13 Step-Path Failure of Rock Slopes

13.1 Problem Statement

While *UDEC* represents a jointed rock structure as a system of discrete blocks by default, it is also a straightforward matter to simulate the case in which joints terminate within intact rock. This is illustrated in this example application, which analyzes the stability of a simple slope containing noncontinuous en echelon jointing. If failure occurs both along the joints and within the intact rock, a "step-path failure" involving a combination of shear failure along the joints and shear and tensile failure within the intact rock bridging between the joints can develop.

Three en echelon joints exist within the slope, as depicted in Figure 13.1. The three joints have a dip of 35°, and terminate within the rock near the slope surface. The slope dips at 50°, and has a height of 11.8 m.

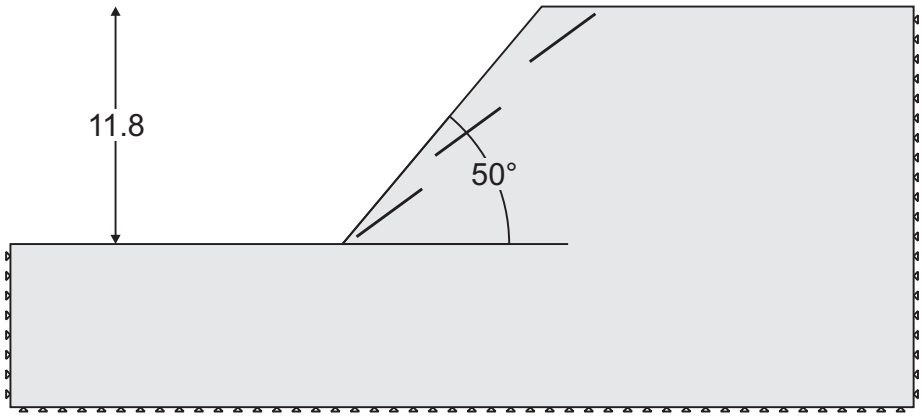

Figure 13.1 Geometry of simple slope containing en echelon joints

The properties of the intact rock are

density	2000 kg/m^3
Young's modulus	20 GPa
Poisson's ratio	0.3
friction angle	25°
dilation angle	0
cohesion	25,000 Pa
tensile strength	0

The properties of the en echelon joints are

normal stiffness	100 GPa/m
shear stiffness	10 GPa/m
friction angle	35°
cohesion	1000 MPa

The failure mode within the slope model is evaluated by performing factor-of-safety calculations based upon the shear strength reduction method (see Section 2 in **Theory and Background**). The failure mode can be identified when the strength properties are reduced to produce the state at which failure occurs.

13.2 *UDEC* Analysis

Discontinuous jointing can be simulated in *UDEC* by combining real joints with construction joints along the paths of the en echelon joints. Note that construction joints effectively glue two blocks together so that the blocks behave as one intact block. The *UDEC* commands to create the en echelon joints are described below, and the resulting joint structure is illustrated in Figure 13.2.

Cracks are introduced along the path of the three en echelon joints by using the **block cut crack** command to create real joints, and the **block cut crack ... join** command to create a construction joint connecting the ends of real joints. Several commands are executed:

```
block cut crack (17,8.2) (18.33,9.37)        join
block cut crack (18.33,9.37) (22.33,12.25)
block cut crack (22.33,12.25) (22.33,13.5)   join
block cut crack (22.33,13.5) (26.26,16)
block cut crack (26.26,16) (26.26,17.16)     join
block cut crack (26.26,17.16) (29.33,19.33)
block cut crack (29.33,19.33) (30,20)        join
```

Each **block cut crack ... join** command creates a construction joint that connects the ends of the real joints to produce a continuous joint through the model. Figure 13.2 displays the real joints, but not the construction joints.

For comparison, two separate models are created: the first contains no joints, and the second is created with three continuous joints located at the same position and orientation as the en echelon joints. The three continuous joints are created with the commands

```
block cut crack (17,8.2) (33.2,20)
block cut crack (15.5,8.2) (31.7,20)
block cut crack (14,8.2) (30.2,20)
```

This joint structure is shown in Figure 13.3.

