2

Installing and running ReActiv

ReActiv can be installed to run on most Windows operating systems, but has been tested on Windows XP and Windows 7. Although you can install the software on as many computers as you like, you will only be able to run the program on those computers to which you attach the supplied security key.

Before you begin installing your copy of ReActiv, there are a few things you should check:

- Examine the contents of your ReActiv package to check we have sent you everything listed below
- Make sure you have the necessary hardware and software to run ReActiv

What's in the ReActiv package

The ReActiv package includes the following items:

- *ReActiv User Manual* (this document)
- Geocentrix Software CD
- One security key (dongle) for each copy of the program you have purchased
- Instructions for installing and running your copy of ReActiv

Hardware and software requirements

In order to run ReActiv, you will need the following hardware and software:

- IBM®-compatible PC with an 80386- (or higher) processor
- Microsoft® Windows® XP (or later)
- At least 9Mb free space on your hard disk for a typical installation
- CD-ROM drive
- Any printer supported by Windows
- A mouse or other pointing device supported by Windows

Upgrading from an earlier version of ReActiv

If you are upgrading your copy of ReActiv from an earlier version, you should note the following:

- ReActiv's setup program installs Version 1.7 in a different directory to Versions 1.0, 1.5, and 1.6 and hence will not overwrite your existing copy of ReActiv
- RAV files created in ReActiv 1.0 *cannot* be read by ReActiv 1.7, owing to an internal restructuring of ReActiv's data files
- RAV files created in ReActiv 1.5 and 1.6 can be read by ReActiv 1.7

To install ReActiv

Instructions for installing ReActiv on Windows systems are provided separately to this User Manual. Please refer to those instructions for further details or contact Geocentrix for assistance.

To run ReActiv

From Windows' Start menu, click **All Programs > Geocentrix > ReActiv 1.7**.

Chapter 3 Overview

This chapter of the *ReActiv User Manual* provides an overview of ReActiv. It describes the main features of the program and the most commonly used commands.

ReActiv implements and extends the design method given in the UK Highways Agency's Advice Note HA68 on *Design methods for the reinforcement of highway slopes by reinforced soil and soil nailing techniques* (1994), which can be found in the HA's *Design manual for roads and bridges*, Volume 4 *Geotechnics and drainage*, Section 1 *Earthworks*, Part 4. For brevity, this document is referred to herein as the *Advice Note*. Chapter 9 explains the background theory and assumptions behind the Advice Note.

ReActiv divides the display of information about your reinforced slope problem between three main views:

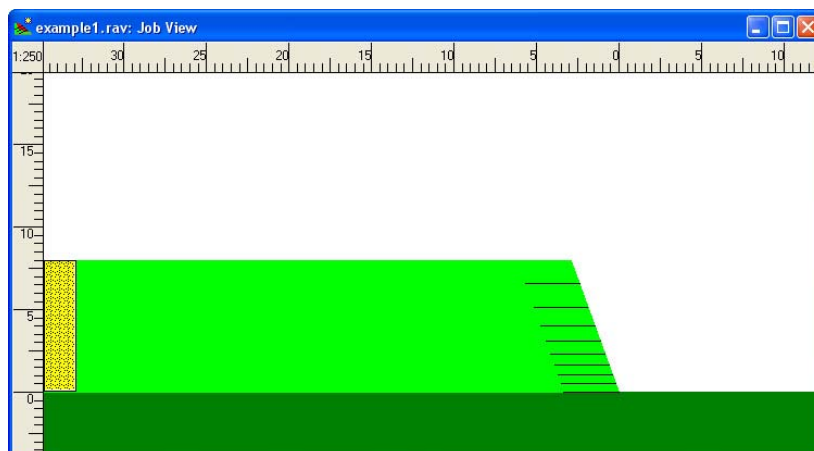
- The *Job View* — allows you to define the problem that you want to analyse
- The *Mechanisms View* — displays the results of calculations using the two-part wedge mechanism
- The *Reinforcement View* — gives a preliminary layout of the reinforcement that will be required

Each of these views is displayed in its own window, which fits inside ReActiv's *Frame Window*. The Frame Window serves as a desktop on which all other views and windows are arranged.

The following sections describe the various views and windows in turn.

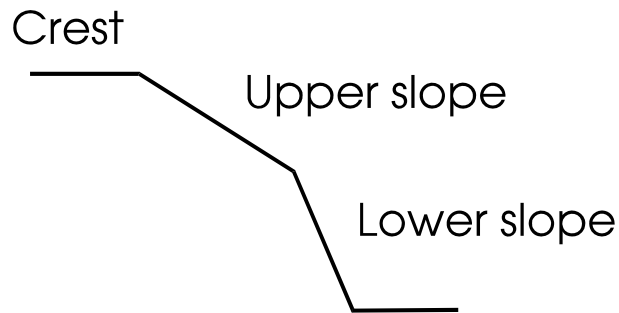
Job View

The Job View is place where you enter information that defines your reinforced slope problem. ReActiv provides you with continuous feedback as you enter this information, by displaying an up-to-date picture of the slope being analysed, including the soil column, water table, and any surcharge applied to the slope.



Slope

The slope is shown at the centre of the Job View and is drawn to a true scale. The names given to various parts of the slope are indicated below.



Soil column



The *Selected Soil* (see page 18) is shown by the soil column near the left hand edge of the Job View. The symbol used to represent the Selected Soil depends on its classification.

The soil column is drawn to a true vertical scale.

Water regime

The slope's water regime is represented by Bishop's pore pressure parameter (r_u). The current value of r_u is displayed underneath the slope's baseline.

Surcharge



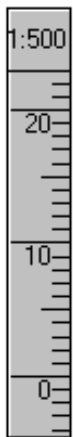
Surcharges are shown by (red) down-pointing arrows. They can be applied to the horizontal crest of *One-* or *Two-part* slopes or to the sloping crest of *Infinite* slopes. They cannot be applied to the lower part of any slope or the upper part of a *Two-part* slope.

The magnitude of the surcharge appears above the surcharge symbol.

Datum line

If the appropriate option on the **View** menu is selected, a datum line is drawn vertically through the toe of the slope. The datum line is coloured grey.

Rulers



Heights above ground level can be measured using the vertical ruler that appears along the left hand edge of the Job View (if the appropriate option on the **View** menu is selected). Similarly, horizontal distances can be measured using the horizontal ruler that appears along the top edge of the Job View.

You can change the scale of the rulers (and hence the size of the drawing in the Job View) by:

- Positioning the mouse pointer over one of the rulers and then clicking the right mouse button. A pop-up menu appears. Choose the scale you want from those listed
- Choosing one of the scales on the **View** menu
- Choosing **Zoom In** or **Zoom Out** on the **View** menu to change the scale to its next level up or down
- Clicking on the **Zoom In** or **Zoom Out** buttons on the Toolbar

The scales that ReActiv provides are:

- 1:50
- 1:100
- 1:250

■ 1:500

Managers

ReActiv's Managers are floating dialog boxes that allow you to add, edit, and delete objects with a minimum of effort. Each Manager displays a list of all the objects of a particular type you have defined. See page 17 for further information about ReActiv's Soil Manager and page 20 for ReActiv's Reinforcement Manager.

Mechanisms View

The Mechanisms View displays the results of your calculations using the two-part wedge mechanism described in Chapter 2.



	Heel X (m)	Heel Y (m)	Angle (deg)	Tension (kN/m)	Notes
1	1.48	0.52	58.8	109.92	Max T in body
2	1.26	0.00	58.3	113.52	Max T along base
3	1.26	0.00	58.3	113.52	Tmax
4	3.39	0.00	62.5	0.00	Tob
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

The purpose of the calculations is to find the largest out-of-balance force that must be resisted by the reinforcement in order to stabilize the slope. ReActiv allows you to calculate:

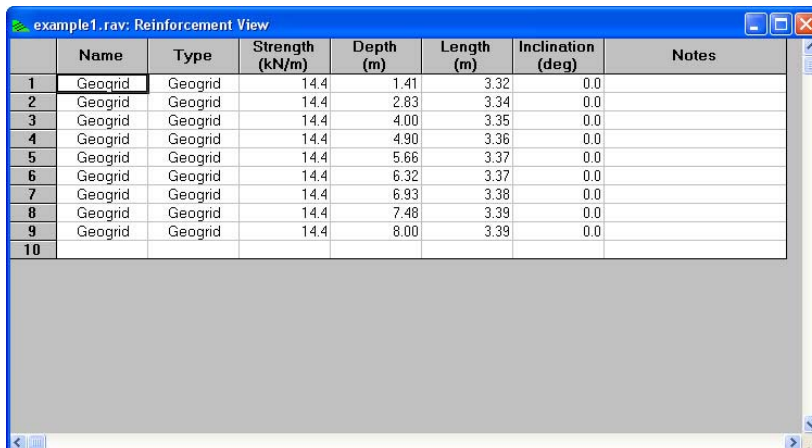
- The out-of-balance force (T) for an individual mechanism
- The largest out-of-balance force for the fan of mechanisms that emanates from each point on a search grid
- The greatest out-of-balance force of any mechanism in the slope (the T_{\max} -mechanism) — see Chapter 7
- The basal mechanism that has an out-of-balance force of zero (the T_{ob} -mechanism) — see Chapter 7

The Mechanisms View displays the results of these calculations in a spreadsheet containing, for each mechanism:

- The X- and Y- coordinate of the mechanism's heel
- The angle of the upper wedge
- The out-of-balance force
- Notes indicating the type of mechanism (see Chapter 7), whether the mechanism is a critical mechanism (see Chapter 7), the T_{\max} or the T_{ob} mechanism
- (Optionally) The type of mechanism (see Chapter 7)

Reinforcement View

The Reinforcement View displays the reinforcement layout required to stabilize the slope.



	Name	Type	Strength (kN/m)	Depth (m)	Length (m)	Inclination (deg)	Notes
1	Geogrid	Geogrid	14.4	1.41	3.32	0.0	
2	Geogrid	Geogrid	14.4	2.83	3.34	0.0	
3	Geogrid	Geogrid	14.4	4.00	3.35	0.0	
4	Geogrid	Geogrid	14.4	4.90	3.36	0.0	
5	Geogrid	Geogrid	14.4	5.66	3.37	0.0	
6	Geogrid	Geogrid	14.4	6.32	3.37	0.0	
7	Geogrid	Geogrid	14.4	6.93	3.38	0.0	
8	Geogrid	Geogrid	14.4	7.48	3.39	0.0	
9	Geogrid	Geogrid	14.4	8.00	3.39	0.0	
10							

The suggested layout is suitable for preliminary design. The procedure for establishing a final design is discussed in Chapter 9.

For each layer of reinforcement in the suggested layout, ReActiv displays:

- The name of the reinforcement
- The reinforcement type (Geotextile, Geogrid, Soil Nails or User-defined)
- The strength of the reinforcement
- The depth of the layer
- The length of the reinforcement
- The reinforcement's inclination
- Notes giving special information relevant to that layer (for example, in the case of soil nails, the horizontal spacing of the nails)

Toolbar

The Toolbar provides mouse-users with quick access to commonly used menu commands.



To find out what each button does, refer to ReActiv's help system or place the mouse pointer over each button in turn and read the tooltip (description) that appears after a short delay.

Status Bar

The Status Bar provides a summary of the key information that you will require when working in each of ReActiv's views.



The Status Bar changes as you move from one view to another and reflects the information that you have entered into the program.

The Status Bar also provides an explanation of menu commands as you scroll through them and descriptions of what the buttons on the Toolbar do as you move the mouse pointer over them.

Soils

ReActiv implements seven types of soil:

- Gravel
- Sand

- Silt
- Clay
- Fill
- Chalk
- Custom

Soil Manager

ReActiv's *Soil Manager* makes it easy to add, edit, and delete soils. The Soil Manager is a floating dialog box that remains on top of all other windows until you choose to close it. The Soil Manager displays the names of every soil that has been created in the current job, and provides buttons that duplicate commands on the **Soil** menu.



If it is not already showing, you can display the Soil Manager by:

- Ticking **View > Soil Manager** on the Job View's menu bar
- Clicking on the Soil Manager button on the Toolbar

You can close the Soil Manager by:

- Unticking **View | Soil Manager** on the Job View's menu bar
- Clicking on the Soil Manager button on the Toolbar
- Choosing the **Close** command from the Soil Manager's control menu

You can move the Soil Manager around the screen in the usual ways, by dragging its title bar with the mouse or by choosing the **Move** command from the Soil Manager's control menu and then using the appropriate cursor keys.

Soil classification system and database

ReActiv uses the information you provide about a soil's classification to check the parameters that you enter via the Soil Properties dialog box.

ReActiv uses the Soil Classification System that was introduced in ReWaRD®, our retaining wall research and design program. The Soil Classification System provides a comprehensive and systematic description of commonly-encountered soil types and is linked to an extensive database of peak and critical state soil parameters.

In the Soil Classification System, each soil is classified according to three main descriptors:

- *Group*
- *Class* (depends on Group)
- *State* (depends on Group and Class)

Chapter 13 lists the various Groups, Classes, and States that ReActiv recognizes and compares them with established soil classification systems.

The selected soil

Although you may define the properties of more than one soil, only one soil is used by the program at any one time. This soil is known as the *Selected Soil*.

You may choose the *Selected Soil* by choosing **Slope | Selected Soil...** from the Job View's menu bar. Select one of the soils listed in the listbox and click the **OK** button, ReActiv re-draws the soil column (if displayed) to reflect the soil you have selected.

Design parameters

When ReActiv performs its calculations, it uses *design* values of the key soil parameters rather than characteristic values. The design value of the soil's angle of shearing resistance (ϕ) is given by:

$$\phi_{design} = \tan^{-1} \left(\frac{\tan \phi}{F_{\phi}} \right)$$

and the design value of the soil's effective cohesion (c') is given by:

$$c'_{design} = \frac{c'}{F_c}$$

If you specify critical state parameters, ReActiv sets the partial factors in these equations to 1.0.

Slopes

ReActiv implements three types of slope:

- One-part
- Two-part
- Infinite

Stability of upper slopes/crests

The upper slope of Two-part slopes and the sloping crest of Infinite slopes are potentially unstable when:

$$\tan i \geq (1 - r_u) \tan \phi$$

where r_u is Bishop's pore pressure parameter, and ϕ is the soil's angle of shearing resistance. The angle i is given by:

- For Two-part slopes, the angle of the upper slope
- For Infinite slopes, the crest angle

ReActiv checks for potential instability of the upper slope or sloping crest when it validates the parameters you enter into the slope's property box. However, even if the slope is unstable, ReActiv allows you calculate the reinforcement required to stabilize the *lower* slope on the assumption that you will analyse the stability of the upper slope/sloping crest as a separate exercise. If you do this using ReActiv, then

you should treat the reinforced lower slope as a competent foundation to the upper slope/sloping crest.

Water regimes

ReActiv implements four types of water regime:

- Parallel
- Horizontal
- Parabolic
- Custom

For water regimes other than custom, ReActiv calculates Bishop's pore pressure parameter (r_u) for you, using the formula given by Mitchell (1983), *Earth structures engineering*, Allen & Unwin Inc., Boston, p128.

Parallel water regime

For parallel water regimes, Bishop's pore pressure parameter (r_u) is given by:

$$r_u = \left(\frac{\gamma_w}{\gamma} \right) \cos^2 \beta$$

where γ_w is the unit weight of water; γ is the unit weight of the *selected soil* (see page 18); and β is the angle of the lower slope.

Horizontal water regime

For horizontal water regimes, Bishop's pore pressure parameter (r_u) is given by:

$$r_u = \left(\frac{\gamma_w}{\gamma} \right)$$

where γ_w and γ are defined above.

Parabolic water regime

For parabolic water regimes, Bishop's pore pressure parameter (r_u) is given by:

$$r_u = \left(\frac{\gamma_w}{\gamma} \right) \cos \beta$$

where γ_w , γ , and β are defined above.

Reinforcements

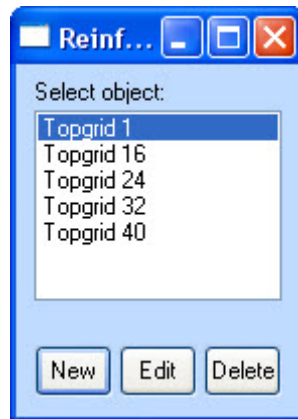
ReActiv implements four types of reinforcement:

- Geotextiles
- Geogrids
- Soil nails
- Custom

Reinforcement Manager

ReActiv's *Reinforcement Manager* makes it easy to add, edit, and delete

reinforcements. The Reinforcement Manager is a floating dialog box that remains on top of all other windows until you choose to close it. The Reinforcement Manager displays the names of every reinforcement that has been created in the current job.



If it is not already showing, you can display the Reinforcement Manager by:

- Ticking **View > Reinforcement Manager** on the Job View's menu bar
- Clicking on the Reinforcement Manager button on the Toolbar

You can close the Reinforcement Manager by:

- Unticking **View > Reinforcement Manager** on the Job View's menu bar
- Clicking on the Reinforcement Manager button on the Toolbar
- Choosing the **Close** command from the Reinforcement Manager's control menu

Design strength

The design strength (P_{des}) that you enter into ReActiv is the long-term factored design strength of the reinforcement per unit width of slope (in kN/m).

According to the Advice Note, the design strength should be derived from the *unfactored* long-term characteristic strength of the reinforcement (P_c) by applying a set of partial safety factors as follows:

$$P_{design} = \frac{P_c}{f_d f_e f_m}$$

where f_d is a factor-of-safety against mechanical damage before and during installation; f_e is a factor-of-safety against environmental (chemical and biological) effects during the reinforcement's design life; and f_m is a factor-of-safety to cover uncertainties in material strength (including extrapolation of data).

Values for P_c , f_d , f_e , and f_m may be taken from the BBA certificate or manufacturer's literature for the reinforcement.

Further guidance is available in the CIRIA Special Publication 123, *Soil reinforcement with geotextiles*, by RA Jewell (1996).

Design factors

ReActiv requires you to specify certain *design factors* that govern the base-sliding and pullout resistance of the reinforcement. The *direct-shear factor* is used in calculations which involve sliding of soil over the surface of the reinforcement, whereas the

bearing factor is used in calculations involving local bearing failure on the ribs of geogrids or custom reinforcement.

Geotextiles

ReActiv uses the direct-shear factor to calculate the resistance that a geotextile provides against base-sliding and also — since pullout failure of a geotextile involves sliding along both its sides — its pullout resistance.

Geogrids

ReActiv uses the direct-shear factor to calculate the resistance that a geogrid provides against base-sliding.

Since pullout failure of a geogrid involves local bearing failure on the front edges of its ribs, ReActiv uses the bearing factor — and not the direct-shear factor — to calculate a geogrid's pullout resistance.

Soil nails

ReActiv uses the direct-shear factor to calculate the resistance that soil nails provide against base-sliding and also — since pullout failure of soil nails involves sliding along their circumference — their pullout resistance.

Custom reinforcement

Since you may want to specify certain types of geogrid as custom reinforcement (perhaps to get around ReActiv's validation checks), ReActiv uses the bearing factor — and not the direct-shear factor — to calculate the pullout resistance of custom reinforcement. This allows you to control the base-sliding and pullout calculations independently of each other.

Calculation options

Interwedge friction factor

The angle of friction (ϕ_{12}) that acts on the boundary between Wedges 1 and 2 (see Chapter 9) is given by:

$$\phi_{12} = f_{iwf} \phi_{soil}$$

where ϕ is the angle of shearing resistance of the soil and f_{iwf} is the *interwedge friction factor*. ReActiv allows you to enter interwedge friction factors between 0 and 1.

Setting $f_{iwf} = 0$ leads to conservative designs but has the advantage that the equations used to calculate the out-of-balance force can be simplified, thereby eliminating the need to decide on which wedge the reinforcement force acts (see Chapter 9 for further discussion of this point).

When you want to minimize the conservatism in your design, you can enter a non-zero value of f_{iwf} . The out-of-balance force then depends on which wedge the reinforcement force acts (see Chapter 9).

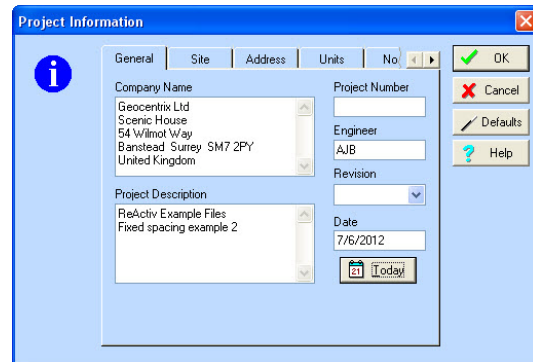
Setting $f_{iwf} = 0.5$ and assuming that all the reinforcement force acts on Wedge 2 provides a reasonable upper bound to results obtained using Caquot and Kerisel's charts and other methods (see Chapter 11). The agreement is less reasonable for small slope angles.

Project information

ReActiv allows you to store project information in each file, so that you can keep a record of the purpose and progress of your calculations.

The Project Information dialog box provides controls for entering your company's name and address, the project description and number, the engineer's initials, a revision letter and date, and notes about the current job.

Choose **Edit > Project Info...** to display the Project Information box.



