SLOPE STABILITY ANALYSIS BY FINITE ELEMENTS

A guide to the use of Program **`slope2`**

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Downloading the **slope2** program

The source code for **slope2** is written in Fortran 95, but users are provided with the executable file **slope2.exe** and the example data files case**1.dat** thru **case5.dat** as described in this report. The slope stability software is in folder

4th_ed/executable/slope_stab/slope2

and can also be found on the course web site at:

http://www.mines.edu/~vgriffit/4th_ed/executable/slope_stab/slope2

The files needed to run a slope analysis are as follows:

slope2.exe	An executable file of the slope1 program
case?.dat	A typical data file as described in this report

Running an example problem

In order to run **slope2** with an example data file, e.g. **case4.dat**, use Windows Explorer to navigate to the folder **4th_ed/executable/slope_stab/slope2,** double click on the executable icon slope2.exe, and when prompted type the base-name of the data file, namely case4

If the program runs properly, you should see evidence of iterations being reported back to the screen. When the job is complete you should see the following additional files in the slope2 folder:

case4.res	Output file giving the estimated Factor of Safety.
case4.msh	PostScript file showing the finite element mesh.
case4.vec	PostScript file showing nodal displacement vectors at failure.
case4.dis	PostScript file showing the deformed mesh at failure.

Running your own problem

Create your own data file. This report explains the layout of data for use with **`slope2`.** It may help to make a copy of one of the example data files closest to your own problem and edit that as needed. Let us assume your data file is called **`fred.dat`**. Note that the extension must be of type **`.dat`**.

In order to run your own data file **`fred.dat`**, once more double- click on the executable icon `slope2.exe`, and when prompted type the basename of the data file, namely `fred`

If all goes well, the following additional files will appear in your folder: **`fred.res, fred.msh, fred.vec`** and **`fred.dis`** with the same meanings as described previously.

Note: Program `slope2.f95` is based closely on `p63.f95` in the textbook, "Programming the Finite Element Method" by I.M. Smith and D.V. Griffiths. 4th ed., 2004. The main difference lies in the mesh generation and the automatic search for the critical strength reduction factor. Users of `slope1` are encouraged to refer to this text and the companion paper, "Slope stability analysis by finite elements", by D.V. Griffiths and P.A. Lane, *Géotechnique* 49, no.3, pp.387-403, (1999).

Explanation of Data for Program `slope2.f95`

A typical configuration is shown in Figure 1

Slope geometry data:

`w1` = Distance foundation extends to left of embankment toe
`s2` = Width of sloping portion of embankment to the left
`w2` = Width of top of embankment
`s2` = Width of sloping portion of embankment to the right
`w3` = Distance foundation extends to right of embankment toe
`h1` = Height of embankment
`h2` = Thickness of foundation layer

Element discretization data:

`nx1` = Number of x-elements to left of embankment
`nx2` = Number of x-elements in embankment
nx3 = Number of x-elements to right of embankment
`ny1` = Number of y-elements in embankment
`ny2` = Number of y-elements in foundation

Soil property data: [1]

`np_types` = Number of different property groups
`phi,c,psi,gamma,e,v` = Material properties $\phi', c', \psi, \gamma, E, \upsilon$ (`np_types` times)
`etype` = Property group assigned to each element (`nels` times)
(data not needed if `np_types`=1)

Pseudo-static analysis: [2]

`k_h` = Horizontal acceleration factor,

Phreatic surface data: [3]

`nosurf` = Number of phreatic surface coordinates
`x, y` = x- and y- coordinates of phreatic surface (`nosurf` times), or the r_u value
`gam_w` = Unit weight of water, γ_w

Iteration ceiling:

`limit` = Iteration ceiling (suggested value, 500)