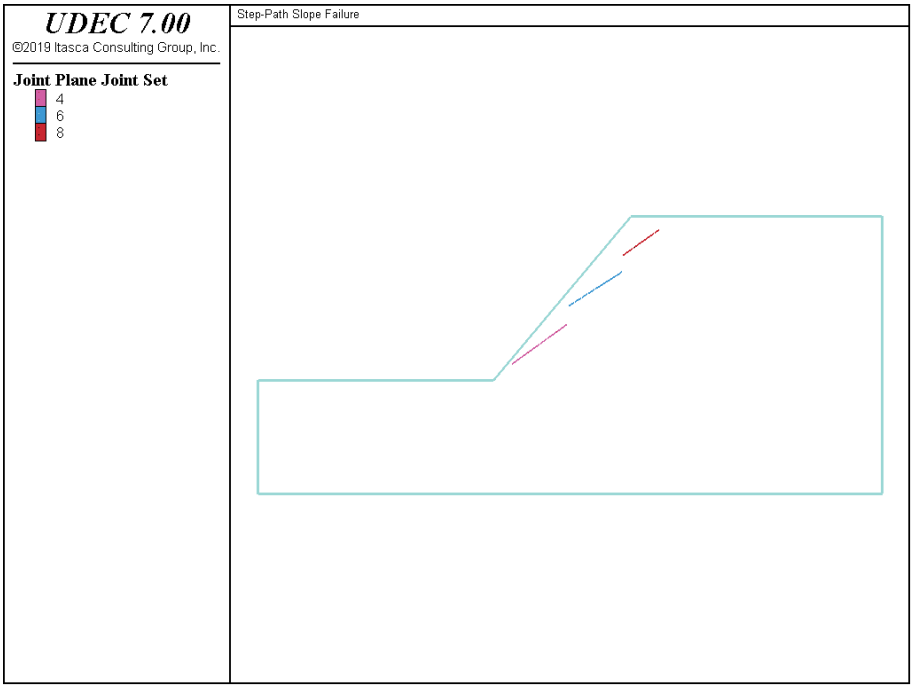

Figure 13.2 En echelon joints in slope model

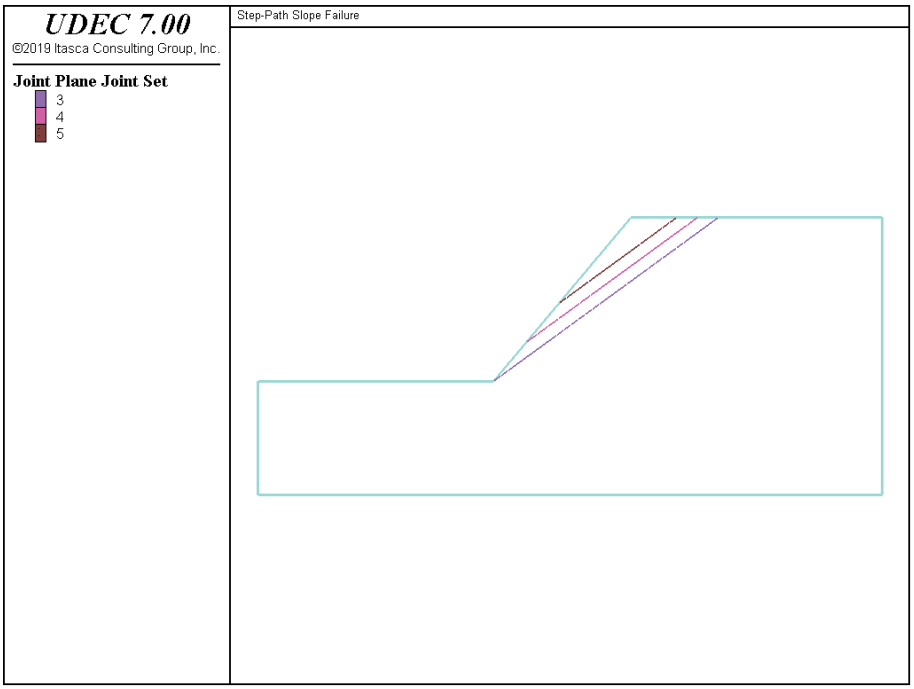

Figure 13.3 Continuous joints in slope model

A factor-of-safety calculation (**block factory-of-safety**) is performed for all three models. The factor of safety for the en echelon joint model is found to be 1.28. A step-path failure mode is indicated by the velocity vectors plot shown in Figure 13.4, and by the contour plot of joint maximum shear displacement and rock maximum shear strain shown in Figure 13.5.

For comparison, the factor of safety was also calculated for the model with no joints (FOS = 1.38, see Figure 13.6) and for the model with continuous joints through the slope (FOS = 1.01, see Figure 13.7). A circular failure mode within the intact rock is indicated in Figure 13.6. A planar shear failure mode along the joints is shown in Figure 13.7.