Printing

ReActiv allows you to print your input and output data on a wide variety of printers and to obtain a preview of the printout on your computer screen.

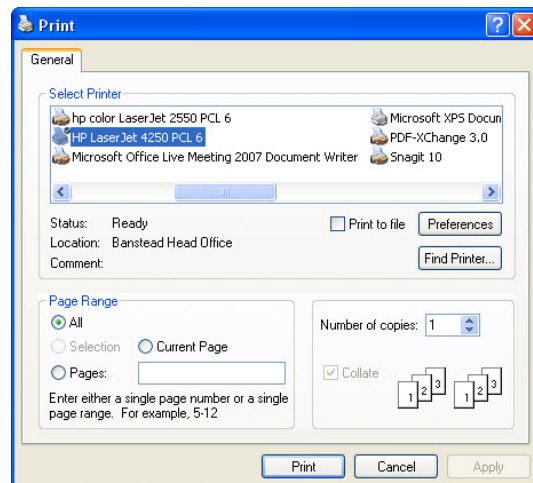
Print

The Print dialog box allows you to select various options for controlling what gets printed and where it gets printed.

You can display the Print dialog box by:

- Choosing **File > Print...** from the menu bar
- Clicking on the Print button on the Button Bar

The currently selected printer is displayed at the top of the dialog box. You can change the properties of the printer by choosing the **Properties...** button.

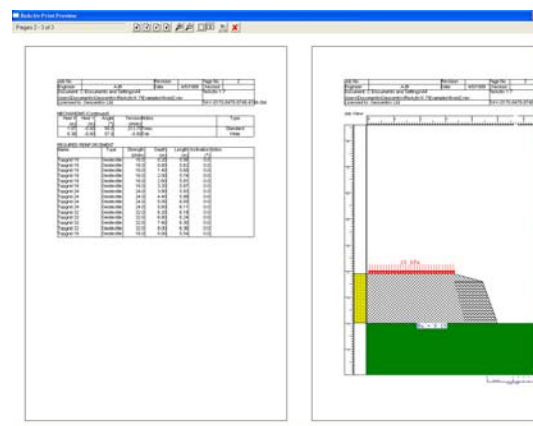


Print preview

ReActiv provides a print preview facility, which allows you to see what will appear on the printed page. This preview facility is extremely useful if you only want to print a part of your input or output data, since it allows you to find out on which page the required data will appear.

You can display the Print Preview window by:

- Choosing **File > Print Preview...** from the menu bar
- Clicking on the Print Preview button on the Button Bar



Customizing the program

You can customize many of the default parameters that ReActiv provides in each dialog box, by holding down the CTRL key and then clicking on the **Defaults** button. ReActiv saves the values given in the dialog box in Windows' Registry, for later recall.

For further information, consult ReActiv's help system.

Chapter 4

Tutorial 1: embankment in dense sand

This chapter shows you how to determine the most critical mechanism in the slope and how to calculate the depth, length, and spacing of the reinforcement needed to stabilize that slope. The *Tutorial* assumes you have no prior knowledge of ReActiv, so takes you step-by-step through setting up and solving this problem.

The chapter shows you how to set up a simple project in in ReActiv, calculate the T_{\max} and T_{ob} mechanisms, determine the required reinforcement, and print the results of your calculations.

The worked example described in this chapter is identical to Example 1 in Appendix J of the UK Highways Agency's Advice Note (see pages J/1 to J/2). If you have a copy of the Advice Note, you may find it helpful to read the relevant pages before working through this chapter.

Embankment in dense sand

The worked example comprises an 8m high slope in dense sand, which is to be reinforced by horizontal geogrids so that it may stand at 70° to the horizontal. The sand has an angle of friction of 35° and a bulk density of 20kN/m^3 . These are design values rather than peak values, hence they should be used with partial safety factors of 1.0.

The reinforcement has a characteristic strength of 20kN/m but, after applying various factors-of-safety, that strength is reduced to 14.4kN/m for design purposes. There is no surcharge at the top of the slope.

The geogrid's bearing factor (α') is 0.95 and its interface sliding factor (α) is 0.8. See sections 2.33 and 2.23 of the Advice Note for the definition of these parameters. Note also that ReActiv uses different terms and symbols for these parameters: the bearing factor is given the symbol f_b and the interface sliding factor is given the symbol f_{ds} and is called the *direct shear factor*.

Creating a project

The instructions that follow describe how you might define this worked example in ReActiv.

Running the program



If ReActiv is not already running, start the program as described on page 12. ReActiv's title screen appears and, after a few moments, is replaced by the program's main window (the *Frame Window*) and the Job View, with the words "Untitled: Job View" in its caption bar. The Job View is where you will enter the data that defines the reinforced slope you want to analyse.

Defining the soil

The first task in defining a new project is to create the soil that makes up the slope.

Creating a new soil

To create a new soil, choose **Insert > Soil > Sand...** from the Job View's menu bar. ReActiv creates the new soil and displays its property box.

Soil properties

The soil properties box is where you enter the angle of shearing resistance, effective cohesion, and bulk density of the soil. Here you will also find a button that takes you to the soil's classification box, where you can enter the soil's engineering description (which ReActiv uses to validate the parameters you enter).

To display the soil classification box, click on the **Classification...** button.

Classifying the soil

ReActiv includes an extensive database of soil properties which is linked to Geocentrix's Soil Classification System (see Chapter 13). By classifying a soil, you allow ReActiv to validate the parameters you enter for it and hence catch any errors made during data entry.

The Soil Classification box lists the relevant classes and states for the soil type you have created. In this instance, the Soil Classification box lists the various classes and states for sand, as shown below.

For this worked example, leave the sand's class as Unclassified but set its state to Dense.

Type a name for the soil in the Name edit box (e.g. "Dense Sand") and then click **OK**. You are returned to the Soil Properties box.

Entering soil properties

Select the **Critical State** button. This tells ReActiv that the strength parameters that you are going to enter for this soil will be critical state (i.e. large displacement) values. The two Factor of Safety boxes are filled with the value 1 and are disabled.

Click the **Defaults** button. The various edit boxes are filled with default parameters for a dense sand (since that is the classification you gave this soil in the previous step). Change the soil's angle of friction from 32 to 35° and its unit weight from 20.348kN/m³ to 20kN/m³. Leave the effective cohesion unchanged as 0kN/m².

Note also that the soil's density changes automatically (to 2039.4kg/m³) when you change the unit weight.

Click **OK** to confirm the values. You are returned to the Job View. Note that several commands on the Job View's Slope menu are now enabled.

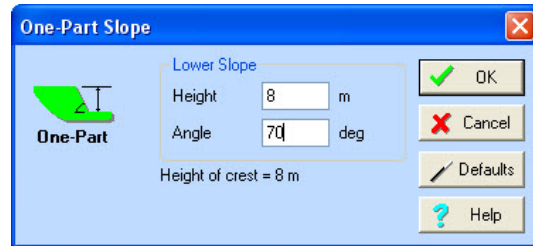
You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 1\STEP1.RAV

Defining the slope

To define the geometry of the slope, choose **Insert > Slope > One-Part...** from the Job View's menu bar. The following property box appears.

Change the Lower Slope **Height** to 8m and the Lower Slope **Angle** to 70°.



Click **OK** to confirm the data entered. When you are returned to the Job View, ReActiv draws the slope with a soil column on its left hand side.

The **Insert > Water Regime** sub-menu and **Edit > Surcharge...** command are now enabled. However, you still can't use any of the commands on the Calculate menu until you have specified the reinforcement to be used.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 1\STEP2.RAV

Viewing the slope

You may want to change the scale at which the slope is drawn in the Job View, in order to see it more clearly. You can change the scale in a number of ways, by:

- Choosing one of the scales on the View menu
- Choosing **Zoom In** or **Zoom Out** on the View menu to change the scale to its next level up or down
- Positioning the mouse pointer over one of the rulers and clicking the right mouse button. A pop-up menu appears, from which you can choose the scale you want
- Clicking on the **Zoom In** or **Zoom Out** buttons on the Button Bar to change the scale to its next level up or down

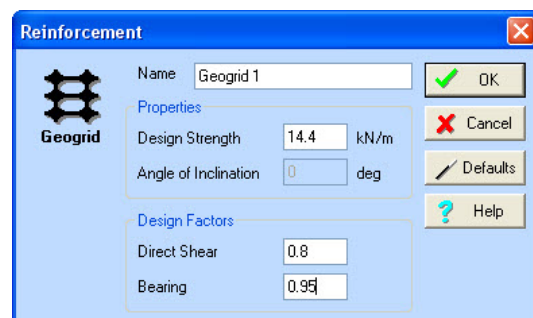
For this example, the best scale is probably 1:100 (provided the Job View is maximized — if not, click on the Frame Window's maximize button *and* the Job View's maximize button to rectify this). Position the mouse pointer over one of the rulers and click the right button. A pop-up menu appears. Choose the scale 1:100. The slope and the soil column are re-drawn at the new scale.

Since this example does not involve a water regime or a surcharge, the next task is to define the reinforcement.

Defining the reinforcement

To define the reinforcement, choose **Insert > Reinforcement > Geogrid...** from the Job View's menu bar. The following property box appears.

Type a name for the reinforcement (e.g. "Geogrid 1") and change the **Design Strength** to 14.4kN/m, the **Direct Shear** factor to 0.8, and the **Bearing** factor to 0.95. The **Angle of Inclination** box is disabled.



Click **OK** to confirm the values you have entered. This time when you return to the Job View, the commands on the Calculate menu are enabled. ReActiv now has enough information to calculate the required reinforcement.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 1\STEP3.RAV

Calculating the reinforcement

To calculate the reinforcement layers required to stabilize the slope as well as the T_{\max} and T_{ob} mechanisms, choose **Calculate > Calculate All** from the Job View's menu bar or click on the **Calculate All** button on the Toolbar.

ReActiv performs a series of calculations that culminate in the required reinforcement being displayed in its Reinforcement View. The steps involved are:

1. The program searches for the T_{\max} and T_{ob} mechanisms
2. It then calculates the required reinforcement
3. Finally, it displays the results in its three main views

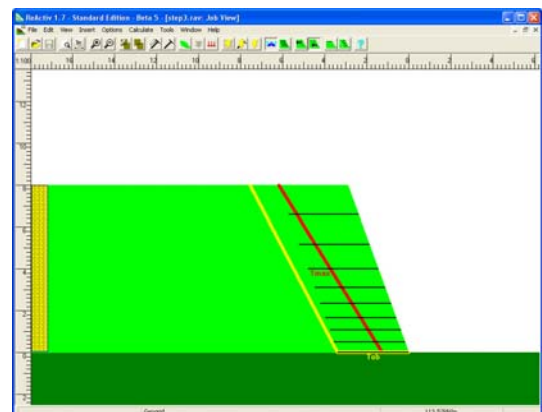
ReActiv performs these steps automatically, so that you get the solution to your problem with the least possible effort and in the quickest possible time.

Reviewing the results

ReActiv draws the required reinforcement layers on top of the picture of the slope in the Job View. To bring the Job View to the front of the display, either click on it or choose the appropriate command from the **Window** menu (labelled **Job View**). You will find it easier to study the contents of the Job View if you maximize its window.

You can also display the T_{\max} and T_{ob} mechanisms in the Job View by:

- Selecting the appropriate commands on the Job Views' **View** menu
- Positioning the mouse pointer anywhere in the Job View and clicking the right mouse button. A pop-up menu appears. Click **Tmax** and **Tob** to display the T_{\max} and T_{ob} mechanisms (respectively)



When you have selected all these options, the Job View looks something like the screenshot shown above.

Reviewing the reinforcement layout

You can review the required reinforcement by inspecting the contents of the Reinforcement View. To bring the Reinforcement View to the front of the display, either click on it or choose the appropriate command from the **Window** menu (labelled **Reinforcement View**). You

	Name	Type	Strength (kN/m)	Depth (m)	Length (m)	Inclination (deg)	Notes
1	Geogrid 1	Geogrid	14.4	1.41	3.32	0.0	
2	Geogrid 1	Geogrid	14.4	2.83	3.34	0.0	
3	Geogrid 1	Geogrid	14.4	4.00	3.35	0.0	
4	Geogrid 1	Geogrid	14.4	4.90	3.36	0.0	
5	Geogrid 1	Geogrid	14.4	5.65	3.37	0.0	
6	Geogrid 1	Geogrid	14.4	6.32	3.37	0.0	
7	Geogrid 1	Geogrid	14.4	6.93	3.38	0.0	
8	Geogrid 1	Geogrid	14.4	7.48	3.39	0.0	
9	Geogrid 1	Geogrid	14.4	8.00	3.39	0.0	
10							

will find it easier to read the contents of the Reinforcement View if you maximize its window.

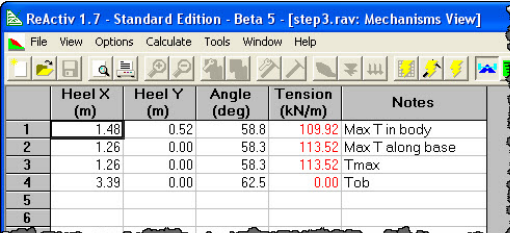
According to ReActiv, the slope being analysed requires nine layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

- Layer 1 at 1.41m
- Layer 2 at 2.83m
- Layer 3 at 4.00m
- Layer 4 at 4.90m
- Layer 5 at 5.66m
- Layer 6 at 6.32m
- Layer 7 at 6.93m
- Layer 8 at 7.48m
- Layer 9 at 8.00m

These depths are identical to those given in the Advice Note. The required length of the layers varies from 3.32m at the top to 3.39m at the bottom.

Reviewing the mechanisms

You can review the results of the searches for the T_{\max} and T_{ob} mechanisms by inspecting the contents of the Mechanisms View. To bring the Mechanisms View to the front of the display, either click on it or choose the appropriate command from the **Window** menu (labelled **Mechanisms View**). You will find it easier to read the contents of the Reinforcement View if you maximize its window.



	Heel X (m)	Heel Y (m)	Angle (deg)	Tension (kN/m)	Notes
1	1.48	0.52	58.8	109.92	Max T in body
2	1.26	0.00	58.3	113.52	Max T along base
3	1.26	0.00	58.3	113.52	Tmax
4	3.39	0.00	62.5	0.00	Tob
5					
6					

According to ReActiv, the mechanism with the largest out-of-balance force anywhere in the slope (i.e. the T_{\max} mechanism) has the following properties:

- $X = 1.26\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 58.3^\circ$, $T = 113.52\text{kN/m}$

These values are in close agreement with the results given in the Advice Note.

The critical mechanism that requires exactly zero reinforcement to be stable (i.e. the T_{ob} mechanism) has the following properties:

- $X = 3.39\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 62.5^\circ$, $T = 0.00\text{kN/m}$

The X-value is in close agreement with the length L_B given in the Advice Note.

The Notes column of the Mechanisms View indicates which mechanism is which and also gives additional information about the T_{\max} mechanism. The word "Baseline" indicates that the T_{\max} mechanism occurred along the slope's *baseline* rather than in the body of the slope. Refer to the page 43 for a full explanation of these terms.

Clearing the results

Although it is automatically done when you perform a new calculation, you can clear the results of the current calculation at any time by choosing **Calculate > Clear Results...** from the menu bar.

Printing the results

When you are happy with the results of your calculations, you will want to obtain a print-out of those results and the corresponding input data. ReActiv uses printer drivers supplied and supported by Microsoft Windows — so you should have no difficulty obtaining high-quality output from ReActiv.

ReActiv allows you to print your input and output data by choosing the **File > Print...** command from the menu bar. ReActiv prints the input data in the following order:

- Project information
- Soils
- Reinforcements
- Slope
- Water regime
- Surcharge
- Options

and the output data in this order:

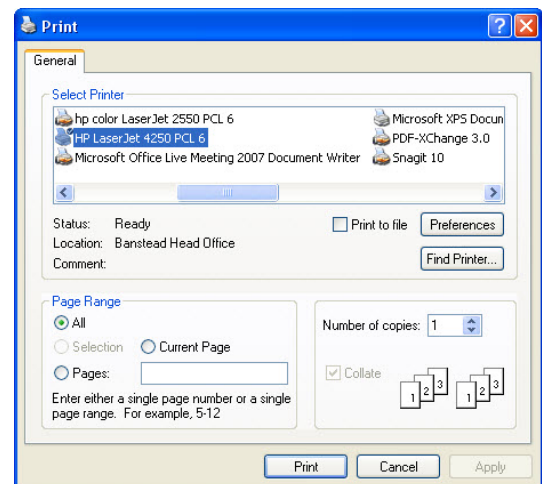
- Mechanisms
- Required reinforcement
- Job View picture

Controlling the printer

The Print dialog box allows you to select various options for controlling what gets printed and where it gets printed. You can display the Print dialog box by:

- Choosing **File | Print...** from the menu bar
- Clicking on the **Print** button on the Button Bar

The currently selected printer is shown highlighted.



Select one of the buttons in the **Page Range** panel, according to whether you want to print **All** the available pages or only certain **Pages** (as specified in the box alongside). You can find out what will be printed on each page by choosing **Print Preview** from the menu bar.

Click **Print** when you are ready to print.

You will find a copy of the project in its final form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 1\TUTORIAL1.RAV

Chapter 5

Tutorial 2: cutting in stiff clay

This chapter describes how you might go about solving a more complicated reinforced slope problem using ReActiv. It assumes that you have already been through Tutorial 1 and that you are familiar with the basic layout of ReActiv, as described in Chapter 3.

The worked example described in this chapter is identical to Example 3 in Appendix J of the Advice Note (see pages J/5 to J/7). If you have a copy of the Advice Note, you may find it helpful to read the relevant pages before working through this chapter.

Cutting in stiff clay

The worked example comprises a 6m high cutting in stiff clay, which is to be reinforced by soil nails so that it may stand at 70° to the horizontal. The clay has an angle of shearing resistance of 20° , effective cohesion of 0kN/m^2 , and a bulk density of 20kN/m^3 . The reinforcement has a design strength of 41.8kN/m after applying various factors-of-safety to it. Bishop's pore pressure parameter for the slope (r_u) is 0.15. There is no surcharge at the top of the slope.

The 16mm diameter soil nails are inclined at 10° to the horizontal, and are spaced at 1m intervals horizontally. The holes into which they are installed and grouted are 150mm in diameter. The nails' interface sliding factor (α) is 0.9. See section 2.23 of the Advice Note for the definition of these parameters, which in ReActiv is given the symbol f_{ds} and is called the *direct shear factor*.

Creating the document

The instructions that follow describe how you might define this worked example in ReActiv.

Running the program



If ReActiv is not already running, start the program as described on page 12. ReActiv's title screen appears and, after a few moments, is replaced by the program's main window, its *Frame Window*.

Creating a new project

To create a new project, choose **File > New** from the program's menu bar or click on the **File New** button on the menu bar. Answer **No** to the question about saving the current document (unless you want to save it, in which case answer **Yes**).

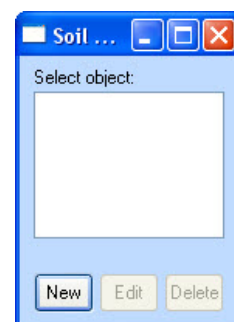
When you do this, ReActiv creates a new window with the words "Untitled: Job View" in its caption bar. This is the new project's Job View, where you will enter the data that defines the reinforced slope that you want to analyse.

Defining soil properties

The first task in defining the new project is to create the soil that defines the properties of the slope.

Using the Soil Manager

In this worked example, you will create the new soil using ReActiv's Soil Manager. To display the Soil Manager, tick **View > Soil Manager** on the Job View's menu bar or click on the

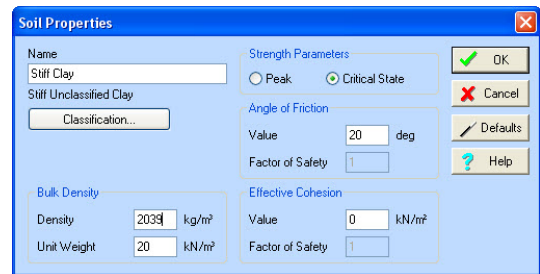


appropriate **Soil Manager** button on the Toolbar. The Soil Manager appears.

Creating the new soil

To create a new soil from the Soil Manager, click the **New** button. A dialog box appears.

Select **Clay** and click **OK** (or double-click on **Clay**). ReActiv creates the new soil and then displays the Soil Properties dialog box.



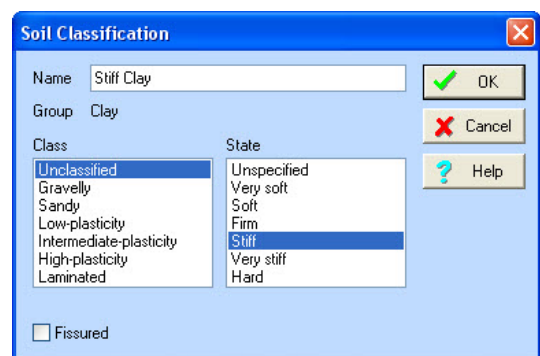
The **Soil Properties** dialog box is shown. It has a blue title bar and a light blue background. The **Name** field contains "Stiff Clay". Below it, there are two radio buttons: **Peak** (unselected) and **Critical State** (selected). To the right of these are **OK**, **Cancel**, **Defaults**, and **Help** buttons. The **Angle of Friction** section has a **Value** of 20 and a unit of **deg**, and a **Factor of Safety** of 1. The **Effective Cohesion** section has a **Value** of 0 and a unit of **kN/m²**, and a **Factor of Safety** of 1. The **Bulk Density** section has a **Density** of 2039 **kg/m³** and a **Unit Weight** of 20 **kN/m³**. There is a **Classification...** button.