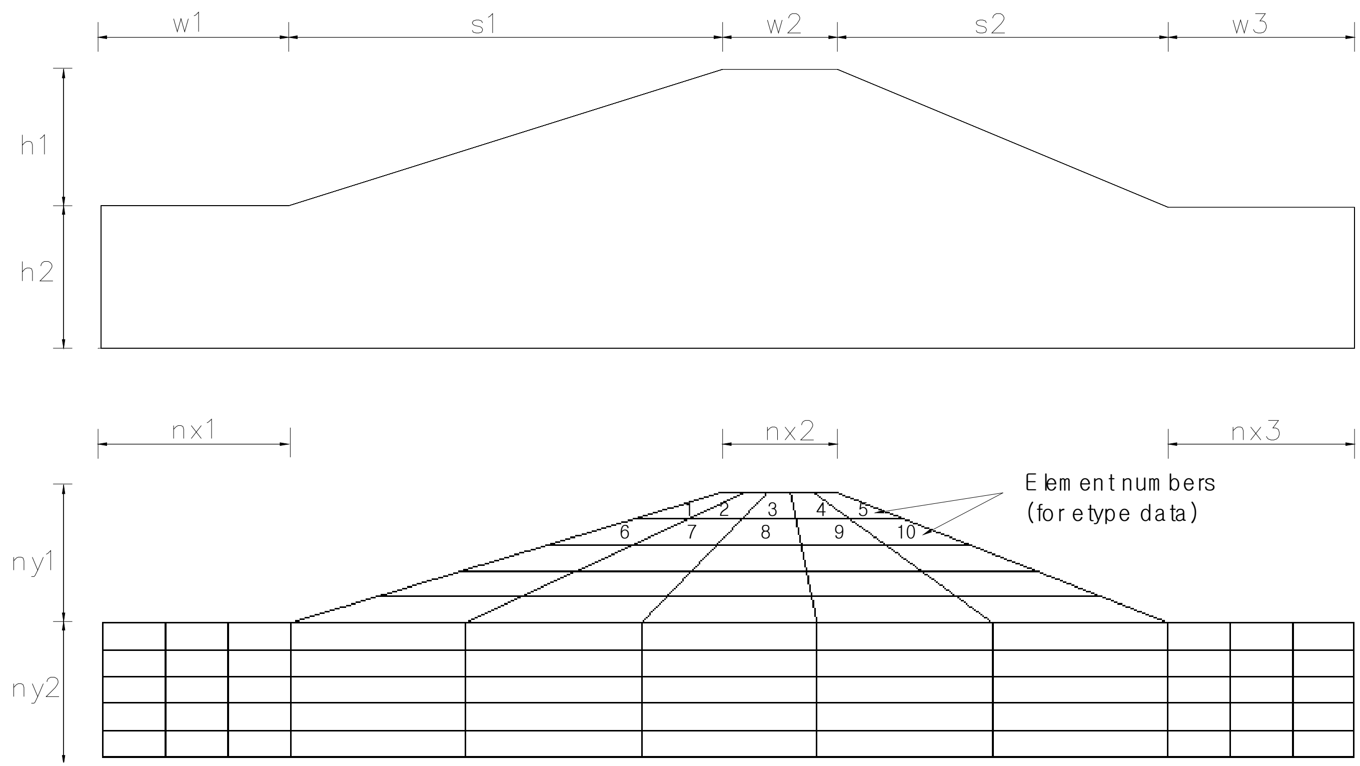
Factor of Safety Tolerance:

`fos_tol` = Factor of safety tolerance (suggested value, 0.05)

[1] ϕ' is the effective friction angle; c' is the effective cohesion; ψ is the dilation angle and can usually be set to zero; γ is the total unit weight; E is Young's modulus and is often set to a nominal value (e.g.10^5); υ is Poisson's ratio and is often set to a nominal value (e.g. 0.3), `nels` is the total number of elements in the mesh and is computed internally by the program

[2] k_h is the horizontal pseudo-static acceleration factor, e.g, for horizontal acceleration of 0.2g, set k_h=0.2

[3] If `nosurf=1`, then instead of x, y data, read a single value of r_u



Number of elements in each section and
element numbering for `etype` data

Fig. 1 Layout and dimensions of embankment geometry

Example 1: A homogenous slope (no phreatic surface)

The stability analysis is of the homogeneous c′-φ′ slope shown in Figure 1.1

Data for Example 1(case1.dat)

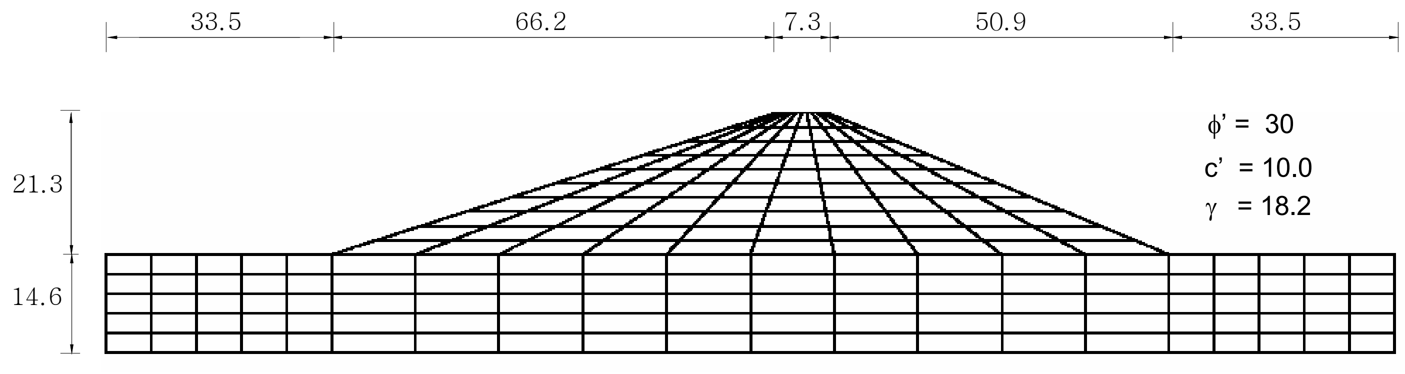


Fig. 1.1 Finite element mesh for example 1

"Example 1 A homogeneous slope (no phreatic surface)"
"Distance foundation extends to left of embankment toe (w1)"
33.5
"Width of sloping portion of embankment to the left (s1)"
66.2
"Width of top of embankent (w2)"
7.3
"Width of sloping portion of embankment to the right (s2)"
50.9
"Distance foundation extends to right of embankment toe (w3)"
33.5
"Height of embankment (h1)"
21.3