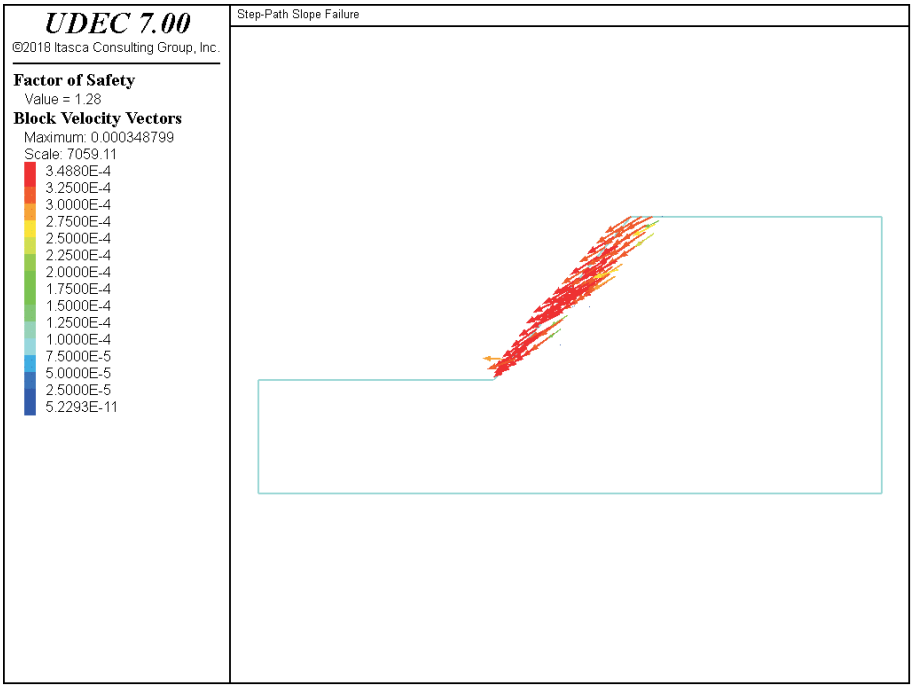

Figure 13.4 Step-path failure of slope – factor-of-safety = 1.28

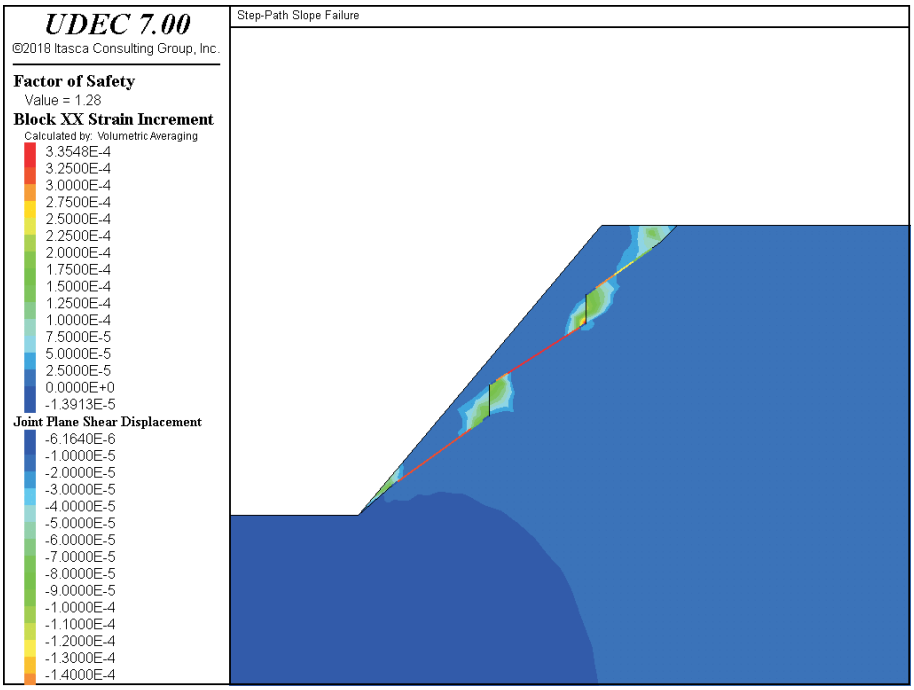

Figure 13.5 Step-path failure depicted by joint maximum shear displacement and rock maximum shear strain