Click on the **Classification...** button to display the soil's classification box.

Classifying the soil

The Soil Classification box lists the relevant classes and states for the soil type you have created. In this instance, the box lists the various classes and states for clay, as shown below.

For this worked example, leave the clay's class as **Unclassified** but set its state to **Stiff**.



The **Soil Classification** dialog box is shown. It has a blue title bar and a light blue background. The **Name** field contains "Stiff Clay". Below it, the **Group** is set to "Clay". There are two columns: **Class** and **State**. The **Class** column lists: **Unclassified** (selected), **Gravelly**, **Sandy**, **Low-plasticity**, **Intermediate-plasticity**, **High-plasticity**, and **Laminated**. The **State** column lists: **Unspecified**, **Very soft**, **Soft**, **Firm**, **Stiff** (selected), **Very stiff**, and **Hard**. There is a **Fissured** checkbox at the bottom left. To the right are **OK**, **Cancel**, and **Help** buttons.

Type a name for the soil in the **Name** edit box (e.g. "Stiff Clay") and then click **OK**. You are returned to the Soil Properties box.

Entering soil properties

The Soil Properties box is where you enter the angle of shearing resistance, effective cohesion, and bulk density of the soil.

Select the **Critical State** button. This tells ReActiv that the strength parameters that you are going to enter for this soil will be critical state (i.e. large displacement) values. The two **Factor of Safety** boxes are filled with the value 1 and are disabled.

Click the **Defaults** button. The various edit boxes are filled with default parameters for a stiff clay (since that is the classification you gave this soil in the previous step). Change the soil's effective cohesion from 2 to 0kN/m² and its unit weight from 20.103kN/m³ to 20kN/m³.

Click **OK** to confirm the values. You are returned to the Soil Manager, which now displays the name of the newly created soil. Close the Soil Manager by unticking **View > Soil Manager** on the Job's View menu bar. Your next task is to define the slope.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP1.RAV

Defining the slope

To define the slope, choose **Insert > Slope > One-part...** from the Job View's menu

bar or click on the **Slope** button on the Toolbar. A dialog box appears.

Change the Lower Slope **Height** to 6m and the Lower Slope **Angle** to 70°.

Click **OK** to confirm the data entered into the Slope box. This time, when you are returned to the Job View, ReActiv draws the slope and (provided the option is set on the **View** menu) displays a soil column on the left hand side of the slope.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP2.RAV

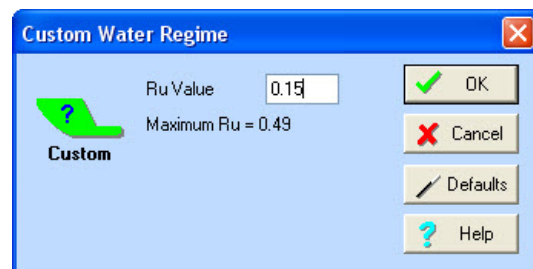
Viewing the slope

For this example, the best scale is probably 1:100 (provided the Job View is maximized — if not, maximize the Job View). Position the mouse pointer over one of the rulers and click the right button. A pop-up menu appears. Choose the scale **1:100**. The slope and the soil column are re-drawn at the new scale.

The next task is to define the water regime.

Defining the water regime

To define the water regime, choose **Insert > Water Regime > Custom...** from the Job View's menu bar. The following dialog box appears.



Change **Ru** to 0.15 and click **OK** to confirm the data entered. When you are returned to the Job View, ReActiv displays the r_u value underneath the slope.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

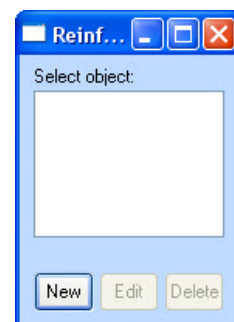
GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP3.RAV

Since this worked example does not involve a surcharge, the next task is to define the reinforcement.

Defining the reinforcement

Using the Reinforcement Manager

In this worked example, you will create the reinforcement using ReActiv's Reinforcement Manager. To display the Manager, tick **View > Reinforcement Manager** on the Job Views' menu bar or click on the **Reinforcement Manager** button on the Toolbar. The Reinforcement Manager appears.

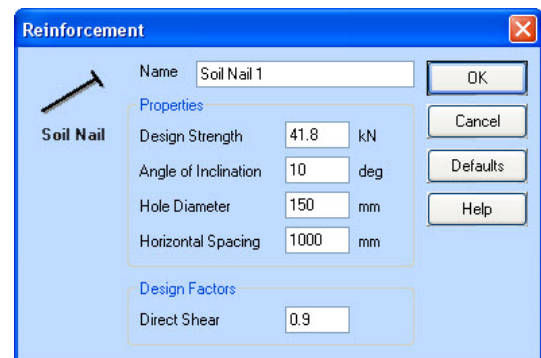


Creating the new reinforcement

To create a new reinforcement from the Reinforcement Manager, click the **New** button. A dialog box appears.

Select Soil Nails from the list and click **OK** to confirm. The following dialog box appears.

The Reinforcement box is where you specify the properties of the reinforcement. Type a name for the reinforcement (e.g. "Soil Nail") and change the **Design Strength** to 41.8kN/m, the **Angle of Inclination** to 10°, the **Hole Diameter** to 150mm, the **Horizontal Spacing** to 1000mm, the **Direct Shear** factor to 0.9.



Click **OK** to confirm the values you have entered. You are returned to the Reinforcement Manager, which now displays the name of the newly created reinforcement. Close the Manager by clicking on the appropriate **Reinforcement Manager** button on the Toolbar.

This time when you return to the Job View, the commands on the **Calculate** menu are enabled. ReActiv now has enough information to calculate the required reinforcement.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP4.RAV

Calculating the reinforcement

In this worked example, you will calculate the required reinforcement manually, step-by-step, rather than use ReActiv's automatic calculation feature. The steps involved in calculating the required reinforcement are:

- First, search for the T_{max} mechanism
- Second, search for the T_{ob} mechanism
- Finally, calculate the required reinforcement

Searching for the T_{max} mechanism

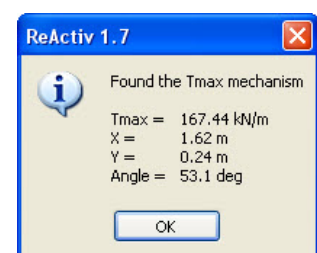
To search for the T_{max} mechanism, choose **Calculate > Tmax** from the Job View's menu bar.

ReActiv performs two separate searches:

- The first for the mechanism with the greatest out-of-balance force anywhere in the body of the slope
- The second for the mechanism with the greatest out-of-balance force anywhere along the baseline of the slope

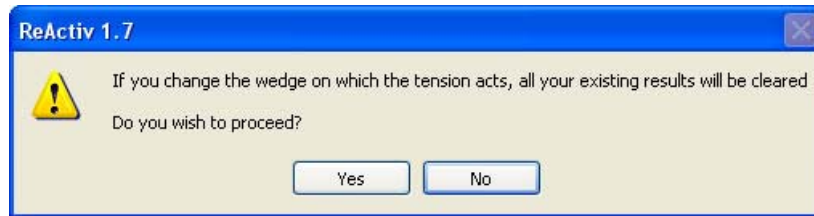
ReActiv keeps you fully informed as to the progress of these calculations and, when it has finished, displays a dialog box giving you the more critical of the two mechanisms that it has found in its searches.

These values differ from the results given in the Advice Note, because by default ReActiv applies all the reinforcement force to Wedge 2 (the lower wedge),



whereas in the Advice Note the reinforcement force is applied to Wedge 1 (the upper wedge).

To reproduce the results given in the Advice Note, first click on the **OK** button to return to the Mechanisms View and then choose **Options > Tension On Wedge 1** from the Mechanisms View's menu bar or click on the **Tension on Wedge 1** button on the Toolbar. The following message box appears:



Click **Yes** to proceed and then repeat the calculation of T_{max} by choosing **Calculate > Tmax** from the menu bar. When it has completed the calculation, ReActiv displays a dialog box giving you the new result:

- $X = 1.54\text{m}$
- $Y = -0.27\text{m}$
- $\theta_1 = 59.2^\circ$
- $T = 207.90\text{kN/m}$

These values are in close agreement with the results given in the **Advice Note**.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP5.RAV

Searching for the T_{ob} mechanism

To search for the T_{ob} mechanism, choose **Calculate > Tob** from the Job View's menu bar. ReActiv performs two separate searches:

- The first for the mechanism with the greatest out-of-balance force anywhere along the baseline of the slope
- The second for the baseline mechanism that has an out-of-balance force of exactly zero

The result of the first search is used as a "seed" for the start of the second search.

ReActiv keeps you informed as to the progress of these calculations and, when it has finished, displays a dialog box giving you the result of its search for T_{ob} .

The X-value is the same as the length L_B given in the Advice Note.

When you click the **OK** button, you are returned to the Mechanisms View, which displays the result of the calculation.



Calculating the required reinforcement

Now that you have calculated T_{max} and T_{ob} , you can proceed to calculate the required reinforcement. To do so, choose **Calculate > Reinforcement** from the menu

bar or click on the **Calculate Reinforcement** button on the Toolbar.

ReActiv creates the Reinforcement View and then uses the results of the T_{\max} and T_{ob} calculations to determine the required number of reinforcement layers and their optimum spacing. It then displays the required reinforcement in the Reinforcement View.

According to ReActiv, the slope being analysed requires six layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

- Layer 1 at 1.34m
- Layer 2 at 2.68m
- Layer 3 at 3.79m
- Layer 4 at 4.65m
- Layer 5 at 5.37m
- Layer 6 at 6.00m

The length of the first layer of reinforcement is 10.05m.

Reducing the nail lengths

The Advice Note describes a method of reducing the required length of soil nails by reducing the horizontal spacing of the first row of nails and determining the layout of the other layers based on the length of the second row. A discussion of this is given in paragraphs 4.20-4.22 of the Advice Note.

To take advantage of this alternative method of calculating the required reinforcement, choose **Options > Reduce Nail Lengths** from the menu bar. Then choose **Calculate > Calculate All** to re-calculate the required reinforcement based on the alternative method and display the results in the Reinforcement View.

According to ReActiv, the length of the top row of soil nails may be reduced to 8.36m (a saving of 1.69m) provided its horizontal spacing is reduced to 775mm. The lengths of the other layers of reinforcement are reduced as well.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

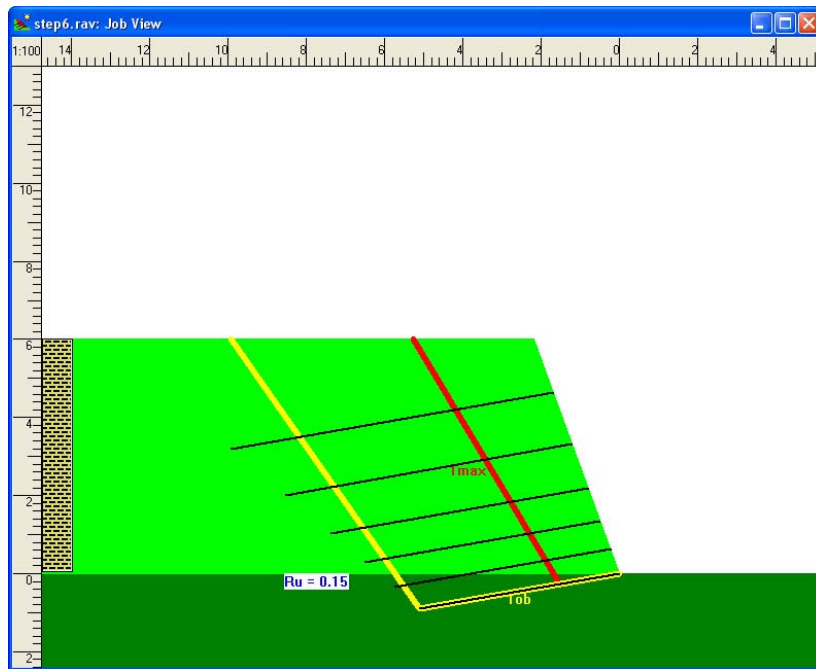
GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\STEP6.RAV

Visualizing the layout

You can view the calculated reinforcement layers in the Job View as well as the Reinforcement View. To bring the Job View to the front of the display, either click on it or choose the appropriate command from the **Window** menu (labelled **Job View**).

You can also display the T_{\max} and T_{ob} mechanisms in the Job View by selecting the appropriate commands on the **View** menu.

When you have selected all these options, the Job View looks something like this:



You will find a copy of the project in its final form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 2\TUTORIAL2.RAV

Chapter 6

Tutorial 3: fixed vertical spacings

This chapter shows you how to optimize your reinforced slope designs using ReActiv. It assumes that you have already been through tutorials 1 and 2 (as described in Chapters 4 and 5).

The worked example described in this chapter uses reinforcement layers at a fixed vertical spacing to reinforce a two-part slope. First, a library of available reinforcement is entered into the program and then ReActiv is left to choose which reinforcement to use at each depth in the slope.

Fixed vertical spacings

The worked example comprises a 9.5 m high slope in sand, which will be reinforced by horizontal geogrids. The lower part of the slope has an inclination of 70° and height of 8m, while the upper part has an inclination of 15° and height of 1.5m. The sand has an angle of shearing resistance of 32° , zero effective cohesion, and a bulk density of 20kN/m^3 . These parameters are critical state values and hence should be used with partial safety factors of 1. Bishop's pore pressure parameter for the slope (r_u) is 0.15. There is a 10kPa surcharge at the top of the slope.

Five different types of geogrid are available with the following strengths: 1, 16, 24, 32, and 40 kN/m. The geogrids will be placed at a constant vertical spacing of 600mm. The geogrids' bearing factors and direct shear factors are all 0.8. The interwedge friction factor is 0.25.

Creating the project

The instructions that follow describe how you use ReActiv's fixed vertical spacing feature. The tutorial illustrates various short-cuts that can be used to speed up your use of the program.

Running the program



If ReActiv is not already running, start the program as described on page 12. ReActiv's title screen appears and, after a few moments, is replaced by the program's main window, its *Frame Window*.

Creating a new project

To create a new project, click on the **New** button on the Toolbar. Answer **No** to the question about saving the current document (unless you want to save it, in which case answer **Yes**).

Defining soil properties

The first task is to create the soil that forms the two-part slope.

In this worked example, you will create the new soil through the pull-down menus. Choose **Insert > Soil > Sand...** from the Job View's menu bar.

Type a name for the soil in the **Name** edit box (e.g. "Sand"). Select the **Critical State** button and enter the remaining properties as follows: angle of friction = 32° , effective cohesion = 0kPa, and unit weight = 20kN/m^3 . Do not change the soil's classification (since it is unspecified). Click **OK** to confirm the values.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP1.RAV

Defining the slope

To define the slope, choose **Insert > Slope > Two-part...** from the Job View's menu bar.

Change the Upper Slope **Height** to 1.5m but leave the Upper Slope **Angle** at 15°. Change the Lower Slope **Height** to 8m and the Lower Slope **Angle** to 70°. Click **OK** to confirm the data entered.



You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP2.RAV

Defining the water regime

To define the water regime, choose **Insert > Water Regime > Custom...** from the Job View's menu bar.

Change **Ru** to 0.15 and click **OK** to confirm the data entered.

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

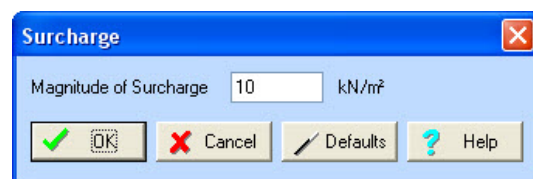


GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP3.RAV

Defining the surcharge

To define the surcharge, choose **Edit > Surcharge...** from the Job View's menu bar.

Enter 10kPa into the dialog box that appears and click **OK** to confirm the data entered.



You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP4.RAV

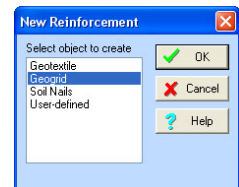
Defining the reinforcement

Using the Reinforcement Manager

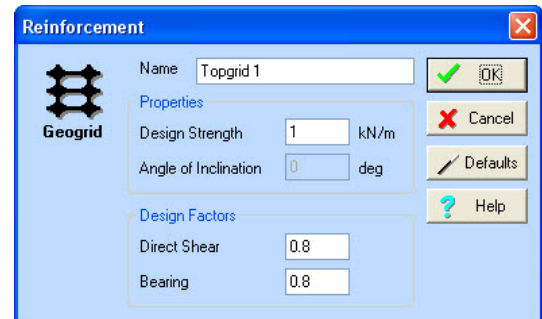
In this worked example, the best way to create the available reinforcements is to use ReActiv's Reinforcement Manager, which you can display by ticking **View > Reinforcement Manager** on the Job View's menu bar.

Creating the new reinforcement

To create a new reinforcement from the Reinforcement Manager, click the **New...** button and select Geogrid in the list that appears. Click **OK** to create the reinforcement.



In the dialog box that appears, type a name for the reinforcement (e.g. "Topgrid 1") and change its **Design Strength** to 1kN/m. Leave the **Direct Shear** and **Bearing** factors as 0.8. Click **OK** to confirm the values you have entered.



Repeat the instructions given above to create the remaining reinforcement types, but enter the following names and strengths (keeping the direct shear and bearing factors all equal to 0.8):

- Topgrid 2, 10kN/m
- Topgrid 3, 24kN/m
- Topgrid 4, 32kN/m
- Topgrid 5, 40kN/m

You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP5.RAV

Calculating the reinforcement layers

Setting the calculation options

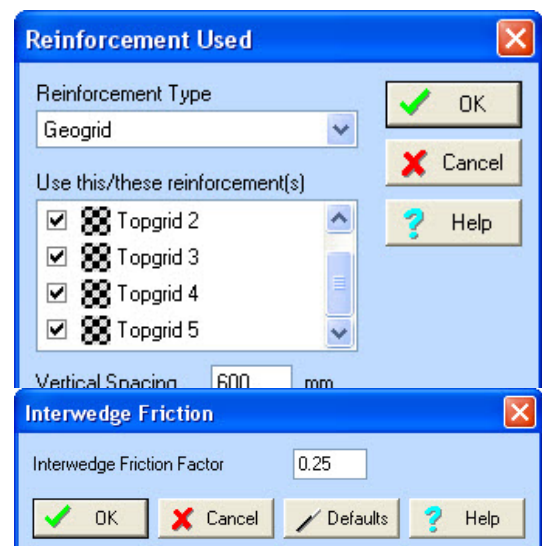
Before asking ReActiv to calculate the reinforcement layout, you need to set the appropriate options for this worked example:

- Select the fixed vertical spacing option
- Select which reinforcements to use
- Enter the magnitude of the vertical spacing
- Enter the value of the interwedge friction factor

To obtain the appropriate calculation, select the **Fixed Vertical Spacing** option from the **Options** menu or click on the **Fixed Vertical Spacing** button on the Toolbar.

Next, choose **Options > Reinforcement Used...** from the menu bar.

Select Geogrid in the **Reinforcement Type** box and then tick all five "Topgrids" in the **Use this/these reinforcement(s)** box. Change the **Vertical Spacing** to 600mm and click **OK** to confirm the data entered.



Finally, change the Interwedge Friction Factor by choosing **Options > Interwedge Friction....** Enter 0.25 and click **OK** to confirm the data entered.

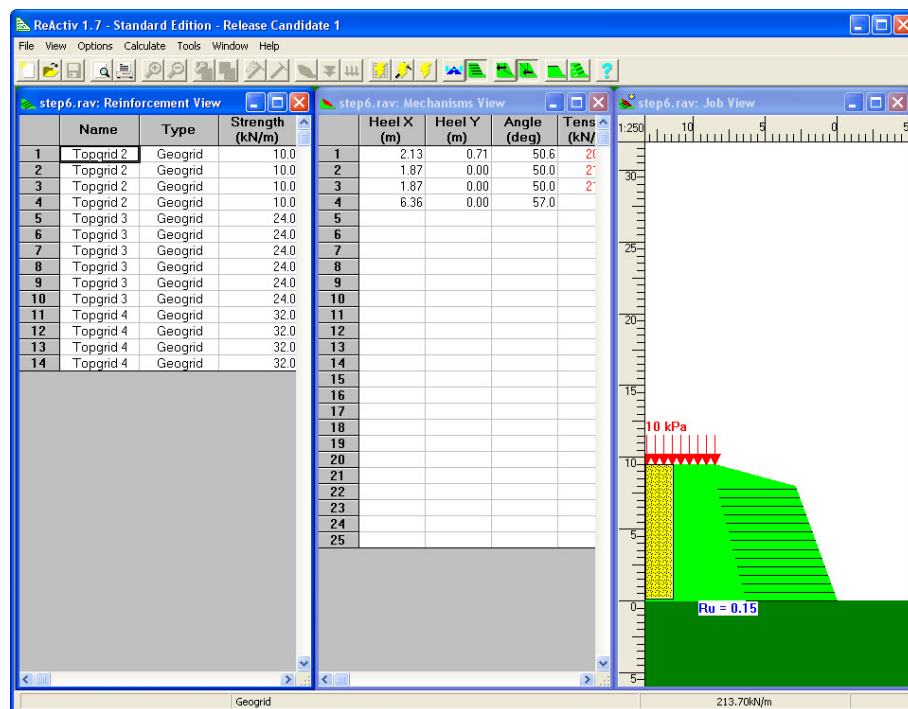
You will find a copy of the project in its current form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\STEP6.RAV

You are now ready to perform the calculation.