"Thickness of foundation layer (h2)"
14.6
"Number of x-elements to left of embankment (nx1)"
5
"Number of x-elements in embankment (nx2)"
10
"Number of x-elements to right of embankment (nx3)"
5
"Number of y-elements in embankment (ny1)"
10
"Number of y-elements in foundation (ny2)"
5
"Number of different property groups (np_types)"
1
"Material properties (phi,c,psi,gamma,e,v) for each group"
30.0 10.0 0.0 18.2 1.e5 0.3
"Property group assigned to each element (etype, data not needed if np_types=1)"
"Pseudo-static analysis: Horizontal acceleration factor (k_h)"
0.0
"Number of free surface points and their coordinates (nosurf, surf(:,nosurf))"
0
"Unit weight of water (gam_w)"
0.0
"Iteration ceiling (limit)"
500
"Factor of Safety accuracy tolerance (fos_tol)"
0.05

Output for Example1 (case1.res)

trial factor	max displ	iterations
0.5000	0.8260E-01	2
1.0000	0.8362E-01	10
1.5000	0.1069E+00	24
1.7500	0.1237E+00	39
1.8125	0.1289E+00	63
1.8281	0.1318E+00	336
1.8438	0.1390E+00	500

Estimated Factor of Safety = 1.84

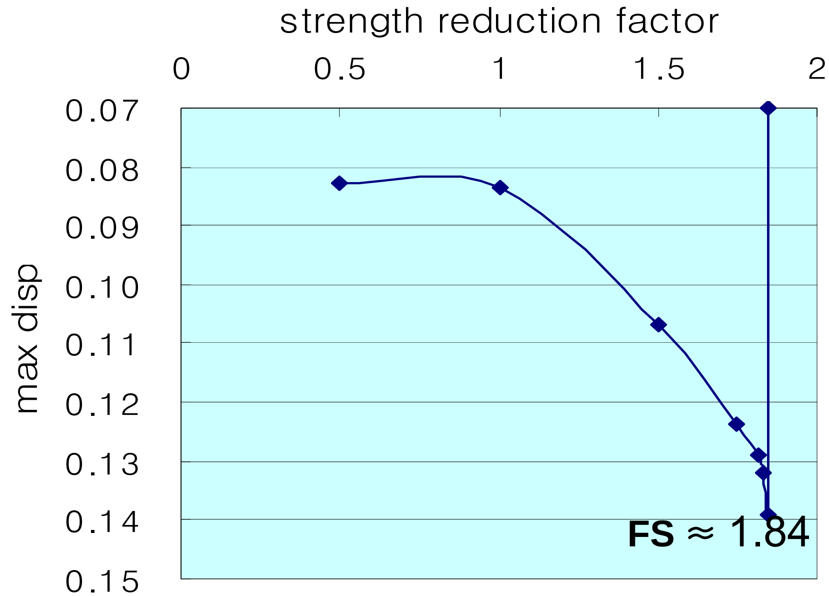


Fig. 1.2 SRF vs d_{max} for Example 1

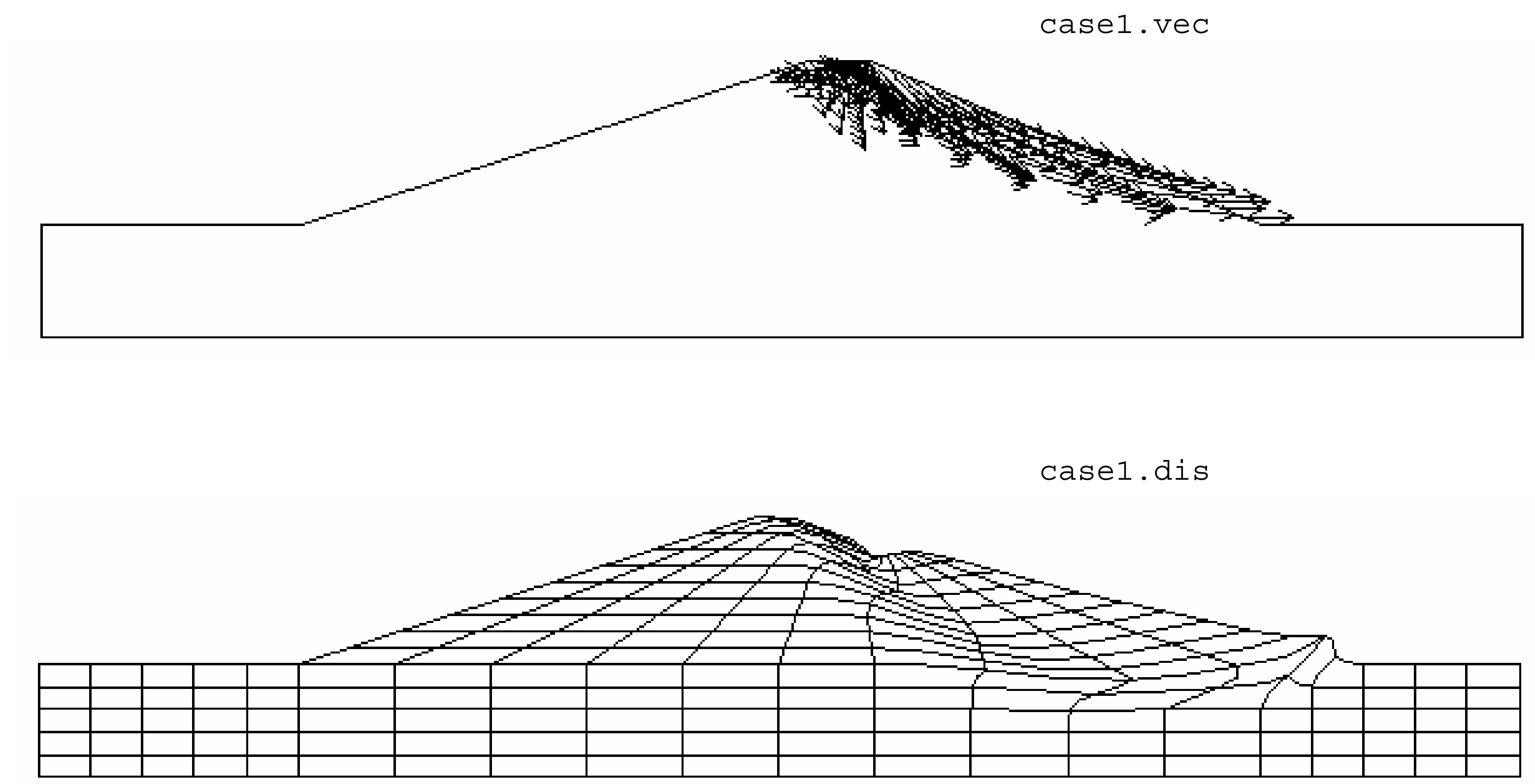


Fig. 1.3 Displacement vector and deformed mesh at failure for Example 1