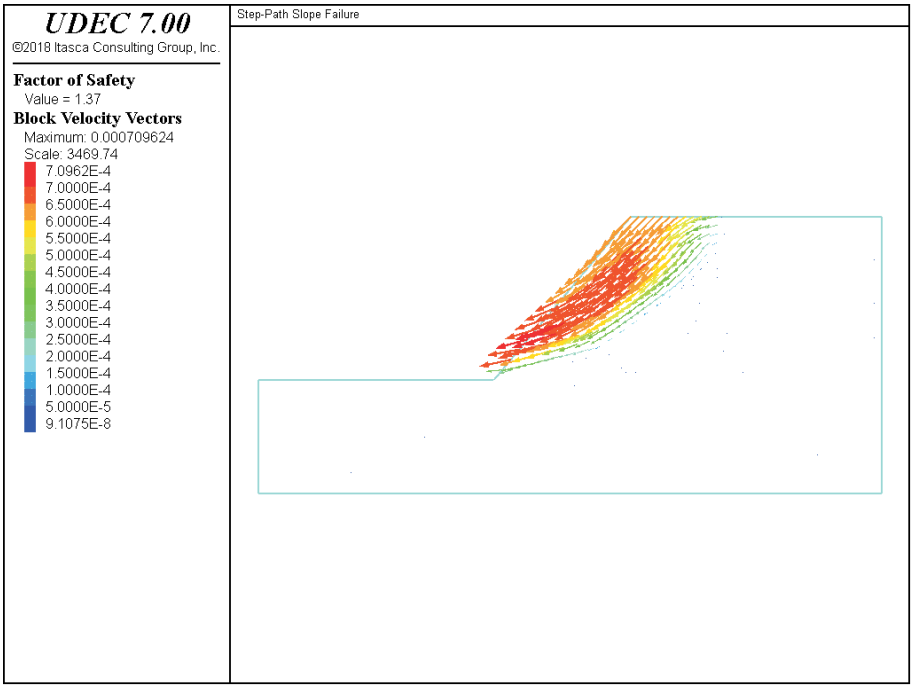

Figure 13.6 Continuum failure of slope – factor-of-safety = 1.38

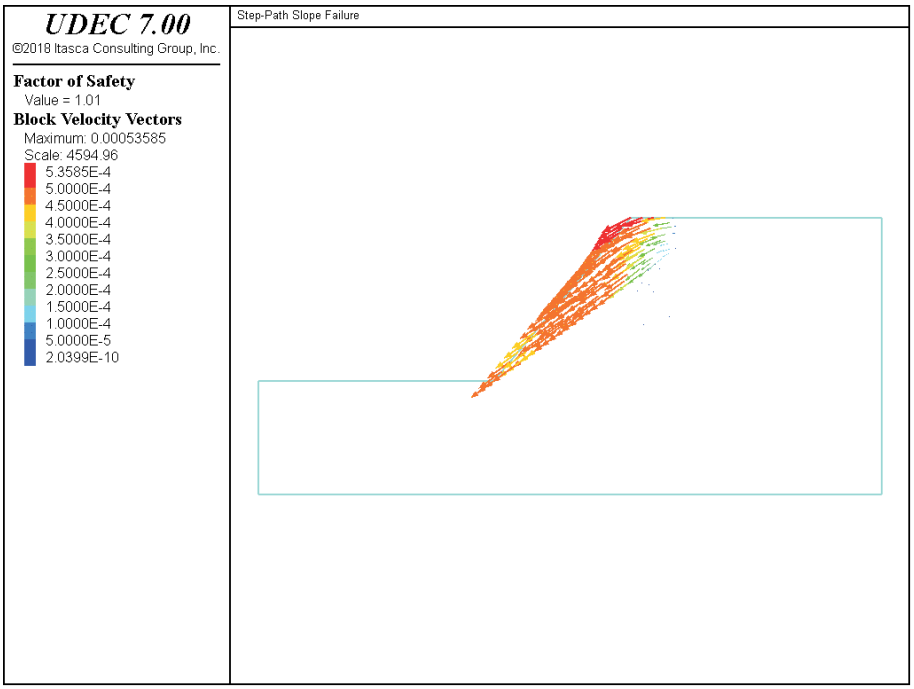

Figure 13.7 Continuous joint shear failure of slope – factor-of-safety = 1.01

13.3 Listing of Data File

Example 13.1 STEPPATH.DAT

```
;File:steppath.dat
model Title 'Step-Path Slope Failure'
model new
; model with en-echelon joint structure
block tolerance corner-round-length 4.5E-2
block tolerance minimum-edge-length 9E-2
block create polygon 0 0 0 20 45 20 45 0
; create en-echelon joints
block cut crack (0,8.2) (17,8.2)
block cut crack (17,8.2) (26.9,20)
block cut crack (17,8.2) (18.33,9.37) join
block cut crack (18.33,9.37) (22.33,12.25)
block cut crack (22.33,12.25) (22.33,13.5) join
block cut crack (22.33,13.5) (26.26,16)
block cut crack (26.26,16) (26.26,17.16) join
block cut crack (26.26,17.16) (29.33,19.33)
block cut crack (29.33,19.33) (30,20) join
block delete range pos-x 0,17 pos-y 8,20
block zone gen edge 1.0
model save 'sp1.sav'
; assign properties
block zone group 'rock'
block zone cmodel assign mohr-c density 2E3 bulk 1.66667E10 ...
  shear 7.69231E9 friction 25 cohesion 2.5E4 range group 'rock'
block contact property material 1 stiffness-shear 1E10 ...
  stiffness-normal 1E11 friction 35 cohesion 1E3
block contact group 'joint'
block contact cmodel assign area st-s 1E10 st-n 1E11 friction 35 ...
  cohesion 1E3 range group 'joint'
; new contact default
block contact cmodel default area st-s=1E10 st-n=1E11 friction=35 ...
  cohesion=1000
; set boundary conditions
block gridpoint apply velocity-x 0 range pos-x -0.1 0.1  pos-y -0.1 8.2
block gridpoint apply velocity-x 0 range pos-x 44.9 45.1 pos-y -0.1 20.1
block gridpoint apply velocity-y 0 range pos-x -0.1 45.1 pos-y -0.1 0.1
model gravity 0.0 -9.81
model save 'sp2.sav'
block solve ratio 1.0E-5 elastic
model save 'sp3.sav'
; Factor of safety
block factor-of-safety no_restore file 'FoSmode1.fsv'
```

```
model save 'FoSmode1.fsv'
;
;
model new
; model with continuous joint structure
block tolerance corner-round-length 4.5E-2