Performing the calculation

To perform the required calculations, simply choose the **Calculate > Calculate All** command from the menu bar or click on the **Calculate All** button on the Toolbar. Then choose **Window > Tile** to display the results in three adjacent windows, as follows:



Note how the program has chosen the weakest reinforcement that provides sufficient strength at each depth to support the slope. If none of the reinforcements you had selected to use had been strong enough, the program would have reported this fact.

You will find a copy of the project in its finals form in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\TUTORIAL 3\TUTORIAL3.RAV

Chapter 7

Calculating mechanisms

ReActiv performs calculations based on limit equilibrium analysis of the two-part wedge mechanism described in Chapter 9.

ReActiv allows you to calculate the out-of-balance force for a single mechanism or for a series of mechanisms set out on a grid. The program will also search automatically for the mechanism that has the largest out-of-balance force (the T_{\max} mechanism) and the basal mechanism that has a zero out-of-balance force (the T_{ob} mechanism). ReActiv uses these two mechanisms to determine the reinforcement required to stabilize the slope (see Chapter 8).

The results of the calculations are displayed in the Mechanisms View, where they can be inspected.

Mechanisms View

ReActiv displays the results of any stability calculations that you ask it to perform in its Mechanisms View. This View is automatically created when you choose any of the available options on the **Calculate** menu.

	Heel X (m)	Heel Y (m)	Angle (deg)	Tension (kN/m)	Notes
1	2.13	0.71	50.6	207.82	Max T in body
2	1.87	0.00	50.0	213.70	Max T along base
3	1.87	0.00	50.0	213.70	Tmax
4	6.36	0.00	57.0	-0.00	Tob
5	12.00	6.00	45.0	47.07	
6	0.29	0.00	43.9	173.24	Critical
7	0.29	0.40	61.0	101.95	Critical
8	0.58	0.00	45.1	186.05	Critical
9	0.58	0.40	44.3	179.97	Critical
10	0.58	0.80	61.0	109.21	Critical
11	0.58	1.20	89.9	2.17	Critical
12	0.87	0.00	46.3	196.66	Critical
13	0.87	0.40	45.7	189.42	Critical
14	0.87	0.80	61.0	134.79	Critical
15	0.87	1.20	61.0	115.70	Critical
16	0.87	1.60	89.9	6.15	Critical
17	0.87	2.00	89.9	3.39	Critical

The Mechanisms View displays the results of the calculations in a spreadsheet containing, for each mechanism:

- The X- and Y- coordinate of the mechanism's heel
- The angle of the upper wedge (θ_1)
- The out-of-balance force or tension
- Notes indicating whether the mechanism is a critical mechanism, the T_{\max} mechanism, or the T_{ob} mechanism
- (Optionally) The mechanism's type (defined below)

Mechanism types

A mechanism's *type* depends on the positions of:

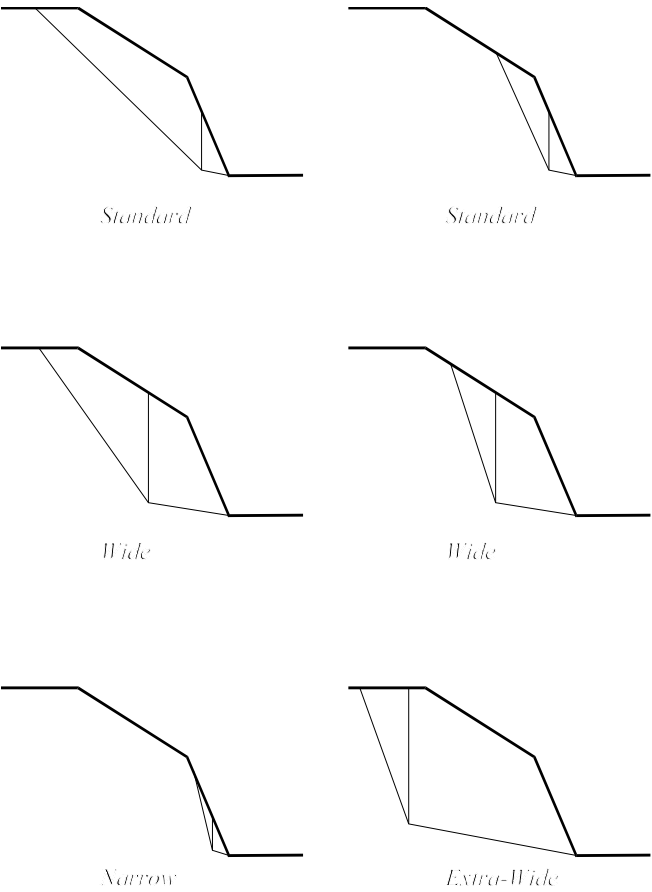
- The outcrop of Wedge 1

■ The interwedge boundary

There are four possible mechanisms, as indicated in the following table.

Mechanism type	Wedge 1 outcrops at...	Interwedge boundary outcrops at...
<i>Standard</i>	Crest or upper slope	Lower slope
<i>Narrow</i>	Lower slope	Lower slope
<i>Wide</i>	Crest or upper slope	Upper slope
<i>Extra-wide</i>	Crest	Crest

The following diagrams illustrate the various mechanism types:



Distribution of reinforcement force

As discussed in Chapter 8, ReActiv provides two methods of calculating the reinforcement force required to stabilize a mechanism. In the first method, it is assumed that the reinforcement force acts solely on Wedge 1; and, in the second method, it is assumed that the reinforcement force acts solely on Wedge 2.

You specify which method you want to use by selecting the appropriate options on the **Options** menu:

- **Tension on Wedge 1** selects the calculation method in which the reinforcement force acts solely on Wedge 1
- **Tension on Wedge 2** selects the calculation method in which the reinforcement force acts solely on Wedge 2

When you display the **Options** menu, a tick mark is shown next to the currently selected option. By default, ReActiv puts all the reinforcement force on Wedge 2.

The assumption made about where the reinforcement force acts is irrelevant when the reinforcement is horizontal ($\delta = 0$) and its interwedge friction factor (f_{wtf}) is zero, since the value of zeta (ζ) given in Chapter 9 is always equal to one.

In all other cases, however, it is necessary to choose between the two methods provided. For most practical cases, it is reasonable to assume that the reinforcement force acts on Wedge 2 (although this may not be so for small slope angles when the interwedge factor is > 0 — see Chapter 9).

It can be shown for *inclined* reinforcement that placing all the reinforcement force on Wedge 1 is always conservative. (Note that the design charts given in Table 4.1 of the Advice Note are based on this assumption.) However, applying all the reinforcement force on Wedge 1 can be unnecessarily conservative for steeply inclined soil nails (e.g. with angles of inclination $> 10^\circ$). As discussed in Chapter 9, the alternative assumption that all the reinforcement force acts on Wedge 2 gives reasonable design results provided the interwedge friction factor is less than or equal to 0.5 and, for this reason, by default the program assumes all the reinforcement force acts on Wedge 2.

Baseline

The *baseline* is a line that passes through the toe of the slope at an angle δ to the horizontal (where δ is the angle of inclination of the reinforcement, measured anticlockwise). For geogrids and geotextiles, δ is always zero; for soil nails and User-defined reinforcement, δ may be greater than or equal to zero.

Invalid mechanisms

Invalid mechanisms are those whose:

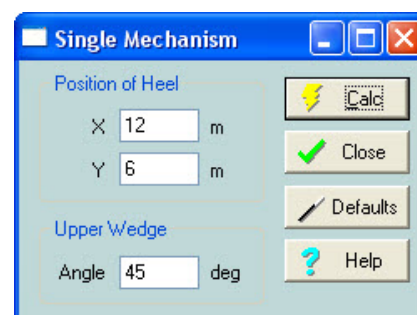
- Heel position (X, Y) is outside the slope
- Heel position is below the lowest layer of reinforcements (i.e. the *baseline*, defined below)
- Upper angle (θ_1) is less than or equal to its lower angle (θ_2) or greater than $90^\circ - \delta$

ReActiv displays the following error message if you attempt to calculate the out-of-balance force for an invalid mechanism.

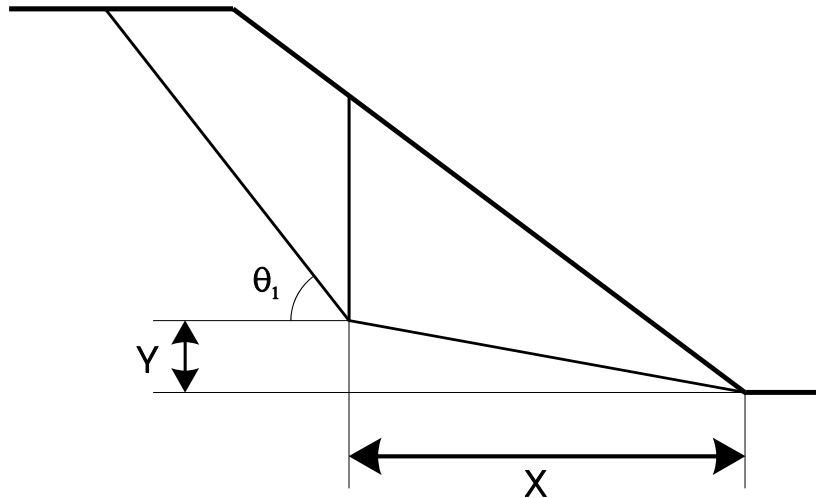
Calculating single mechanisms

You can calculate the out-of-balance force (T) for a single mechanism by choosing **Calculate > Single Mechanism...** from the menu bar. If it has not already done so, ReActiv creates the Mechanisms Window and then displays the dialog box shown.

The Single Mechanism box is a floating dialog box that allows you to calculate the out-of-



balance force for a single mechanism. You specify the X- and Y-coordinates of the mechanism's heel and the angle that the upper wedge (Wedge 1) makes to the horizontal (θ_1) by entering appropriate values into the **X**, **Y**, and **Angle** edit boxes.



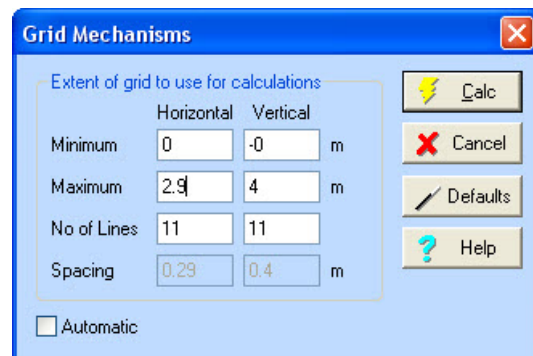
When you choose the **Calc** button, ReActiv first of all checks whether the specified mechanism is valid (see below) and — if it is — then:

- Calculates the out-of-balance force for that mechanism (which could be positive or negative)
- Appends the result of the calculation to the list of mechanisms displayed in the Mechanisms View

Calculating grid mechanisms

You can calculate the out-of-balance force (T) for a series of mechanisms by choosing **Calculate > Grid Mechanisms...** from the menu bar. If it has not already done so, ReActiv creates the Mechanisms View and then displays the dialog box shown.

The Grid Mechanisms box allows you to specify a series of uniformly spaced gridlines, along which the program will perform successive calculations in order to find the *critical mechanism* (see page 46) at each intersection point on the grid. Only the critical mechanism for each grid point is displayed in the Mechanisms View.



You do not need to use ReActiv's grid feature in order to find the T_{\max} or T_{ob} mechanisms, since these are calculated for you automatically when you choose **Calculate > Tmax** or **Calculate > Tob** from the menu bar.

When you choose the **Calc** button, ReActiv does the following:

- Displays a dialog box which keeps you informed as to the progress of the calculations
- Performs a search for the most critical mechanism at each intersection point on the grid and (when it has found it) displays that mechanism in the Mechanisms View

View

- Updates the progress bar as each critical mechanism is found
- Allows you to cancel the remaining calculations by choosing the **Cancel** button
- Removes the dialogue box once all the calculations have been performed

Minimum and maximum co-ordinates

The starting and ending co-ordinates of the horizontal and vertical gridlines are given in their respective **Minimum** and **Maximum** boxes. To alter the given values:

- Turn off the check mark in the **Automatic** box
- Enter your own values in the **Minimum** and **Maximum** boxes

To restore the original values in the **Minimum** and **Maximum** boxes:

- Turn on the check mark in the **Automatic** box

Number of lines

The number of gridlines in the horizontal and vertical directions are given in their respective **No of Lines** boxes. To alter the given values:

- Turn off the check mark in the **Automatic** box
- Enter your own values in the **No of Lines** boxes

To restore the original values in the **No of Lines** boxes:

- Turn on the check mark in the **Automatic** box

When the number of gridlines in any direction is one, its maximum co-ordinate is reset to its minimum, its **Maximum** box is disabled, and its **Spacing** box is hidden.

Spacing

ReActiv automatically calculates the spacing of the gridlines in each direction from the appropriate minimum and maximum co-ordinates and number of lines. The spacing is calculated from:

$$\text{Spacing} = \frac{\text{Maximum} - \text{Minimum}}{\text{No. of lines} - 1}$$

Automatic grid

When the **Automatic** box is checked, ReActiv selects the most suitable grid for multiple calculations by setting the grid co-ordinates and number of lines as follows:

For the horizontal gridlines:

- Minimum co-ordinate = breadth of lower slope times the tangent of the reinforcement's angle of inclination
- Maximum co-ordinate = height of slope / 2
- No of lines = 11

For the vertical gridlines:

- Minimum co-ordinate = 0m
- Maximum co-ordinate = breadth of lower slope (i.e. $H/\tan \beta$)
- No of lines = 11

Default grid

When you choose the **Default** button in the Grid Mechanisms box, ReActiv puts the following default parameters in the appropriate edit boxes.

For the horizontal gridlines:

- Minimum co-ordinate = R_y^{\min} times H
- Maximum co-ordinate = R_y^{\max} times H

where H is the total height of the slope (to its crest).

For the vertical gridlines:

- Minimum co-ordinate = R_x^{\min} times B
- Maximum = R_x^{\max} times B

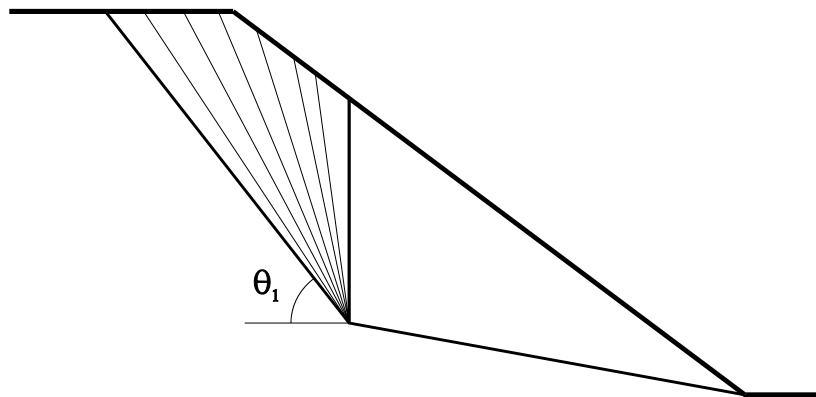
where B is the breadth of the slope.

The various min. and max. ratios are taken from Window's Registry. If you don't override the factory-supplied defaults, ReActiv uses the following values:

- $R_y^{\min} = 0$
- $R_y^{\max} = 0.5$
- $R_x^{\min} = 0$
- $R_x^{\max} = 1.0$

Critical mechanisms

For each point on the grid there is a fan of mechanisms, each with a different upper wedge angle (θ_1) and out-of-balance force (T). The *critical mechanism* is the one that has the largest value of out-of-balance force (where $\partial T / \partial \theta_1 = 0$).



Search algorithm

ReActiv searches for the critical mechanism within each fan using a variant of the *Golden Section Search* algorithm, known as *Brent's Method*. Brent's Method uses a technique called *inverse parabolic interpolation* to find the minimum (or maximum) of a one-dimensional function. A full description of the method is given by Press *et al.* (1992), *Numerical recipes in C (2nd edition)*, Cambridge University Press, pp397-402.

ReActiv indicates those mechanisms which are critical mechanisms by displaying the word "Critical" in the **Notes** column of the Mechanisms View.

Calculating the T_{\max} mechanism

You can find the largest out-of-balance force (T_{\max}) of any mechanism in the slope by choosing **Calculate > Tmax** from the menu bar. If it has not already done so, ReActiv creates the Mechanisms View and then begins searching for the T_{\max} mechanism.

Searching for T_{\max}

The steps that ReActiv follows in searching for the T_{\max} mechanism are as follows:

- First, ReActiv displays a dialog box that keeps you informed about the progress of the calculations (the number displayed in the progress bar is the number of X, Y co-ordinates that have been considered in the search)
- Second, ReActiv performs a search for the critical mechanism (see page 46) that has the largest out-of-balance force *anywhere in the slope* (you can cancel the search for T_{\max} at any time by choosing the **Cancel** button in the dialog box)
- Third, ReActiv repeats the search from a new starting point, in order to ensure that it has not accidentally picked up a local maximum
- Fourth, ReActiv searches along the baseline for the mechanism with the largest out-of-balance force
- Fifth, ReActiv compares the body mechanism with the baseline mechanism, and sets the T_{\max} mechanism to be the one with the larger out-of-balance force.
- Finally, ReActiv displays the result in a dialog box.

When you click the **OK** button, ReActiv dismisses this box and adds the T_{\max} mechanism to the Mechanisms View. ReActiv marks the T_{\max} mechanism with the word "Tmax" in the **Notes** column of the Mechanisms View.



Search algorithms

The search for T_{\max} in the body of the slope is performed using the *Downhill Simplex Method* to find the minimum/ maximum of a two-dimensional function. A full description of the method is given by Press et al. (1992), *Numerical recipes in C (2nd edition)*, Cambridge University Press, pp408-412.

The search for T_{\max} along the baseline of the slope is performed using *Brent's Method* (see page 46).

Calculating the T_{ob} mechanism

You can find the critical baseline mechanism that requires precisely zero reinforcement force to establish its equilibrium (i.e. the T_{ob} mechanism) by choosing **Calculate > Tob** from the menu bar. If it has not already done so, ReActiv creates the Mechanisms View and then begins searching for the T_{ob} mechanism.

Searching for T_{ob}

The steps that ReActiv follows in searching for the T_{ob} mechanism are as follows:

- First, ReActiv searches along the baseline for the mechanism with the largest out-of-balance force
- Second, ReActiv searches outwards from this point along the baseline for the critical mechanism that has zero out-of-balance force

When it has found the T_{ob} mechanism, ReActiv displays the result in a dialog box.

When you choose the **OK** button, ReActiv dismisses this



box and adds the T_{ob} mechanism to the Mechanisms View. ReActiv marks the T_{ob} mechanism with the word "Tob" in the **Notes** column of the Mechanisms View.

Search algorithm

ReActiv searches for the T_{ob} mechanism using the method due to van Wijngaarden *et al.*, as improved by Brent. A full description of the method is given by Press *et al.* (1992), *Numerical recipes in C (2nd edition)*, Cambridge University Press, pp359-362. The baseline T_{max} mechanism is used in the initial bracketing of T_{ob} , hence the need to search for the baseline T_{max} first.

Chapter 8

Calculating the required reinforcement

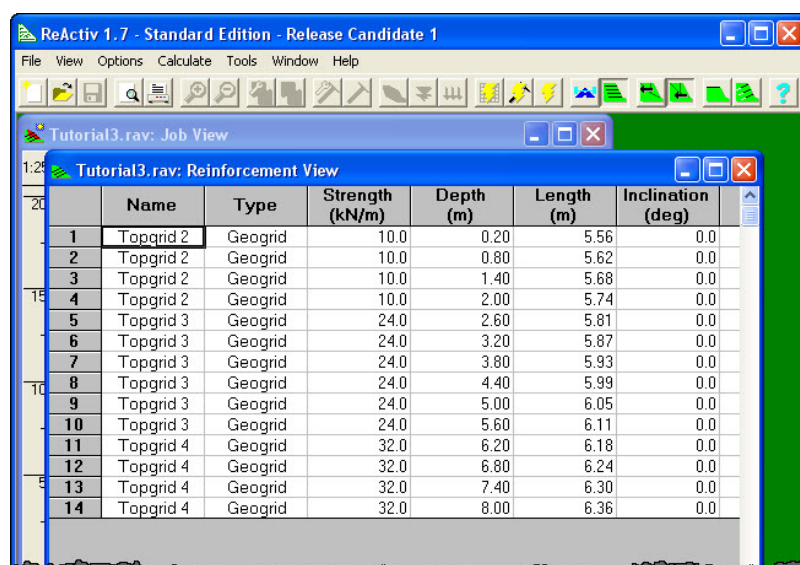
ReActiv determines the reinforcement required to stabilize a given slope based on the results of the T_{\max} and T_{ob} calculations described in Chapter 7.