Example 2: A two layer slope (no phreatic surface)

The stability analysis is of a two-layer c'- φ' slope consisting of a stronger soil in the embankment overlying a weaker soil in the foundation as shown in Figure 2.1.

Data for Example 2 (case2.dat)

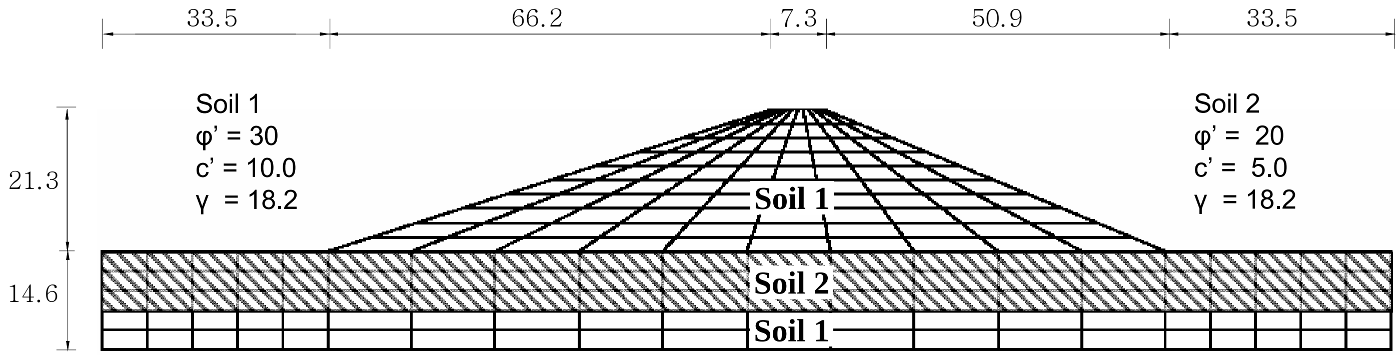


Fig.2.1 Finite element mesh for example 2

"Example 2 A two-layer slope(no phreatic surface)"
"Distance foundation extends to left of embankment toe (w1)"
33.5
"Width of sloping portion of embankment to the left (s1)"
66.2
"Width of top of embankent (w2)"
7.3
"Width of sloping portion of embankment to the right (s2)"
50.9
"Distance foundation extends to right of embankment toe (w3)"
33.5

```
"Height of embankment (h1)"
 21.3
"Thickness of foundation layer (h2)"
 14.6
"Number of x-elements to left of embankment (nx1)"
5
"Number of x-elements in embankment (nx2)"
10
"Number of x-elements to right of embankment (nx3)"
5
"Number of y-elements in embankment (ny1)"
10
"Number of y-elements in foundation (ny2)"
5
"Number of different property groups (np_types)"
2
"Material properties (phi,c,psi,gamma,e,v) for each group"
30.0  10.0  0.0  18.2  1.e5  0.3
20.0    5.0  0.0  18.2  1.e5  0.3
```