block tolerance minimum-edge-length 9E-2
block create polygon 0 0 0 20 45 20 45 0
; create continuous joints
block cut crack 0 8.2 17 8.2
block cut crack 17 8.2 26.9 20
block cut crack 17 8.2 33.2 20
block cut crack 15.5 8.2 31.7 20
block cut crack 14 8.2 30.2 20
block delete range pos-x 0 19 pos-y 8 20
block zone gen edge 1.0
model save 'sp1a.sav'
; assign properties
block zone group 'rock'
block zone cmodel assign mohr-c density 2E3 bulk 1.66667E10 ...
  shear 7.69231E9 friction 25 cohesion 2.5E4 range group 'rock'
block contact group 'joint'
block contact cmodel assign area st-s 1E10 st-n 1E11 friction 35 ...
  cohesion 1E3 range group 'joint'
; new contact default
block contact cmodel default area st-s 1E10 st-n 1E11 friction 35 ...
  cohesion 1000
; set boundary conditions
block gridpoint apply velocity-x 0 range pos-x -0.1 0.1  pos-y -0.1 8.2
block gridpoint apply velocity-x 0 range pos-x 44.9 45.1 pos-y -0.1 20.1
block gridpoint apply velocity-y 0 range pos-x -0.1 45.1 pos-y -0.1 0.1
model gravity 0.0 -9.81
model save 'sp2a.sav'
block solve ratio 1.0E-5 elastic
model save 'sp3a.sav'
; Factor of safety
block factor-of-safety no_restore file 'FoSmode2.fsv'
model save 'FoSmode2.fsv'
;
model new
; model with no joints
block tolerance corner-round-length 4.5E-2
block tolerance minimum-edge-length 9E-2
block create polygon 0 0 0 8.2 17 8.2 26.9 20 45 20 45 0
block zone gen edge 1.0
model save 'sp1b.sav'
```

```
; assign properties
block zone group 'rock'
block zone cmodel assign mohr-c density 2E3 bulk 1.66667E10 ...
  shear 7.69231E9 friction 25 cohesion 2.5E4 range group 'rock'
; set boundary conditions
block gridpoint apply velocity-x 0 range pos-x -0.1 0.1  pos-y -0.1 8.2
block gridpoint apply velocity-x 0 range pos-x 44.9 45.1 pos-y -0.1 20.1
block gridpoint apply velocity-y 0 range pos-x -0.1 45.1 pos-y -0.1 0.1
model gravity 0.0 -9.81
model save 'sp2b.sav'
block solve ratio 1.0E-5 elastic
model save 'sp3b.sav'
; Factor of safety
block factor-of-safety no_restore file 'FoSmode3.fsv'
model save 'FoSmode3.fsv'
ret
```