ReActiv allows you to calculate the number of reinforcement layers required, their optimum spacing, and their length. ReActiv also allows you to save on reinforcement when using soil nails by decreasing the horizontal spacing of the top row of nails. You can also choose to provide an extra layer of reinforcement at the top of the slope, set a fixed vertical spacing between the layers of reinforcement or change the wedge on which the tension is applied.

The required reinforcement layers are listed in the Reinforcement View and displayed on the slope in the Job View.

Reinforcement View

ReActiv displays the required reinforcement layout in its Reinforcement View. This View is automatically created when you choose **Calculate > Reinforcement** from the menu bar.



	Name	Type	Strength (kN/m)	Depth (m)	Length (m)	Inclination (deg)
1	Topgrid 2	Geogrid	10.0	0.20	5.56	0.0
2	Topgrid 2	Geogrid	10.0	0.80	5.62	0.0
3	Topgrid 2	Geogrid	10.0	1.40	5.68	0.0
4	Topgrid 2	Geogrid	10.0	2.00	5.74	0.0
5	Topgrid 3	Geogrid	24.0	2.60	5.81	0.0
6	Topgrid 3	Geogrid	24.0	3.20	5.87	0.0
7	Topgrid 3	Geogrid	24.0	3.80	5.93	0.0
8	Topgrid 3	Geogrid	24.0	4.40	5.99	0.0
9	Topgrid 3	Geogrid	24.0	5.00	6.05	0.0
10	Topgrid 3	Geogrid	24.0	5.60	6.11	0.0
11	Topgrid 4	Geogrid	32.0	6.20	6.18	0.0
12	Topgrid 4	Geogrid	32.0	6.80	6.24	0.0
13	Topgrid 4	Geogrid	32.0	7.40	6.30	0.0
14	Topgrid 4	Geogrid	32.0	8.00	6.36	0.0

The Reinforcement View displays the required reinforcement in a spreadsheet and gives, for each layer:

- The name of the reinforcement
- Its type
- Its strength
- The depth of the layer
- Its length
- Its inclination to the horizontal
- Notes giving special information relevant to that layer (for example, in the case of soil nails, their horizontal spacing)

Calculating the required reinforcement

When you choose the **Calculate > Reinforcement** command, ReActiv performs a number of calculations that culminate in the required reinforcement being displayed in the Reinforcement View. These calculations are described in full in Chapter 9 but,

for convenience, are summarized below.

- First, a search is made for the T_{\max} mechanism (if it has not already been found)
- Second, a search is made for the T_{ob} mechanism (if it has not already been found)
- Third, the total number of reinforcement layers (n) is calculated
- Fourth, the depth to the first layer of reinforcement (z_1) is calculated
- Fifth, the pullout length of the first layer (L_{e1}) is calculated
- Sixth, the depths of the remaining layers are calculated
- Finally, the lengths of these layers are calculated

Minimizing the length of soil nails

The Advice Note describes a method of reducing the length of soil nails by decreasing the horizontal spacing of the first layer of nails and adjusting the length of the other layers accordingly. The method is described in Chapter 9.

To minimize the length of soil nails, choose the **Reduce Nail Lengths** option from the **Options** menu in the Reinforcement View or click on the **Reduce Nail Lengths** button on the Toolbar. ReActiv will then automatically reduce the horizontal spacing of the top layer of nails when you next calculate the reinforcement. The actual spacing adopted in the calculations is displayed in the **Notes** column of the Reinforcement View.

Providing an additional layer at the top of the slope

When ReActiv optimizes the depths of the reinforcement layers, it places the first layer of reinforcement at some depth below the top of the slope. Because of this, there is the potential, particularly for Two-part or Infinite slopes, for the soil above the first layer to be unstable. This instability can be avoided:

- In the case of geotextiles and geogrids, by providing a "wrap-around" front face
- In the case of soil nails, by providing a mesh and shotcrete front face

In the absence of measures such as these to support the soil above the first layer, it may be necessary to provide an extra layer of reinforcement at the top of the slope. You can instruct ReActiv to provide this extra layer of reinforcement by selecting the **Extra Layer At Top** command from the Reinforcement View's **Options** menu or by clicking on the **Extra Layer At Top** button on the Toolbar. A tick mark is displayed next to this option when it is selected.

ReActiv asks you whether you want to provide an extra layer at the top of the slope whenever both of the following conditions are met:

- The angle between the reinforcement and the upper slope of crest is greater than or equal to 10°
- The **Extra Layer At Top** option is not already selected Reinforcement View

Setting a the vertical spacing between the layers

When **HA68/94** is selected on the **Options** menu, ReActiv calculates the vertical spacing between reinforcement layers according to the optimised procedure given in HA68 (see Chapter 9).

When the **Fixed Vertical Spacing** option is chosen on the **Options** menu, ReActiv places the layers at a fixed spacing (which you specify), but allows more than one strength of reinforcement to be used. At each depth, the program automatically selects the weakest layer that it can use to provide stability. The reinforcement layers that the program uses and the spacing between them can be set via the

Reinforcement Used... command on the **Options** menu.

Tension on Wedge 1 or 2

ReActiv automatically specifies Wedge 2 as the wedge on which the tensions are to be applied. However, the program allows you to change it if you wish to.

To change the wedge on which the tensions are applied, choose the **Tension on Wedge 1** option or the **Tension on Wedge 2** option from the **Options** menu in the Menu bar; alternatively, click on the **Tension on Wedge 1** button or on the **Tension on Wedge 2** button on the Toolbar.

Chapter 9

Background theory and assumptions

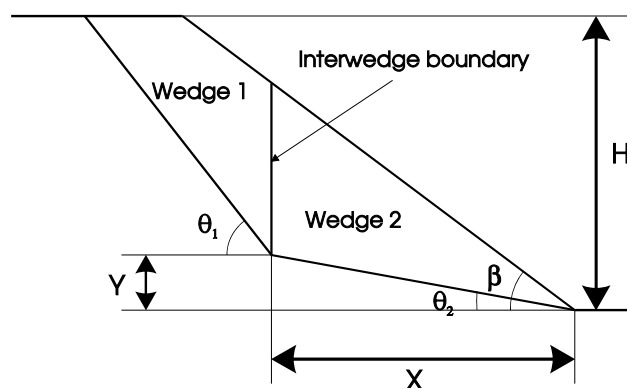
The UK Highways Agency's (HA's) Advice Note *Design methods for the reinforcement of highway slopes by reinforced soil and soil nailing techniques* (hereinafter called the Advice Note) describes a simple design method for the preliminary assessment of reinforcement requirements for highway slopes, using either reinforced soil or soil nailing techniques.

ReActiv follows this design method step-by-step, and is intended to fully compliment the Advice Note. However, the *User Manual* is also designed as a stand-alone document, so that it is not necessary to refer to the Advice Note to use the program. The theory behind ReActiv is, in some places, more advanced than that in the Advice Note.

This chapter gives a brief résumé of the basic theory and assumptions behind the design method used by ReActiv. The design is carried out in terms of effective stresses and applies to the long-term condition of permanent works. In some cases the notation adopted in this *User Manual* differs from that used in the Advice Note. A translation table of the terms that are different is given at the end of the chapter.

Two-part wedge mechanism with horizontal reinforcement

The design method used by ReActiv is based on limiting equilibrium of a two-part wedge mechanism (as shown below).



The mechanism considered has a vertical interwedge boundary. When there is no friction on the interwedge boundary, it provides inherently conservative solutions combined with reasonable simplicity, and is particularly suitable to reinforced soil geometries.

The inherent conservatism of the method can be reduced by taking interwedge friction into account. Guidance is given on this later in this chapter. Guidance is also given on the assumptions behind the method's simplified reinforcement distribution.

The design method assumes that a competent bearing material (which is significantly stronger than the slope fill) exists beneath the retained slope. The two-part wedge mechanism is constrained to pass through the toe of the slope.

ReActiv may be used as an automatic design tool or as a calculator. When used as a design tool, the program automatically and rapidly leads you to an optimized reinforcement layout for the given slope geometry, soil parameters, water regime, reinforcement type, etc. You do not have to guess a reinforcement layout or perform trial-and-error calculations (although you may do so, if you so wish).

Factors-of-safety

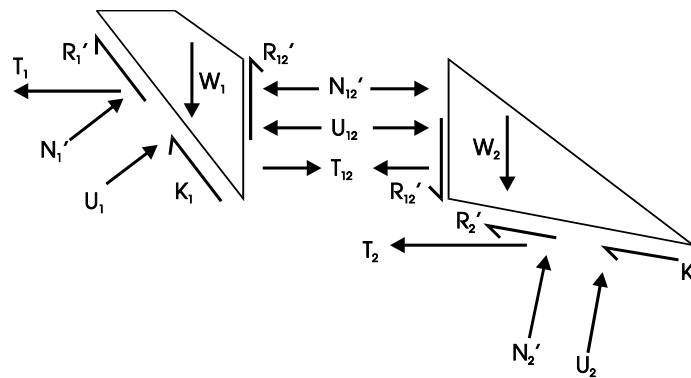
ReActiv employs partial factors-of-safety, along the lines given in the Advice Note.

The reinforcement strength that is entered into the program is assumed to be a *design* value (i.e. already factored).

You can enter soil strength parameters either as design values (i.e. critical state or large displacement values) or as peak values. When you specify strength parameters in terms of peak values, the program requires you to enter the partial factors-of-safety that should be applied to these peak values before using them for design.

Governing equations

The following diagram defines the forces acting on the two-part wedge mechanism when horizontal reinforcement is used.



The various symbols on this diagram have the following meanings:

- W_i is the weight of Wedge i
- N_i' is the force due to effective earth pressures acting on the base of Wedge i
- U_i is the force due to water pressures acting on the base of Wedge i
- R_i' is the force due to friction along the base of Wedge i
- K_i is the force due to effective cohesion along the base of Wedge i
- N_{12}' is the force due to effective earth pressures on the interwedge boundary
- U_{12} is the force due to water pressures on the interwedge boundary
- R_{12}' is the force due to friction along the interwedge boundary
- T_i is the reinforcement force provided through the base of Wedge i
- T_{12} is the reinforcement force transferred through the interwedge boundary

The expression for the out-of-balance horizontal reinforcement force (T) required for equilibrium is:

$$T = T_1 + T_2$$

The value of T can be derived from the expressions given in Appendix A of the Advice Note.

Equations with zero interwedge friction

If it is assumed that there is no friction on the interwedge boundary (i.e. $R_{12}' = 0$), the equation for T is given by:

$$T = \frac{W_1(\tan \theta_1 - \tan \phi) + \left(\frac{U_1 \tan \phi - K_1}{\cos \theta_1} \right)}{1 + \tan \theta_1 \tan \phi}$$

$$+ \frac{W_2(\tan \theta_2 - \lambda_s \tan \phi) + \lambda_s \left(\frac{U_2 \tan \phi - K_2}{\cos \theta_2} \right)}{1 + \lambda_s \tan \theta_2 \tan \phi}$$

The symbols in this equation that are not defined above are as follows:

- ϕ is the angle of friction of the soil
- θ_i is the angle that the base of Wedge i makes to the horizontal
- λ_s is a *sliding factor* (see below)

The *sliding factor* (λ_s) depends on the properties of the reinforcement and, in particular, on how much of the sliding surface the reinforcement occupies.

Equations with interwedge friction

If it is assumed that friction acts on the interwedge boundary (i.e. $R'_{12} \neq 0$), then the general equation for T is not determinate unless an assumption is made regarding the relative magnitudes of T_1 , T_2 , and T_{12} .

The simplest option is to adopt one or other of the following assumptions:

- All the reinforcement force acts on Wedge 1 (in which case $T_{12} = T_2$)
- All the reinforcement force acts on Wedge 2 (in which case $T_{12} = T_1$)

In both cases, the equation for T is:

$$T = \zeta_n \left[\frac{W_1(\tan \theta_1 - \tan \phi) + \left(\frac{U_1 \tan \phi - K_1}{\cos \theta_1} \right) - U_{12}(1 + \tan \theta_1 \tan \phi)}{(1 + \tan \theta_1 \tan \phi) + (\tan \theta_1 - \tan \phi) \tan \phi_{12}} \right]$$

$$+ \zeta_n \left[\frac{W_2(\tan \theta_2 - \lambda_s \tan \phi) + \lambda_s \left(\frac{U_2 \tan \phi - K_2}{\cos \theta_2} \right) - U_{12}(1 + \lambda_s \tan \theta_2 \tan \phi)}{(1 + \lambda_s \tan \theta_2 \tan \phi) + (\tan \theta_2 - \lambda_s \tan \phi) \tan \phi_{12}} \right]$$

where ϕ_{12} is the angle of interwedge friction and ζ_n (zeta) is given below. The subscript n ($= 1$ or 2) denotes which wedge the reinforcement force acts on.

ζ_1 or ζ_2 ?

The assumption that the reinforcement force is carried solely by Wedge 1 (i.e. using ζ_1) leads to overly conservative designs for horizontal reinforcement.

The formula for ζ_1 is:

$$\zeta_1 = 1 + \left[\frac{\sin \theta_1 - \cos \theta_1 \tan \phi}{\cos \theta_1 - \sin \theta_1 \tan \phi} \right] \tan \phi_{12}$$

The alternative assumption, that the reinforcement force is carried solely by Wedge 2 (i.e. using ζ_2), leads to less conservative but more reasonable designs.

The formula for ζ_2 is:

$$\zeta_2 = 1 + \left[\frac{\sin \theta_2 - \lambda_s \cos \theta_2 \tan \phi}{\cos \theta_2 - \lambda_s \sin \theta_2 \tan \phi} \right] \tan \phi_{12}$$

Interwedge friction angle

The value of ζ_n depends on what angle of friction (ϕ_{12}) is assumed to act along the interwedge boundary. When $\phi_{12} = 0$, $\zeta_n = 1$. Appendix A of the Advice Note describes the results of a parametric study of the effects of ϕ_{12} on the maximum out-of-balance force (T_{\max}) for slopes inclined at angles (β) between 40 and 70°. The figures from the Advice Note, which are reproduced here in Appendix 2, indicate that the maximum safe value for the interwedge friction angle is $\frac{1}{2}\phi$.

Critical mechanism

The *critical mechanism* at any one point in the slope is the mechanism that requires the greatest reinforcement force to establish its equilibrium. The critical mechanism is found by varying the angle of the upper wedge (θ_1) while keeping the mechanism's heel (X, Y) in the same place.

T_{\max} mechanism

The T_{\max} mechanism is the critical mechanism anywhere in the slope (including the baseline) that requires the greatest reinforcement force to establish its equilibrium. The T_{\max} mechanism is used to calculate the required number of reinforcement layers (as described below).

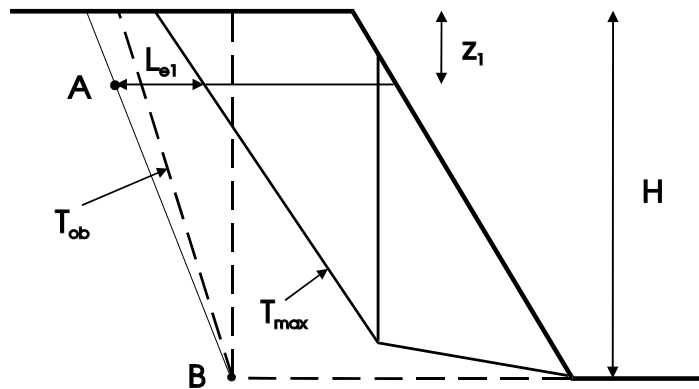
T_{ob} mechanism

The T_{ob} mechanism is the critical base-sliding mechanism that requires precisely zero reinforcement force to establish its equilibrium. The T_{ob} mechanism is used to calculate the lengths of the reinforcement layers (as described below).

Required reinforcement

The method of calculating the required reinforcement can be summarized as follows:

- First, a search is made for the T_{\max} mechanism
- Second, the total number of reinforcement layers (n) is calculated from T_{\max} and the long-term design strength of the reinforcement (P_{des})
- Third, the depth to the first layer of reinforcement (z_1) is calculated
- Fourth, the pullout length of the first layer (L_{e1}) is calculated – this defines point A on the following diagram
- Fifth, a search is made for the T_{ob} mechanism – this defines point B on the following diagram
- Sixth, the depths of the remaining layers are calculated
- Finally, the lengths of all the layers are calculated as the distance from their intersection with line AB to their intersection with the front face of the slope (if the line AB leans to the *right*, ReActiv sets it to vertical instead, as recommended in the Advice Note)



Number of layers

The total number of reinforcement layers (n) is given by the equation:

$$n = \frac{T_{\max}}{P_{\text{des}}} + 1$$

where P_{des} (in kN per metre width of slope) is the long-term (factored) design strength of each reinforcement layer. Fractional values of n are not allowed: such values are rounded up to the next whole number.

The "+1" in the equation above ensures that a layer of reinforcement is provided at the base of the slope. As discussed in Appendix G of the Advice Note, this is not a source of over-design.

The terminology used in ReActiv differs from that given in the Advice Note, which uses the symbol N to represent the "minimum number of required layers". N is given by:

$$N = \frac{T_{\max}}{P_{\text{des}}}$$

and $N + 1$ layers of reinforcement are provided.

ReActiv's symbol n is related to the Advice Note's N by:

$$n = N + 1$$

Depth to the first layer

The depth to the first reinforcement layer (z_1) is given by:

$$z_1 = \frac{0.5H}{\sqrt{n-1}}$$

where H is the height of the (lower) slope and n the total number of reinforcement layers.

Pullout length of the first layer

The pullout length of the first layer of reinforcement (L_{e1}) is given by:

$$L_{e1} = \frac{P}{\lambda_p (\sigma'_n \tan \phi + c')}$$

where λ_p is the *pullout factor*; σ'_n is the normal effective stress acting on the reinforcement (see below); and ϕ and c' are the soil's effective stress design parameters. The parameters ϕ and c' in ReActiv correspond to ϕ_{des} and c'_{des} in the Advice Note.

The value of P is taken as the lesser of:

- The design strength of the reinforcement (P_{des})
- T_{max}

Normal effective stress

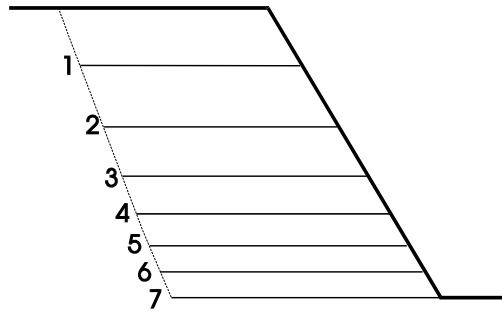
The normal effective stress (σ'_n) that acts on horizontal reinforcement, assuming it is flat, is equal to the vertical effective stress in the soil (σ'_v) mid-way along the pullout length of the reinforcement.

Depths of layers 2-n

The depths (z_i) of layers 2 to n are given by:

$$z_i = H \sqrt{\frac{i-1}{n-1}} \quad \text{for } i > 1$$

The diagram below illustrates a typical arrangement of layers using this formula.



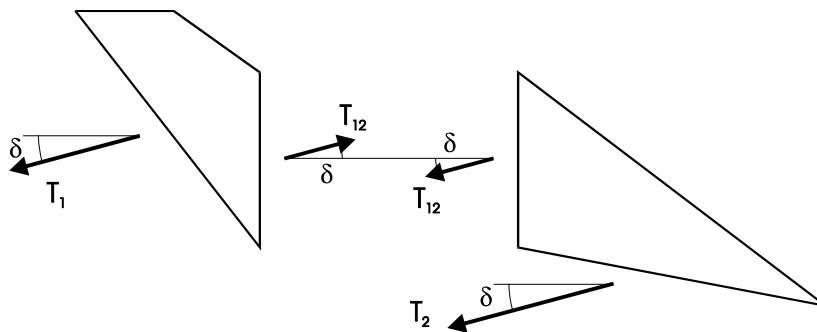
Further checks

For most practical design cases, the reinforcement layout defined in the Advice Note will adequately cover all possible intermediate two-part wedge mechanisms. ReActiv may be used to confirm this, by performing spot checks of individual mechanisms, especially for $\phi_{12} > 0$.

Two-part wedge mechanism with inclined reinforcement

The design method given in the Advice Note for inclined reinforcement is identical to that for horizontal reinforcement, except as described below:

- The equation for the total out-of-balance force (T) is more complicated because the components T_1 , T_2 , and T_{12} are inclined to the horizontal (see below)



- The T_{\max} and T_{ob} mechanisms are called the $T_{\max\delta}$ and $T_{\text{ob}\delta}$ mechanisms to emphasize the fact that they are calculated for inclined reinforcement
- The average normal effective stress that acts on soil nails is not equal to the vertical effective stress in the soil

Governing equations

The general expression for the out-of-balance inclined reinforcement force (T) required for equilibrium is as given for horizontal reinforcement, except that the equation for zeta (as given below) is different.