"Property group assigned to each element (etype, data not needed if np_types=1)[1]“

```
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

"Pseudo-static analysis: Horizontal acceleration factor (k_h)"

0.0

"Number of free surface points and their coordinates (nosurf, surf(:,nosurf))"

0

"Unit weight of water (gam_w)"

0.0

"Iteration ceiling (limit)"

500

"Factor of Safety accuracy tolerance (fos_tol)"

0.05

[1] Element properties are numbered in the order shown in Figure 1, namely starting at the top of the embankment and going from left to right, then top to bottom.

Output for Example 2 (case2.res)

trial factor	max displ	iterations
0.5000	0.8260E-01	2
1.0000	0.9186.E-01	17
1.5000	0.1440E+00	487
1.5156	0.1620E+00	500

Estimated Factor of Safety = 1.52

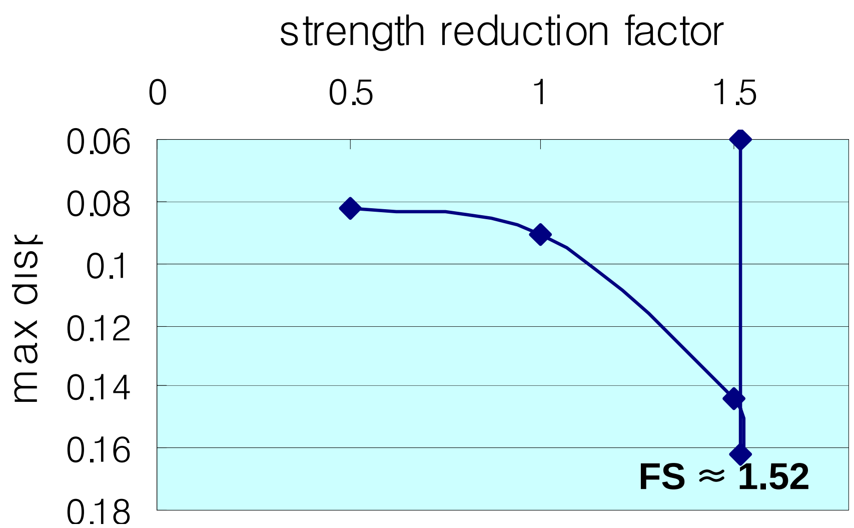


Fig 2.2 SRF vs d_{max} for Example 2

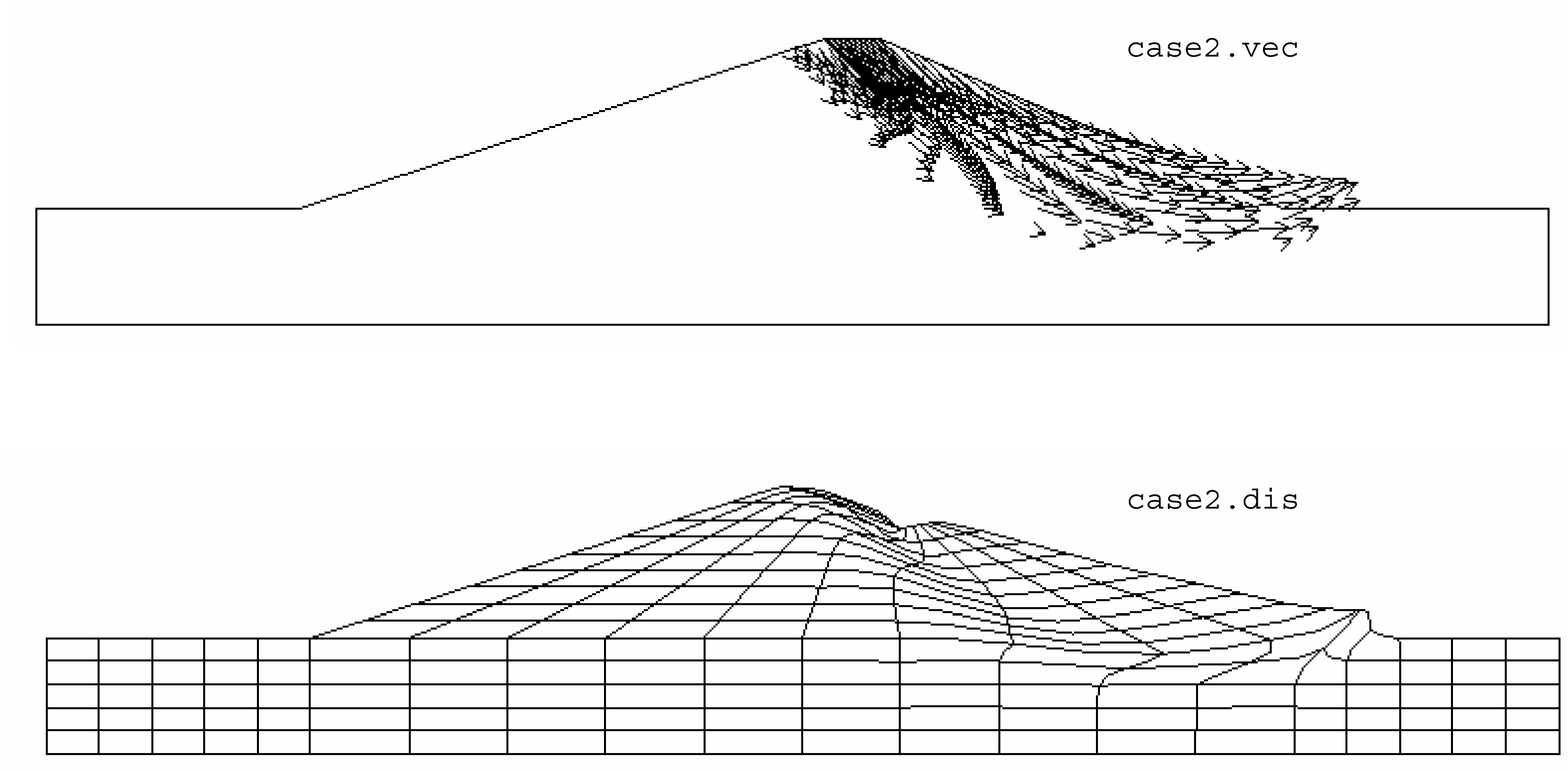


Fig. 2.3 Displacement vector and deformed mesh at failure for Example 2

Example 3: A homogenous slope (including a phreatic surface)

The stability analysis is of a homogeneous slope with the phreatic surface shown in Figure 3.1

Data for Example 3 (case3.dat)

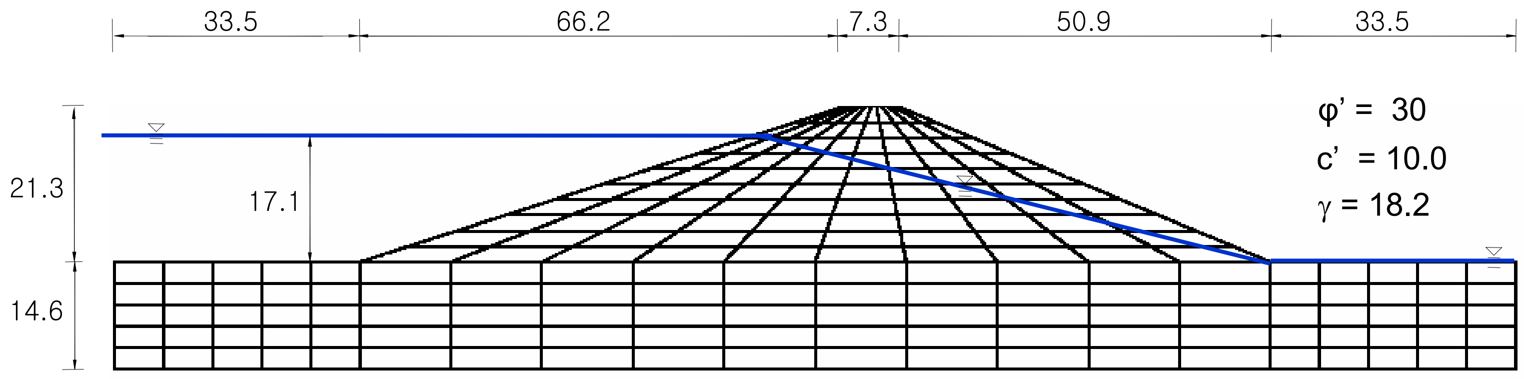


Fig.3.1 Finite element mesh for example 3

"Example 3 Wet condition slope (steady state seepage)"

"Distance foundation extends to left of embankment toe (w1)"

33.5

"Width of sloping portion of embankment to the left (s1)"

66.2

"Width of top of embankent (w2)"

7.3

"Width of sloping portion of embankment to the right (s2)"

50.9

"Distance foundation extends to right of embankment toe (w3)"

33.5

"Height of embankment (h1)"

21.3

"Thickness of foundation layer (h2)"

14.6

"Number of x-elements to left of embankment (nx1)"

5

"Number of x-elements in embankment (nx2)"

10

"Number of x-elements to right of embankment (nx3)"

5

"Number of y-elements in embankment (ny1)"

10

"Number of y-elements in foundation (ny2)"

5

"Number of different property groups (np_types)"

1

"Material properties (phi,c,psi,gamma,e,v) for each group"

30.0 10.0 0.0 18.2 1.e5 0.3

""Property group assigned to each element (etype, data not needed if np_types=1)"

"Pseudo-static analysis: Horizontal acceleration factor (k_h)"

0.0