ζ_1 or ζ_2 ?

The assumption that the reinforcement force is carried solely by Wedge 1 (i.e. using ζ_1) can lead to overly conservative designs for inclined reinforcement, particularly when the angle of interwedge friction (ϕ_{12}) is set to zero. This is the combination of parameters that was used to produce Table 4.1 in the Advice Note and is the most conservative set of assumptions that can be made.

The equation for ζ_1 is:

$$\zeta_1 = \left[\frac{(\cos \theta_1 + \sin \theta_1 \tan \phi) + (\sin \theta_1 - \cos \theta_1 \tan \phi) \tan \phi_{12}}{\cos(\theta_1 + \delta) + \sin(\theta_1 + \delta) \tan \phi} \right]$$

The derivation of this factor is given in the Advice Note.

The alternative assumption, that the reinforcement force is carried solely by Wedge 2 (i.e. using ζ_2), leads to less conservative but more reasonable designs. Comparing the results based on ζ_2 with solutions obtained from Caquot and Kerisel's charts (see Appendix 2), indicates that calculations based on ζ_2 are safe for interwedge friction angles (ϕ_{12}) up to $\frac{1}{2}\phi$ (where ϕ is the angle of shearing resistance of the soil).

The equation for ζ_2 is:

$$\zeta_2 = \left[\frac{(\cos \theta_2 + \lambda_s \sin \theta_2 \tan \phi) + (\sin \theta_2 - \lambda_s \cos \theta_2 \tan \phi) \tan \phi_{12}}{\cos(\theta_2 + \delta) + \lambda_s \sin(\theta_2 + \delta) \tan \phi} \right]$$

$T_{\max\delta}$ mechanism

The $T_{\max\delta}$ mechanism is the mechanism that requires the greatest reinforcement force to establish its equilibrium. This definition is identical to that for the T_{\max} mechanism: the change in notation merely emphasizes the fact that $T_{\max\delta}$ is inclined at $-\delta$ to the horizontal, whereas T_{\max} is horizontal. For simplicity, ReActiv uses the term T_{\max} to represent both T_{\max} and $T_{\max\delta}$.

The $T_{\max\delta}$ mechanism is used to calculate the required number of reinforcement layers (as described below).

$T_{o\delta}$ mechanism

The $T_{o\delta}$ mechanism is the base-sliding mechanism that requires precisely zero reinforcement force to establish its equilibrium. This definition is identical to that for the T_{ob} mechanism: the change in notation merely emphasizes the fact that the base of the $T_{o\delta}$ mechanism is inclined at $-\delta$ to the horizontal, whereas the base of the T_{ob} mechanism is horizontal. For simplicity, ReActiv uses the term T_{ob} to represent both T_{ob} and $T_{o\delta}$.

The $T_{o\delta}$ mechanism is used to calculate the lengths of the reinforcement layers (as described below).

Required reinforcement

The method of calculating the required reinforcement is identical to that described previously, except that the normal effective stress (σ'_n) that is used to calculate the pullout length of the first layer of reinforcement is no longer equal to the vertical effective stress in the soil, owing to the inclination of the reinforcement. σ'_n is calculated as described below.

Normal effective stress

The normal effective stress (σ'_n) that acts on soil nails is given by:

$$\sigma'_\phi = \left(\frac{3 + K_a}{4} \right) \sigma'_v$$

where σ'_v is the vertical effective stress in the soil at a point mid-way along the

pullout length of the nail and K_a is the soil's coefficient of active earth pressure, given by:

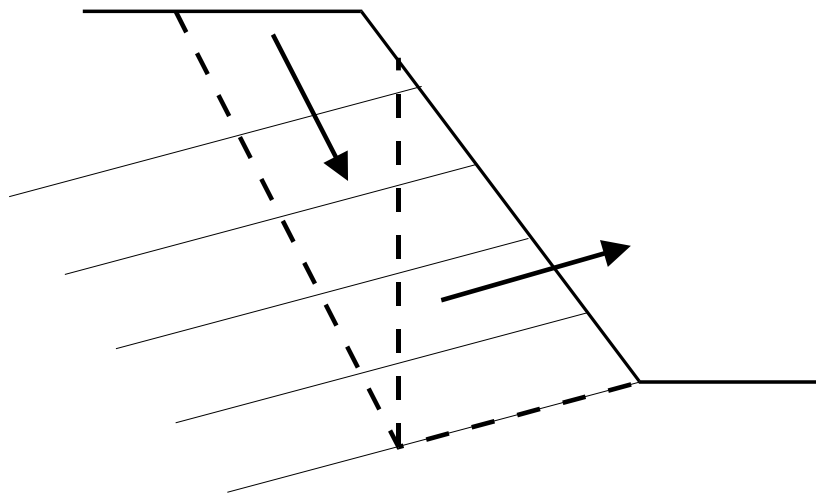
$$K_a = \frac{1 - \sin \phi}{1 + \sin \phi}$$

where ϕ is the soil's design angle of shearing resistance.

The derivation of the equation for σ'_n is given in Appendix D of the Advice Note.

Base-sliding resistance

Base sliding occurs when the lower wedge (Wedge 2) of a two-part wedge mechanism slides directly over the surface of a layer of reinforcement (as shown below).



The base-sliding resistance of the reinforcement is incorporated in the general stability calculations presented previously via the terms R'_2 and K_2 , defined as follows:

$$R'_2 = \lambda_s N'_2 \tan \phi$$

$$K_2 = \frac{\lambda_s c' X}{\cos \delta}$$

where λ_s is a non-dimensional *sliding factor* (defined below); N'_2 and X are defined previously in this chapter; δ is the angle of inclination of the reinforcement; and ϕ and c' are the design effective stress parameters of the soil.

The sliding factor (λ_s) depends on the properties of the reinforcement and, in particular, on how much of the sliding surface the reinforcement occupies. The following table summarizes the values of λ_s that ReActiv adopts for the different types of reinforcement according to whether the angle of the lower wedge (θ_2) equals the angle of inclination of the reinforcement ($-\delta$) or not.

Wedge angle (θ_2)	Reinforcement	λ_s
$\theta_2 \neq \delta$	All	1
$\theta_2 = \delta \pm 0.1^\circ$	Geotextile	f_{ds}
	Geogrid	
	Custom	
	Soil nails	$f_{ds}d_h/S_h + (1 - d_h/S_h)$

In this table, f_{ds} is the reinforcement's direct-shear factor; and d_h and S_h are the effective hole diameter and horizontal spacing of the soil nails.

Compatibility with the Advice Note

The Advice Note uses the term *interface sliding factor* to quantify the reduction in shearing resistance caused by soil sliding over an interface instead of over soil. The interface sliding factor (α) is defined as:

$$\alpha = \frac{\tan \phi_{\text{interface}}}{\tan \phi_{\text{soil}}} = \frac{c'_{\text{interface}}}{c'_{\text{soil}}}$$

where ϕ is an angle of friction; c' is an effective cohesion; and the subscripts *interface* and *soil* denote values obtained in soil-on-interface and soil-on-soil tests, respectively. The values are obtained from shearing tests taken to large displacements. The soil parameters in these equations are *design* values, i.e. they include appropriate partial factors-of-safety or are large-displacement values.

The parameter f_{ds} used by ReActiv is identical to the parameter α used in the Advice Note.

Pullout resistance

The pullout resistance (P) of the reinforcement is calculated from the formula:

$$P = \lambda_p L_e (\sigma'_n \tan \phi + c')$$

where λ_p is a non-dimensional *pullout factor* (defined below); L_e is the length of the reinforcement that extends beyond the failure mechanism; σ'_n represents the average normal effective stress acting on the pullout length of the reinforcement; and ϕ and c' are the design effective stress parameters of the soil.

The pullout factor (λ_p) depends on the properties of the reinforcement and, in particular, on its mode of failure in pullout. The following table summarizes the values of λ_p that ReActiv adopts for the different types of reinforcement.

Reinforcement	Mode of failure	λ_p
Geotextile	Direct-shear	$2f_{ds}$
Geogrid	Bearing failure on ribs	$2f_b$
Soil nails	Direct-shear	$\pi d_h f_{ds} / S_h$
Custom	Unknown	$2f_b$

In this table, f_{ds} and f_b are the reinforcement's direct-shear and bearing factors,

respectively; and d_h and S_h are the effective hole diameter and horizontal spacing of the soil nails.

For geotextiles, geogrids, and custom reinforcement, the normal effective stress (σ'_n) is equal to the vertical effective stress (σ'_v) acting midway along the pullout length of the reinforcement, where:

$$\sigma'_v = \gamma \left(z + \frac{q}{\gamma} \right) (1 - r_u)$$

and z is the depth of soil above the reinforcement, midway along its pullout length; γ is the unit weight of the soil; q is the applied surcharge; and r_u is Bishop's pore pressure parameter for the slope.

For soil nails σ'_n is given by:

$$\sigma'_n = \frac{1}{4} (3 + K_a) \sigma'_v$$

where K_a is given by Coulomb's equation:

$$K_a = \frac{1 - \sin \phi}{1 + \sin \phi}$$

The value of ϕ in the last equation is the *design* value.

See Appendix D of the Advice Note for further discussion of the pullout resistance of soil nails.

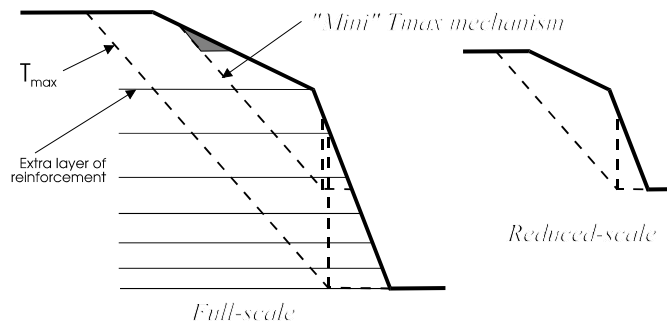
Compatibility with the Advice Note

The parameter f_b used by ReActiv is identical to the parameter α' used in the Advice Note.

Minimizing soil nail pullout lengths

Pullout lengths for the top row of soil nails can sometimes be too long to be practical. The Advice Note describes an option whereby the pullout length of the upper layer (L_{e1}) may be reduced to L'_{e1} , as shown below, by reducing the horizontal spacing of the upper layer of nails from S_{h1} to S'_{h1} , where:

$$S'_{h1} = \frac{L'_{e1}}{L_{e1}} S_{h1}$$



In such situations, it is normally sufficient to provide an extra layer of reinforcement at the level of the slope crest.

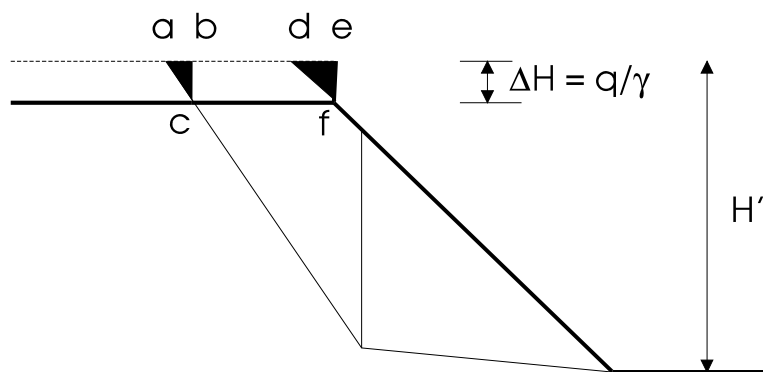
Surcharges

The Advice Note allows a uniform vertical surcharge on the slope crest to be considered either explicitly or, more simply, as an equivalent additional thickness of fill. ReActiv adopts the latter approach. When a surcharge is specified, the program determines the T_{\max} and T_{ob} mechanisms based on the effective height of the slope (H'):

$$H' = H + \Delta H = H + \frac{q}{\gamma}$$

where H is the actual slope height (in metres); q is the surcharge (in kN/m^2); and γ is the unit weight of fill (kN/m^3).

This method is an approximation, and introduces small errors into the calculation of the out-of-balance force. Instead of attributing the extra weight of $b c f e$ to Wedge 1 (see below), ReActiv uses the slightly smaller weight of $a c f d$. ReActiv also (conservatively) overestimates the pore pressures by $r_u \gamma \Delta H$ and (unconservatively) includes cohesion on the surface $a c$.



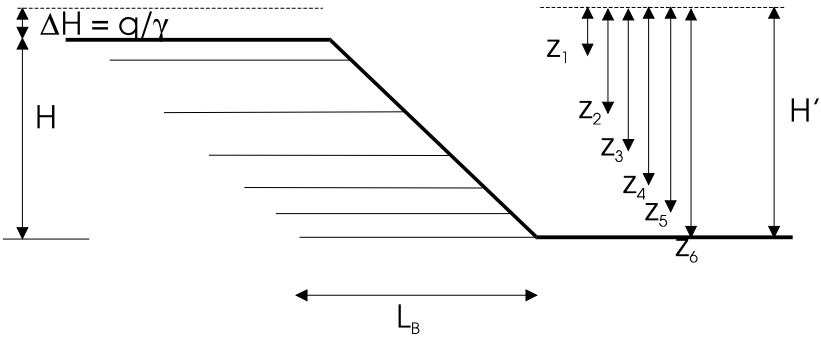
When a surcharge is present, ReActiv calculates layer spacings from the expressions:

$$z_1 = \frac{0.5H'}{\sqrt{n-1}}$$

and

$$z_i = H' \sqrt{\frac{i-1}{n-1}} \quad \text{for } i > 1$$

where n is the total number of layers. The depths (z_i) are measured from the top of the "equivalent" slope, as shown below.



Compatibility with the Advice Note

A number of symbols are used in the *ReActiv User Manual* that are different from those used in the Advice Note. The following table provides a "translation" between the two documents.

Symbol used in...	
<i>ReActiv User Manual</i>	Advice Note
ϕ	ϕ'_{des}
c'	c'_{des}
T_{max}	$T_{\text{max}}, T_{\text{max}\delta}$
T_{ob}	$T_{\text{ob}}, T_{\text{o}\delta}$
f_{ds}	α
f_{b}	α'
n	$N + 1$

Chapter 10

Proceeding to a final design

This chapter of the *ReActiv User Manual* discusses the results obtained from the program and summarizes the steps that need to be followed in order to proceed to a final design.

The chapter also discusses ReActiv's limitations and inherent conservatism and compares ReActiv to other calculation methods.

Checking individual mechanisms

The reinforcement layout that ReActiv determines will, for most practical design cases, ensure that all possible two-part wedge mechanisms passing through the reinforced zone are stable. You can check the stability of any particular mechanism by choosing **Calculate > Single Mechanism...** from the menu bar. This will give you the *required* reinforcement force: you will have to calculate the *available* force by hand.

Appendix G of the Advice Note gives guidance on sensible mechanisms to check.

Competent foundation

ReActiv assumes the existence of a competent bearing material directly beneath the slope. If the foundation is not competent, or is not significantly better than the slope material, then underlying slip mechanisms should be checked by alternative means (for example, Janbu's or Bishop's methods, etc.). If the foundation is independently improved (e.g. by replacement or separate stabilization methods), then the reinforcement layout from ReActiv will be relevant. If the foundation is not independently improved (more likely to be the case for cuttings than for embankments), then the reinforced zone may need extending and/or increasing in density, as dictated by the results of slip calculations for mechanisms which penetrate the underlying soils.

Front facing

In most practical cases you will need to provide front face protection to the slope to guard against damage caused by ultra-violet radiation, fire, and/or vandalism. ReActiv implicitly assumes the presence of a "structural" front facing (e.g. wrap-around construction, in the case of geotextiles and geogrids, or shotcrete or similar, in the case of soil nailing).

Appendix G of the Advice Note discusses the effects of the absence of structural facings

Checking pullout of the base layer

ReActiv implicitly assumes that the T_{ob} mechanism allows sufficient pullout length on the base layer of reinforcement behind the T_{max} mechanism. In extreme cases, where the reinforcement has a long pullout length requirement (perhaps widely spaced, high strength strip reinforcement or soil nails), this may not be the case and should be checked, and the base width of the reinforcement zone extended as necessary. This is not normally necessary.

Elongation of reinforcement

Elongation of the reinforcement under working conditions needs to be checked in terms of both the serviceability requirements of the reinforced slope, and also strain

compatibility with the soil. (A method for estimating front face displacements for the former can be found at the end of Section 3 of the Advice Note.) Strain compatibility with the soil is important if $\phi = \phi_{\text{critical state}}$ is *not* selected. The reinforcement should not be so extensible that the soil strength passes through "peak" and starts "strain softening" to below its design strength before the reinforcement has picked up its working load.

Drainage

Drainage measures should be provided as appropriate to ensure that the pore pressures assumed in the analysis will never be exceeded. The design should also be checked for the potential effects of water filled tension cracks, if it is likely that these would form behind the reinforced zone.

Inherent conservatism of a frictionless interwedge boundary

ReActiv's calculation method is based on the two-part wedge mechanism with a vertical interwedge boundary. The User may specify whether the interwedge boundary is frictional or frictionless, and may also specify what wedge the reinforcement force should be applied to. The mechanism is simple enough to check by hand-calculation, is intuitive, and is particularly suited to the case of base sliding over a planar layer of reinforcement.

The assumption of a frictionless interwedge boundary (i.e. $\phi_{12} = 0$) yields inherently conservative values of out-of-balance reinforcement force when compared to more exact solutions (e.g. Caquot & Kerisel, Sokolovsky, and the log spiral method), by typically 10 to 30% in terms of reinforcement density and 5 to 10% in terms of reinforcement length. In cases where these percentages do not represent a significant extra cost to the project as a whole, then setting $\phi_{12} = 0$ is attractive in that it is inherently conservative and relieves the designer of having to justify the actual distribution of the reinforcement force (see Chapter 8).

In cases where these percentages do represent a significant extra cost to the project as a whole, ReActiv allows the User to take into account friction on the interwedge boundary (although it is recommended that ϕ_{12} is never taken to be greater than $\frac{1}{2}\phi$). As explained in Chapter 8, this requires some assumption to be made about the *distribution* of the reinforcement force between the two wedges.

ReActiv allows you to choose between having all the reinforcement force acting on Wedge 1 or all on Wedge 2. The latter option is preferable since it yields a lower reinforcement requirement and a better conditioned set of equations. It is considered to be a reasonable assumption for most design cases and, for this reason, is the program default.

If interwedge friction is employed, then you should satisfy yourself that it is reasonable to place all the reinforcement force on Wedge 2 (if that is the option you choose). See Chapter 8 for information on doing this. You should also look at the shape of the T_{max} mechanism relative to the reinforcement layout and check that most of the reinforcement force does indeed act on Wedge 2 (note, in this context, that it is the *top* of the interwedge boundary that determines where the force from a particular layer of reinforcement acts). For borderline cases (typically for slopes with small angles), you are advised to check how different the design layout is if you adopt the alternative assumption of all the reinforcement force on Wedge 1 or change the interwedge friction angle.

Using ReActiv to check other design methods

When checking a design which does not adopt the optimum layer spacing theory

embodied in the Advice Note (e.g. designs which adopt constant vertical spacing with depth or multiples of fixed vertical spacings) then ReActiv may not be used in "automatic" mode. ReActiv can however be usefully employed to identify the key mechanisms (T_{\max} , T_{ob}) against which the design can be assessed. The Advice Note suggests that any design is acceptable provided that:

- The T_{\max} and T_{ob} mechanisms are satisfied
- All intermediate mechanisms are sufficiently catered for
- No individual layers are locally over-stressed

The *available* force from the lengths of reinforcement projecting beyond the mechanism in question may then be compared, by hand calculation or otherwise, with the *required* force (calculated by ReActiv).

Chapter 11

Comparison with published results

This appendix compares results obtained by GCG ReActiv with those published in the geotechnical literature by Sokolovski, Caquot and Kerisel, and Jewell. In each case, the maximum out-of-balance force (T_{\max}) has been compared at varying slope angles (β). To facilitate these comparisons, T_{\max} has been normalized as follows:

$$K = \frac{T_{\max}}{\frac{1}{2}\gamma H^2}$$

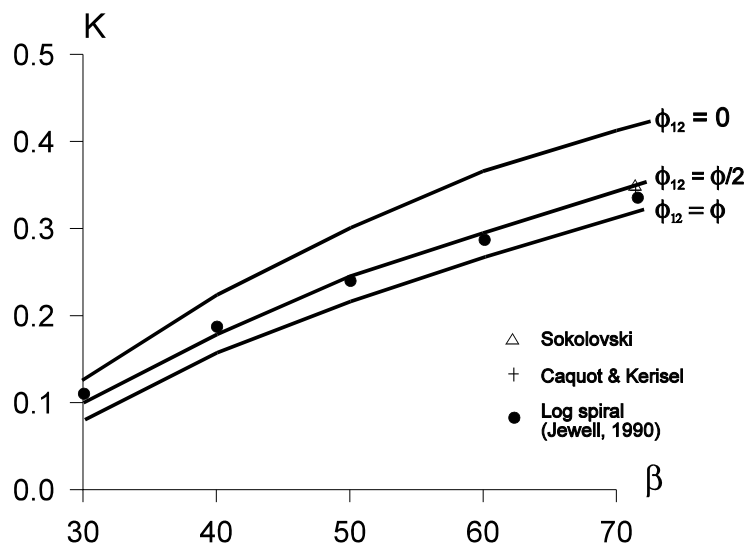
where γ is the unit weight of the soil and H is the height of the slope. Other parameters that have been varied are ϕ , c' , ϕ_{12} , δ , λ_s , i , and r_u ; and whether the reinforcement force acts on Wedge 1 or 2. See Chapter 9 for a full explanation of these terms and symbols.