"Number of phreatic surface points and their coordinates (nosurf, surf(:,nosurf))"

4

0.0 17.1

86.6 17.1

157.9 0.0

191.4 0.0

"Unit weight of water (gam_w)"

9.81

"Iteration ceiling (limit)"

500

"Factor of Safety accuracy tolerance (fos_tol)"

0.05

Output for Example 3 (case3.res)

trial factor	max displ	iterations
0.5000	0.9158E-01	27
1.0000	0.1158E+00	23
1.2500	0.1348E+00	51
1.3750	0.1503E+00	78
1.4062	0.1557E+00	91
1.4219	0.1593E+00	110
1.4375	0.2096E+00	500

Estimated Factor of Safety = 1.44

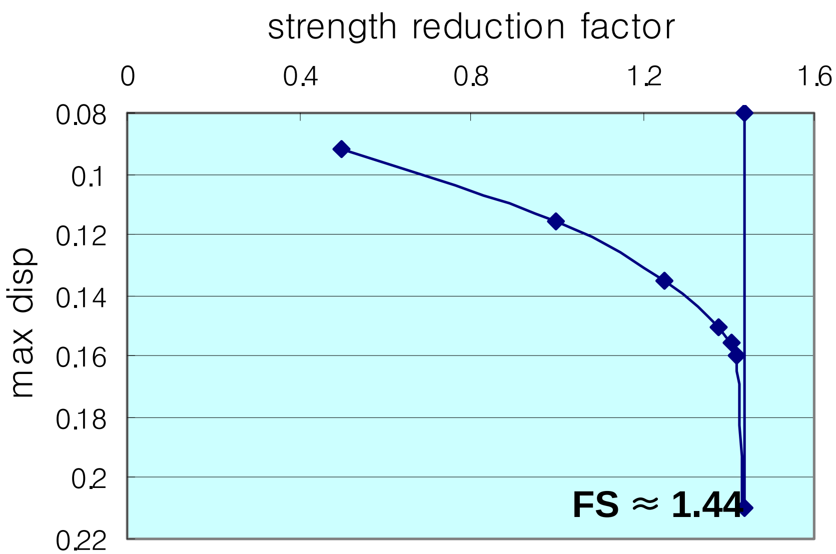
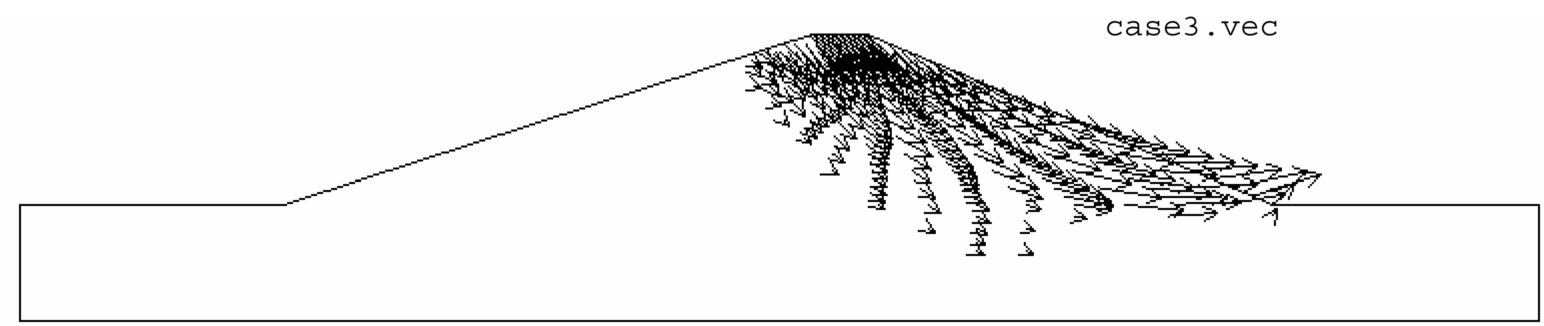


Fig 3.2 SRF vs d_{max} for Example 3



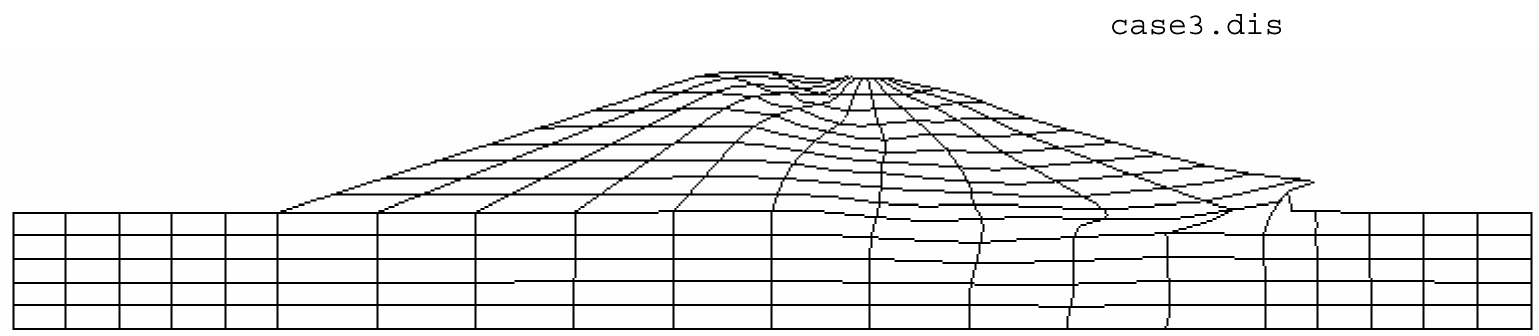


Fig. 3.3 Displacement vector and deformed mesh

at failure for Example 3

Example 4: Radid drawdown analysis

The stability analysis is of the rapid drawdown shown in Figure 4.1

Data for Example 4 (case4.dat)

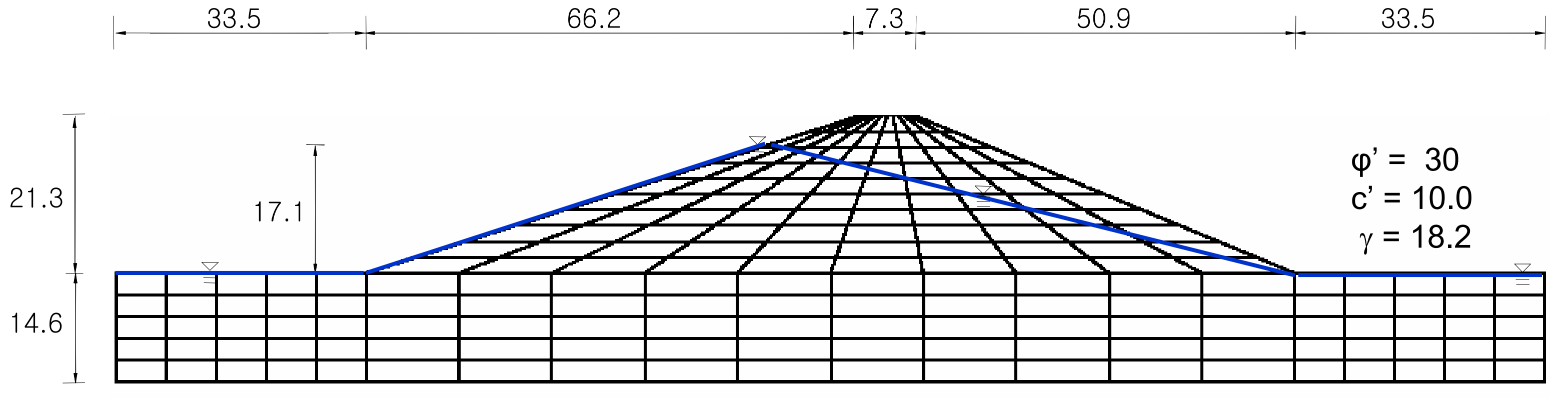


Fig. 4.1 Finite element mesh for example 4

"Example 4 Wet condition slope (rapid drawdown)"

"Distance foundation extends to left of embankment toe (w1)"

33.5

"Width of sloping portion of embankment to the left (s1)"

66.2

"Width of top of embankent (w2)"