Horizontal reinforcement

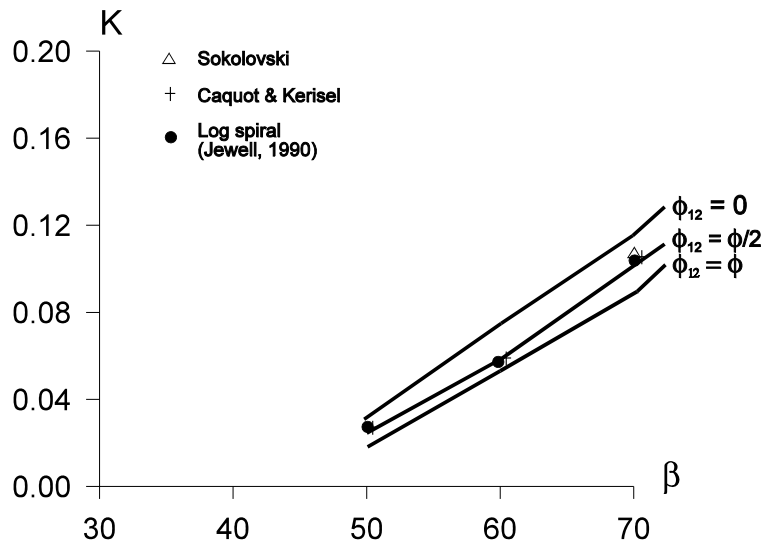
The following figures present values of K obtained by ReActiv for horizontal reinforcement with varying angles of interwedge friction ($\phi_{12} = 0$, $\phi_{12} = \phi/2$, and $\phi_{12} = \phi$). Also shown are results presented by Sokolovski, Caquot and Kerisel, and Jewell.

In most cases, setting $\phi_{12} = \phi/2$ yields results that are in reasonable agreement with the published values. In all cases, setting $\phi_{12} = 0$ yields conservative values of K (i.e. values above the published results) and setting $\phi_{12} = \phi$ yields unconservative values (i.e. values below the published results).

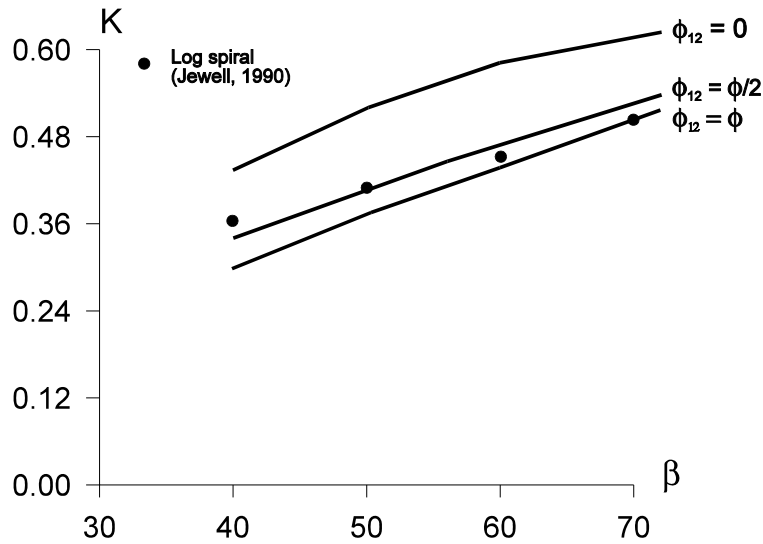
Parameters for the following figure are: $\delta = 0$, $\lambda_s = 1$, $i = 0$, $r_u = 0$, $\phi = 20^\circ$, $c' = 0$.



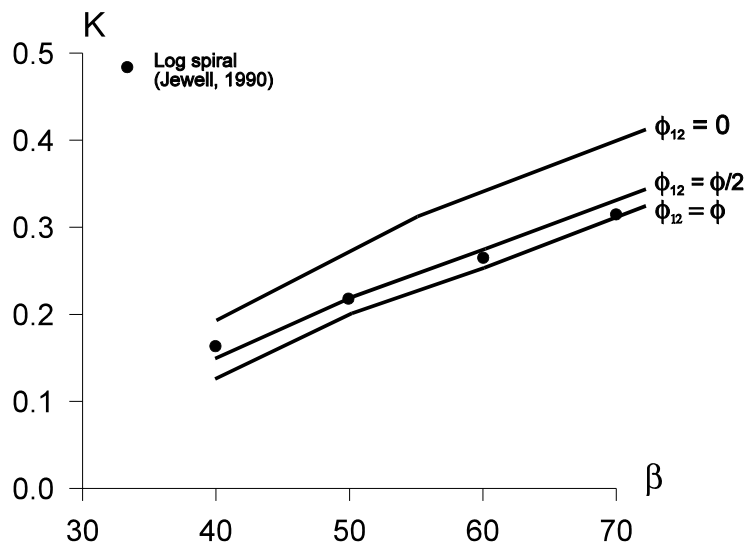
Parameters for the next figure are as above, except $\phi = 40^\circ$.



Parameters for the next figure are: $\delta = 0$, $\lambda_s = 1$, $i = 0$, $r_u = 0.5$, $\phi = 30^\circ$, $c' = 0$.



Parameters for the next figure are as above, except $r_u = 0.25$.



Inclined reinforcement

The following figures present values of K obtained by ReActiv for inclined

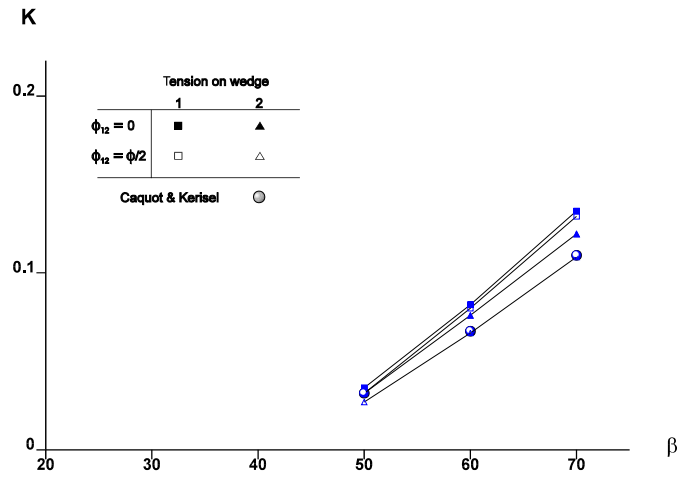
reinforcement with varying angles of interwedge friction ($\phi_{12} = 0$ and $\phi_{12} = \phi/2$) and varying the wedge on which the tension force acts (Wedge 1 or 2). Also shown are results derived from Caquot and Kerisel.

In all cases, applying the tension force on Wedge 1 yields conservative values of K (i.e. values above the published results).

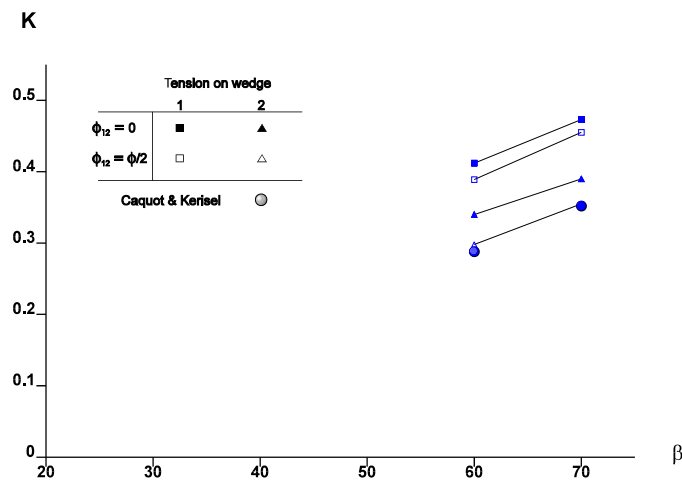
Less conservative values of K are obtained when the tension force is applied to Wedge 2 and ϕ_{12} is set to zero. However, the best fit to the published results is obtained when the tension force is applied to Wedge 2 and ϕ_{12} is set to $\phi/2$. Unfortunately, with this combination of parameters, the results are unconservative at low slope angles.

By default, ReActiv applies the tension force to Wedge 2 and sets ϕ_{12} equal to zero. This is conservative.

Parameters for the following figure are: $\delta = 10^\circ$, $\lambda_s = 1$, $i = 0$, $r_u = 0$, $\phi = 40^\circ$, $c' = 0$.

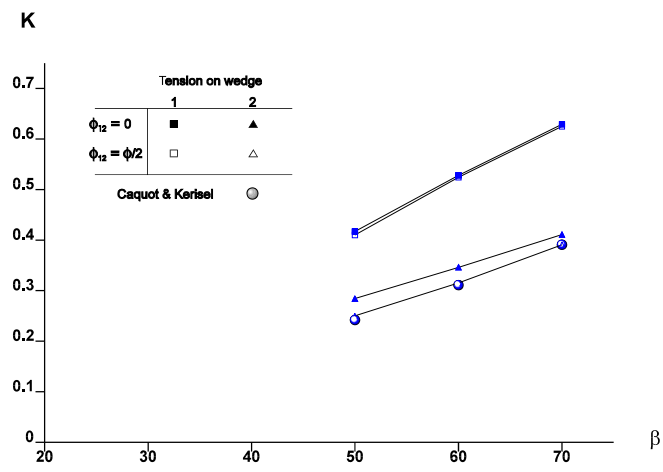


Parameters for the next figure are as above, except $\phi = 20^\circ$.



Parameters for the next figure are: $\delta = 20^\circ$, $\lambda_s = 1$, $i = 0$, $r_u = 0$, $\phi = 40^\circ$, $c' = 0$.

Parameters for the next figure are as above, except $\phi = 20^\circ$.



Chapter 12

Further examples

The examples described in this chapter are identical to the examples given in Appendix J of the UK Highways Agency's Advice Note. If you have a copy of the Advice Note, you may find it helpful to read the relevant pages before working through this chapter.

Exploring ReActiv's capabilities

If you have worked through the worked examples given in Chapters 4-6, you will already know how easy ReActiv is to use and how quickly it performs the calculations necessary to design a reinforced slope. Moreover, there is still plenty of scope for you to experiment with the program. In particular, you can:

- Change the water regime in the slope
- Change the surcharge that acts at the crest of the slope
- Change the type and properties of the reinforcement
- Calculate the reinforcement required to stabilize the slope
- Change various options that control those calculations
- Change the project information attached to the document
- Print the input and output data for the supplied examples
- Preview the printer's output on screen

In order to obtain a better appreciation of ReActiv's technical capabilities, we recommend that you try changing some or all of the options listed above and see what effect this has on the results of the calculations.

If you want to check that ReActiv is producing correct results, you can run one or more of the supplied examples and compare the results with those given in the Advice Note.

Supplied examples

A number of example projects are copied onto your hard disk when you install ReActiv. The projects have been given the names `EXAMPLEn.RAV`, where n is an integer between 1 and 7. The examples have been taken from Appendix J of the Advice Note and are described briefly on the following pages (please note that Example 4 is intentionally missing).

Example 1: embankment in dense sand

Example 1 is described in Tutorial 1 on page 24.

Example 2: embankment in stiff clay

Example 2 comprises a 10m high slope made out of stiff clay, which is reinforced by horizontal geotextiles so that it can stand at 30° to the horizontal.

The clay has an angle of shearing resistance of 20° , effective cohesion of 1kN/m^2 , and a bulk density of 19kN/m^3 . Bishop's pore pressure parameter for the slope (r_u) is 0.25. There is a surcharge of 10kN/m^2 at the top of the slope.

The reinforcement has a design strength of 28.9kN/m (after applying various factors-of-safety to it). The geotextile's direct shear factor is 0.95 (in the Advice Note, this parameter is called the interface sliding factor, α). Since the Advice Note does not allow for interwedge friction, the interwedge friction factor is set to zero.

You will find a copy of this project in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\EXAMPLES\EXAMPLE2.RAV

T_{\max} mechanism

According to ReActiv, the mechanism with the largest out-of-balance force anywhere in the slope (i.e. the T_{\max} mechanism) has the following properties:

■ $X = 13.27\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 46.4^\circ$, $T_{\max} = 301.68\text{kN/m}$

In the Advice Note, the equivalent height of the slope (H') is rounded down to 10.5m from 10.53m. This causes the Advice Note to give slightly different results to those obtained by ReActiv (i.e. $T_{\max} = 298\text{kN/m}$).

T_{ob} mechanism

The critical mechanism that requires exactly zero reinforcement to be stable (i.e. the T_{ob} mechanism) has the following properties:

■ $X = 22.46\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 55.0^\circ$, $T_{\max} = 0.00\text{kN/m}$

The X-value is in close agreement with the length L_b given in the Advice Note (despite the rounding mentioned above).

Required reinforcement

The slope being analysed requires twelve layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

■ 1.06, 2.65, 3.96, 4.97, 5.82, 6.57, 7.25, 7.87, 8.45, 9.00, 9.51, and 10.00m

These depths are identical to those given in the Advice Note. The required length of the layers varies from 8.14m at the top to 22.46m at the bottom.

Example 3: cutting in stiff clay

Example 3 is described in Tutorial 2 on page 30.

Example 5: slip repair in stiff clay

Example 5 comprises a 7m high embankment made out of stiff clay. The embankment has suffered a surface slip which is to be repaired by replacing the slipped material with soil reinforced by geotextiles. The slope is to stand at an angle of 26.56° to the horizontal (i.e. 1:2 vertical to horizontal).

From a back analysis of the slip, the clay has an angle of shearing resistance of 20° , effective cohesion of 1.5kN/m^2 , and a bulk density of 20kN/m^3 , assuming Bishop's pore pressure parameter for the slope (r_u) is 0.0. For design purposes, however, the angle of shearing resistance is to be reduced to 18.3° and the effective cohesion to 0kN/m^2 . There is no surcharge at the top of the slope.

The reinforcement has a design strength of 15.8kN/m (after applying various factors-of-safety to it). The geotextile's direct shear factor is 0.8 (in the Advice Note, this parameter is called the interface sliding factor, α). Since the Advice Note does not allow for interwedge friction, the interwedge friction factor is set to zero.

You will find a copy of this project in Windows' Shared Documents folder, located at:

GEOCENTRIX\REACTIV\1.7\EXAMPLES\EXAMPLE5.RAV

T_{\max} mechanism

According to ReActiv, the T_{\max} mechanism has the following properties:

■ $X = 8.79\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 42.3^\circ$, $T_{\max} = 76.96\text{kN/m}$

These values are in close agreement with the Advice Note.

T_{ob} mechanism

The T_{ob} mechanism has the following properties:

■ $X = 13.90\text{m}$, $Y = 0.00\text{m}$, $\theta_1 = 54.1^\circ$, $T_{\max} = 0.00\text{kN/m}$

The X-value is in close agreement with the length L_b given in the Advice Note.

Required reinforcement

The slope being analysed requires six layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

■ 1.57, 3.13, 4.43, 5.42, 6.26, and 7.00m

These depths are identical to those given in the Advice Note. The required length of the layers varies from 4.83m at the top to 13.90m at the bottom.

Example 6: cutting with unstable upper slope

Example 6 comprises a 9m high two-part slope, made out of stiff clay. The lower part of the slope is 3m high and is to stand at 60° to the horizontal. The upper part of the slope is 6m high and is to stand at 27° to the horizontal. The slope is reinforced by inclined soil nails.

The clay has an angle of shearing resistance of 22° , effective cohesion of 2kN/m^2 , and a bulk density of 20kN/m^3 . Bishop's pore pressure parameter for the slope (r_u) is 0.25. There is no surcharge at the top of the slope.

The reinforcement has a design strength of 41.8kN/m (after applying various factors-of-safety to it). The 16mm diameter soil nails are inclined at 10° to the horizontal, and are spaced at 1m intervals horizontally in the lower slope and at 2m intervals horizontally in the upper slope. The holes in which they are installed are 150mm in diameter. The nails' direct shear factor is 0.8 (in the Advice Note, this parameter is called the interface sliding factor, α). Since the Advice Note does not allow for interwedge friction, the interwedge friction factor is set to zero.

Analysing two-part slopes

When ReActiv analyses a Two-part slope, it determines the reinforcement required to stabilize the *lower* part, assuming that the upper slope is stable (and therefore requires no reinforcement). If the upper slope is not stable, it is necessary to conduct a second analysis in order to determine what reinforcement should be placed in the upper slope to correct this.

To analyse the upper slope, all you need to do is regard the lower slope as a competent bearing foundation and to treat the upper slope as if it were a One-part slope. In the example considered here, that means treating the upper slope as a 6m high slope standing at 27° to the horizontal.

The example project that are supplied with ReActiv illustrate how this can be done. The file `EXAMPLE6.RAV` can be used to determine the reinforcement required to stabilize the lower slope and `EXAMPLE7.RAV` to determine the reinforcement required to stabilize the upper slope.

You will find a copy of Example 6 in Windows' Shared Documents folder, located at:

`GEOCENTRIX\REACTIV\1.7\EXAMPLES\EXAMPLE6.RAV`

T_{\max} mechanism

According to ReActiv, the T_{\max} mechanism for the lower slope has the following properties:

■ $X = 9.54\text{m}$, $Y = 2.00\text{m}$, $\theta_1 = 46.4^\circ$, $T_{\max} = 140.13\text{kN/m}$

These values differ from the Advice Note because, by default, ReActiv applies all the reinforcement force to Wedge 2 (the lower wedge), whereas in the Advice Note the reinforcement force is applied to Wedge 1 (the upper wedge). A full discussion of these issues can be found in Chapter 9.

To reproduce the results given in the Advice Note, choose **Options | Tension on Wedge 1** from the menu bar and answer **Yes** to the question asking whether you want to proceed. When you recalculate T_{\max} , it has the following properties:

■ $X = 8.92\text{m}$, $Y = 1.44\text{m}$, $\theta_1 = 47.1^\circ$, $T_{\max} = 159.4\text{kN/m}$

These values are in reasonable agreement with the Advice Note (which gives $X = 8.0\text{m}$, $Y = 0.8\text{m}$, $\theta_1 = 45^\circ$, and $T_{\max} = 160\text{kN/m}$).

T_{ob} mechanism

With the **Tension on Wedge 1** option set, the T_{ob} mechanism has the following properties:

■ $X = 10.93\text{m}$, $Y = -1.93\text{m}$, $\theta_1 = 53.8^\circ$, $T_{\max} = 0.00\text{kN/m}$

The X-value is in reasonable agreement with the length L_B given in the Advice Note (which gives $L_B = 10.7\text{m}$).

Required reinforcement

The slope being analysed requires five layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

■ 0.75, 1.50, 2.12, 2.60, and 3.00m

The required length of the layers varies from 10.39m at the top to 11.0m at the bottom.

Example 7: upper slope of Example 6

Example 7 comprises the upper slope of Example 6 (see above).

You will find a copy of Example 7 in Windows' Shared Documents folder, located at:

`GEOCENTRIX\REACTIV\1.7\EXAMPLES\EXAMPLE7.RAV`

T_{\max} mechanism

According to ReActiv, the T_{\max} mechanism for the upper slope has the following properties:

■ $X = 7.24\text{m}$, $Y = 0.10\text{m}$, $\theta_1 = 41.5^\circ$, $T_{\max} = 32.17\text{kN/m}$

These values differ from the Advice Note because, by default, ReActiv applies all the reinforcement force to Wedge 2 (the lower wedge), whereas in the Advice Note the reinforcement force is applied to Wedge 1 (the upper wedge). A full discussion of these issues can be found in Chapter 9.

To reproduce the results given in the Advice Note, choose **Options | Tension on Wedge 1** from the menu bar and answer **Yes** to the question asking whether you want to proceed. When you recalculate T_{\max} , it has the following properties:

■ $X = 5.31\text{m}$, $Y = -0.94\text{m}$, $\theta_1 = 37.9^\circ$, $T_{\max} = 36.41\text{kN/m}$

These values differ slightly from the results given in the Advice Note, but the difference is not of engineering significance.

T_{ob} mechanism

With the **Tension on Wedge 1** option set, the T_{ob} mechanism has the following properties:

■ $X = 8.52\text{m}$, $Y = -1.50\text{m}$, $\theta_1 = 49.6^\circ$, $T_{\max} = 0.00\text{kN/m}$

The X-value is in reasonable agreement with the length L_b given in the Advice Note (which gives $L_b = 8.4\text{m}$).

Required reinforcement

The slope being analysed requires three layers of reinforcement and, for the most efficient layout, the layers would be placed at the following depths:

■ 2.12, 4.24, and 6.00m

The required length of the layers varies from 9.14m at the top to 8.65m at the bottom.

Chapter 13

Soil Classification System

The Soil Classification System used by ReActiv is based on a combination of:

- The British Soil Classification System (BSCS), as described in BS 5930:1981
- The Unified Soil Classification System (USCS), as described in ASTM D2487-1069
- The German Soil Classification System (DIN), as described in DIN 18 196

In addition to the basic groupings of Gravel, Sand, Silt, and Clay that are common to all these systems, the Soil Classification system includes commonly-encountered soils under the headings Organic, Fill, Chalk, Rock, River Soil, and Custom.

The following table lists the soils that are included in the Soil Classification System and give the corresponding group symbols from each of the established systems listed above (where they are available).

	Class	Symbol	BSCS	USCS	DIN	States
Gravel	Unclassified*	G	G	G	G	Unspecified (Unsp)
	Well-graded	GW	GW	GW	GW	Very loose (VL)¶
	Uniformly-gr'd	GPu	GPu	GP	GE	Loose (L)
	Gap-graded	GPg	GPg	GP	GI	Medium dense (MD)
	Silty	G-M	G-M	G?-GM	GU	Dense (D)
	Clayey*	G-C	G-C	G?-GC	GT	Very dense (VD)
	Very silty*	GM	GM	GM	GU	Poorly comp'd (PC)
	Very clayey*	GC	GC	GC	GT	Well comp'd (WC)
Sand	Unclassified*	S	S	S	S	Same as GRAVEL
	Well-graded	SW	SW	SW	SW	
	Uniformly-gr'd	SPu	SPu	SP	SE	
	Gap-graded	SPg	SPg	SP	SI	
	Silty	S-M	S-M	S?-SM	SU	
	Clayey*	S-C	S-C	S?-SC	ST	
	Very silty*	SM	SM	SM	SU	
	Very clayey*	SC	SC	SC	ST	
Granular silt	Unclassified	M	M	M	U	Unspecified (Unsp)
	Gravelly	MG	MG	ML/MH	-	Very loose (VL)¶
	Sandy	MS	MS	ML/MH	-	Loose (L)
	Low-plasticity	ML	ML	ML	UL	Medium dense (MD)
						Dense (D)
Cohesive silt	Unclassified*†	M	M	M	U	Same as CLAY
	Int.-plast.*†	MI	MI	ML	UM	
	High-plast.*†	MH	MH-ME	MH	-	
Clay	Unclassified*†\$	C	C	C	T	Unspecified (Unsp)*\$
	Gravelly*†	CG	CG	CL/CH	-	Very soft (VSo)
	Sandy*†	CS	CS	CL/CH	-	Soft (So)
	Low-plast.*†	CL	CL	CL	TL	Firm (F)*\$
	Int.-plast.*†\$	CI	CI	CL	TM	Stiff (St)*\$
	High-plast.*†\$	CH	CH-CE	CH	TA	Very stiff (VSt)*\$
	Laminated*†	Lam	-	-	-	Hard (H)*\$
Organic	Unclassified†	O	O	O	O	Same as CLAY
	Organic clay†	MO	MLO/H	OL	(OU)	
	Organic silt†	CO	CLO/H	OH	OT	
	Peat†	Pt	Pt	Pt	HN/HZ	
	Loam†	Loam	-	-	-	

	Class	Symbol	BSCS	USCS	DIN	States
Granular fill	Unclassified	MdG				Unspecified
	Rock fill	RockF				Poorly-comp'd (PC)
	Slag fill	Slag				Well-compacted (WC)
	Gravel fill	GravF				
	Sand fill	SandF				
	Chalk fill	ChkF				
	Brick hardcore	Brick				
	Ashes	Ash				
	PFA	PFA				
	Clay fill†	ClayF				Same as CLAY
Chalk	Unclassified*	Chk				Unspecified (Unsp)
	Grade I*	Chk1				
	Grade II*	Chk2				
	Grade III*	Chk3				
	Grade IV*	Chk4				
	Grade V	Chk5				
	Grade VI	Chk6				
Rock	Marl*	Marl				Unspecified (Unsp)
	Weathered rock*	Rock				
River soil	River mud†	RivM				Unspecified (Unsp)
	Dock silt†	DockS				Very soft (VSo)
	Alluvium†	Alluv				Soft (So)
	Custom*†\$	Cust				Unspecified (Unsp)*\$

G? = G, GW, or GP; S? = S, SW, or SP; Int. = intermediate; plast. = plasticity
 *may have effective cohesion (if symbol appears next to Class & State)
 †may be undrained
 \$may be fissured (if symbol appears next to Class & State)
 ‡potential for liquefaction

Database of soil properties

ReActiv uses a database of soil properties to check that any parameters you enter for a soil are compatible with that soil's engineering description.

ReActiv's checking system is based on the concept that there are *normal* and *extreme* ranges for each soil parameter.

If you enter a value that is outside the *extreme* range for a particular soil parameter, ReActiv issues an error message and prevents you from proceeding until you have changed the offending value.

If you enter a value that is outside the *normal* range, ReActiv issues a warning message and allows you to proceed only if you confirm that the value entered is correct.

The default parameters are provided to assist in initial design studies only, and should not be used as a substitute for measured parameters. As in all forms of geotechnical design, parameters should be chosen on the basis of adequate site investigation, including suitable laboratory and field measurements.

The publications that have been referred to in compiling the database include:

- Terzaghi & Peck (1967)
- NAVFAC DM-7 (1971)
- Peck, Hanson, & Thornburn (1974)
- Winterkorn & Fang (1975)

- Canadian Foundation Engineering Manual (1978)
- Reynolds & Steedman (1981)
- Bell (1983)
- Mitchell (1983)
- TradeARBED's *Spundwand-Handbuch Teil 1, Grundlagen* (1986)
- Bolton (1986)
- Clayton & Militiski (1986)
- Clayton (1989)
- Tomlinson (1995)
- British Steel's *Piling Handbook* (1997)

Invaluable advice regarding the properties of various soils was provided by Professors JB Burland, PR Vaughan, and DW Hight and by Dr G Sills.

In the following table ρ_d = dry density; ρ_w = wet density; ϕ_{peak} = peak angle of friction; ϕ_{crit} = critical state angle of friction; c'_{peak} = peak effective cohesion; c'_{crit} = critical state effective cohesion; S_u = undrained shear strength; ΔS_u = rate of increase in S_u with depth.

	Parameter	Classification		Minimum		Default	Maximum	
		Class	State	Ext.	Normal		Normal	Ext.
Gravel	ρ_d (kg/m ³)	All	Unsp	1200	1400	2050	2200	2500
			VL	1200	1300	1500	1600	1800
			L	1300	1400	1650	1800	2000
			MD	1400	1500	1850	2000	2200
			D	1500	1700	2050	2200	2400
			VD	1700	2000	2250	2400	2500
			PC	1200	1400	1650	1800	2200
			WC	1400	1700	2050	2200	2500
	ρ_s (kg/m ³)	All	Unsp	1500	1800	2200	2300	2500
			VL	1500	1700	1850	1900	2100
			L	1700	1800	2000	2100	2200
			MD	1800	1900	2100	2200	2300
			D	1900	2000	2200	2300	2400
			VD	2000	2200	2250	2400	2500
			PC	1500	1800	2000	2100	2300
			WC	1800	2000	2200	2300	2500
	ϕ_{peak} (deg)	All	Unsp	28	35	37	50	60
			VL	28	32	34	38	40
			L	30	35	37	40	45
			MD	35	40	42	45	50
			D	40	45	47	50	55
			VD	45	50	52	55	60
			PC	28	35	37	40	50
			WC	35	45	47	50	60
	ϕ_{crit} (deg)	All	All	28	35	37	40	45
	c'_{peak} (kPa)	G	All	0	0	0	0	10
		G_C GM GC						
		Others	All	Not applicable				
	c'_{crit} (kPa)	G	All	0	0	0	0	5
		G_C GM GC						
		Others	All	Not applicable				

	Parameter	Classification		Minimum		Default	Maximum	
		Class	State	Ext.	Normal		Normal	Ext.
Sand	ρ_d (kg/m ³)	All	Unsp	1200	1275	1675	1800	2200
			VL	1200	1225	1450	1550	1750
			L	1225	1275	1500	1600	1850
			MD	1275	1350	1575	1700	1950
			D	1350	1450	1675	1800	2050
			VD	1450	1575	1800	1900	2200
			PC	1200	1275	1500	1600	1950
			WC	1275	1450	1675	1800	2200
	ρ_s (kg/m ³)	All	Unsp	1600	1800	2075	2150	2400
			VL	1600	1750	1900	1975	2000
			L	1750	1800	1950	2000	2050
			MD	1800	1850	1975	2050	2150
			D	1850	1950	2075	2150	2250
			VD	1950	2050	2175	2250	2400
			PC	1600	1800	1950	2000	2150
			WC	1800	1950	2075	2150	2400
	ϕ_{peak} (deg)	All	Unsp	20	30	32	40	55
			VL	20†	25†	26†	28†	30†
			L	26	30	32	35	40
			MD	29	33	34	37	45
			D	33	36	37	40	50
			VD	37	40	42	45	55
			PC	23	30	32	35	45
			WC	29	36	37	40	55
	ϕ_{crit} (deg)	All	All	23	30	32	35	40
	c'_{peak} (kPa) discounting natural cementation	S	All	0	0	0	0	10
		S_C SM SC						
		Others	All	Not applicable				
	c'_{crit} (kPa)	S	All	0	0	0	0	5
		S_C SM SC						
		Others	All	Not applicable				
Granular silt	ρ_d (kg/m ³)	All	All	1100	1275	1850	2150	2200
	ρ_s (kg/m ³)	All	All	1500	1800	2050	2150	2400
	ϕ_{peak} (deg)	All	Unsp	20	27	28	33	45
			VL	20†	25†	26†	28†	30†
			L	23	27	28	31	35
			MD	25	28	29	32	37
			D	27	29	30	33	40
			VD	30	32	33	36	45
	ϕ_{crit} (deg)	All	All	20	27	28	31	35
	c'_{peak} (kPa)	All	All	0	0	0	5	10
	c'_{crit} (kPa)	All	All	0	0	0	0	5
Cohesive silt	ρ_d (kg/m ³)	All	All	1100	1275	1850	2150	2200
	ρ_s (kg/m ³)	All	All	1500	1800	2050	2150	2400
	ϕ_{peak} (deg)	M	All	17	25	28	35	45
		MI MH		17 17	25 20	28 23	35 30	40 35

Parameter	Classification		Minimum		Default	Maximum	
	Class	State	Ext.	Normal		Normal	Ext.
φ_{crit} (deg)	M	All	17	22	25	30	32
	MI		20	22	25	30	32
	MH		17	18	19	22	25
c'_{peak} (kPa)	All	VSo-So	0	0	0	0	0
		Others	0	0	0	5	10
c'_{crit} (kPa)	All	VSo-So	0	0	0	0	0
		Others	0	0	0	0	5
S_u (kPa)	All	Unsp	1	20	20	150	1000
		VSo	1	5	10	20	30
		So	10	20	25	40	60
		F	30	40	50	75	100
		St	60	75	100	150	200
		VSt	100	150	200	300	400
		H	200	300	375	500	1000
ΔS_u (kPa)	All	VSo-So	-100	-10	0	4	100
		Others	-100	-10	0	8	100
Clays	ρ_d (kg/m ³)	Unsp	1200	1500	2050	2200	2500
		VSo	1200	1400	1650	1800	2000
		So	1300	1500	1750	1900	2100
		F	1450	1650	1900	2050	2250
		St	1600	1800	2050	2200	2400
		VSt	1750	1950	2200	2350	2450
		H	1900	2100	2300	2400	2500
	ρ_s (kg/m ³)	Unsp	1200	1500	2050	2200	2500
		VSo	1200	1400	1650	1800	2000
		So	1300	1500	1750	1900	2100
		F	1450	1650	1900	2050	2250
		St	1600	1800	2050	2200	2400
		VSt	1750	1950	2200	2350	2450
		H	1900	2100	2300	2400	2500
	φ_{peak} (deg)	C	15	20	20	33	39
		CG	18	20	24	33	39
		CS	18	20	24	33	39
		CL	20	24	27	33	39
		CI	18	20	23	30	37
		CH	15	16	20	27	31
		Lam	15	16	19	25	39
	φ_{crit} (deg)	C	8	20	23	33	39
		CG	18	20	24	33	39
		CS	18	20	24	33	39
		CL	18	20	23	28	30
		CI	18	20	23	28	30
		CH	8	15	18	20	22
		Lam	8	12	16	20	22
c'_{peak} (kPa)	All	Unsp	0	0	0	10	15
		VSo	0	0	0	0	0
		So	0	0	0	0	0
		Others	0	0	2	10	15
c'_{crit} (kPa)	All	VSo-So	0	0	0	0	0
		Others	0	0	0	0	5

	Parameter	Classification		Minimum		Default	Maximum	
		Class	State	Ext.	Normal		Normal	Ext.
Organic	S _u (kPa)	All	Unsp	1	20	20	150	1000
			VSo	1	5	10	20	30
			So	10	20	25	40	60
			F	30	40	50	75	100
			St	60	75	100	150	200
			VSt	100	150	200	300	400
			H	200	300	375	500	1000
	ΔS _u (kPa)	All	VSo-So	-100	-10	0	8	100
			Others	-100	-10	0	8	100
	ρ _d (kg/m ³)	Uncl	All	800	1000	1500	2050	2250
		MO		1000	1250	1500	1600	1750
		CO		1000	1250	1500	1600	1750
		Pt		800	1000	1200	1300	1400
		Loam		1450	1650	1900	2050	2250
	ρ _s (kg/m ³)	Uncl	All	850	1050	1650	2050	2250
		MO		1400	1500	1650	1750	1950
		CO		1400	1500	1650	1750	1950
		Pt		850	950	1250	1400	1500
		Loam		1450	1650	1900	2050	2250
	φ _{peak} (deg)	Uncl	All	18	20	23	30	39
		MO		18	20	23	30	37
		CO		18	20	23	30	37
		Pt		18	20	23	30	37
		Loam		20	24	27	33	39
	φ _{crit} (deg)	Uncl	All	18	20	23	30	39
		MO		18	20	23	30	37
		CO		18	20	23	30	37
		Pt		18	20	23	30	37
Loam		20		24	27	33	39	
c' _{peak} (kPa)	All	All	Not applicable					
c' _{crit} (kPa)	All	All	Not applicable					
Granular fill	S _u (kPa)	All	Unsp	1	20	20	150	1000
			VSo	1	5	10	20	30
			So	10	20	25	40	60
			F	30	40	50	75	100
			St	60	75	100	150	200
			VSt	100	150	200	300	400
			H	200	300	375	500	1000
	ΔS _u (kPa)	All	VSo-So	-100	-10	0	8	100
			Others	-100	-10	0	8	100
	ρ _d (kg/m ³)	MdG	All	600	1225	1600	1800	2500
		RockF		1400	1500	1900	2100	2200
		Slag		1000	1200	1450	1600	1800
		GravF		1200	1400	1950	2200	2500
		SandF		1200	1225	1600	1800	2200
		ChkF		1250	1300	1350	1400	1450
		Brick		1100	1300	1600	1750	1900
		Ash		600	650	1000	1000	1200
		PFA		900	1000	1350	1500	1700

Parameter	Classification		Minimum		Default	Maximum		
	Class	State	Ext.	Normal		Normal	Ext.	
ρ_s (kg/m ³)	MdG	All	1200	1650	2000	2150	2500	
	RockF		1750	1900	2100	2200	2300	
	Slag		1400	1700	1850	1900	2000	
	GravF		1500	1800	2150	2300	2500	
	SandF		1600	1800	2050	2150	2400	
	ChkF		1700	1750	1825	1850	1900	
	Brick		1400	1650	1850	1950	2100	
	Ash		1200	1300	1450	1500	1800	
	PFA		1350	1500	1750	1800	2000	
φ_{peak} (deg)	MdG	All	23	30	35	45	60	
	RockF		35	40	43	50	60	
	Slag		25	30	33	40	50	
	GravF		28	35	40	50	60	
	SandF		23	30	32	35	40	
	ChkF		25	30	32	37	43	
	Brick		35	40	42	45	50	
	Ash		30	35	37	40	45	
	PFA		27	30	32	37	40	
φ_{crit} (deg)	MdG	All	25	30	32	35	45	
	RockF		30	35	37	40	45	
	Slag		25	30	32	35	45	
	GravF		28	35	37	40	45	
	SandF		23	30	32	35	40	
	ChkF		25	30	32	35	40	
	Brick		25	30	32	35	40	
	Ash		27	30	33	38	42	
	PFA		27	30	32	35	40	
Cohesive fill	ρ_d (kg/m ³)	All	All	950	1100	1550	1750	1900
	ρ_s (kg/m ³)	All	All	1300	1500	1850	2050	2250
	φ_{peak} (deg)	All	All	15	17	21	30	35
	φ_{crit} (deg)	All	All	15	17	21	28	30
	c'_{peak} (kPa)	All	All	Not applicable				
	c'_{crit} (kPa)	All	All	Not applicable				
	S_u (kPa)	All	Unsp	1	20	20	150	1000
			VSo	1	5	10	20	30
			So	10	20	25	40	60
			F	30	40	50	75	100
		St	60	75	100	150	200	
		VSt	100	150	200	300	400	
		H	200	300	375	500	1000	
ΔS_u (kPa)	All	VSo-So	-100	-10	0	8	100	
		Others	-100	-10	0	8	100	
Chalk	ρ_d (kg/m ³)	Chk		1255	1275	1450	2250	2500
		Chk1		1525	1650	2050	2250	2500
		Chk2		1350	1400	1575	1650	1725
		Chk3		1275	1325	1450	1500	1550
		Chk4		1250	1300	1375	1425	1475
		Chk5		1225	1275	1350	1400	1450
		Chk6		1225	1275	1350	1400	1450

Parameter	Classification		Minimum		Default	Maximum	
	Class	State	Ext.	Normal		Normal	Ext.
ρ_s (kg/m ³)	Chk		1725	1750	1900	2450	2600
	Chk1		1925	2025	2300	2450	2600
	Chk2		1800	1850	1975	2025	2075
	Chk3		1750	1800	1900	1925	1950
	Chk4		1750	1775	1850	1875	1900
	Chk5		1725	1750	1825	1850	1900
	Chk6		1725	1750	1825	1850	1900
ϕ_{peak} (deg)	Chk		25	30	35	45	55
	Chk1		25	30	35	45	55
	Chk2		25	30	34	43	52
	Chk3		25	30	34	41	49
	Chk4		25	30	33	39	46
	Chk5		25	30	32	37	43
	Chk6		25	30	32	35	40
ϕ_{crit} (deg)	All		25	30	32	35	40
c'_{peak} (kPa)	Chk		0	0	0	20	100
	Chk1		0	0	10	20	100
	Chk2		0	0	5	20	50
	Chk3		0	0	5	20	50
	Chk4		0	0	2	10	20
	Chk5		0	0	0	0	0
	Chk6		0	0	0	0	0
c'_{crit} (kPa)	All		0	0	0	0	5
Rock	ρ_d (kg/m ³)	All	2050	2100	2250	2300	2500
	ρ_s (kg/m ³)	All	2050	2100	2250	2300	2500
	ϕ_{peak} (deg)	All	27	30	33	38	42
	ϕ_{crit} (deg)	All	27	30	33	38	42
	c'_{peak} (kPa)	All	0	0	5	10	20
	c'_{crit} (kPa)	All	0	0	0	0	5
River Soil	ρ_d (kg/m ³)	All	1200	1250	1600	1800	2000
		VSo	1200	1250	1600	1800	2000
		So	1200	1400	1650	1800	2000
	ρ_s (kg/m ³)	All	1200	1250	1600	1800	2000
		VSo	1200	1250	1600	1800	2000
		So	1200	1400	1650	1800	2000
	ϕ_{peak} (deg)	All	All	15	16	22	33
	ϕ_{crit} (deg)	All	All	15	16	22	33
	c'_{peak} (kPa)	All	All	Not applicable			
	c'_{crit} (kPa)	All	All	Not applicable			
	S_u (kPa)	All	1	20	20	40	60
		VSo	1	5	10	20	30
		So	10	20	25	40	60
	ΔS_u (kPa)	All	All	-100	-10	0	100
Custom	ρ_d (kg/m ³)	Uncl	Unsp	600	1200	2000	2400
	ρ_s (kg/m ³)	Uncl	Unsp	850	1200	2000	2400
	ϕ_{peak} (deg)	Uncl	Unsp	10	20	30	50

Parameter	Classification		Minimum		Default	Maximum	
	Class	State	Ext.	Normal		Normal	Ext.
ϕ_{crit} (deg)	Uncl	Unsp	8	20	25	35	45
c'_{peak} (kPa)	Uncl	Unsp	0	0	0	10	100
c'_{crit} (kPa)	Uncl	Unsp	0	0	0	0	5
S_u (kPa)	Uncl	Unsp	1	5	20	300	1000
ΔS_u (kPa)	Uncl	Unsp	-100	-10	0	10	100