7.3

"Width of sloping portion of embankment to the right (s2)"

50.9

"Distance foundation extends to right of embankment toe (w3)"

33.5

"Height of embankment (h1)"

21.3

"Thickness of foundation layer (h2)"

14.6

"Number of x-elements to left of embankment (nx1)"

5

"Number of x-elements in embankment (nx2)"

10

"Number of x-elements to right of embankment (nx3)"

5

"Number of y-elements in embankment (ny1)"

10

"Number of y-elements in foundation (ny2)"

5

"Number of different property groups (np_types)"

1

"Material properties (phi,c,psi,gamma,e,v) for each group"

30.0 10.0 0.0 18.2 1.e5 0.3

""Property group assigned to each element (etype, data not needed if np_types=1)"

"Pseudo-static analysis: Horizontal acceleration factor (k_h)"

0.0

"Number of free surface points and their coordinates (nosurf, surf(:,nosurf))"

5

0.0 0.0

33.5 0.0

86.6 17.1

157.9 0.0

191.4 0.0

"Unit weight of water (gam_w)"

9.81

"Iteration ceiling (limit)"

500

"Factor of Safety accuracy tolerance (fos_tol)"

0.05

Output for Example4 (case4.res)

trial factor	max displ	iterations
0.5000	0.1047E+00	39
1.0000	0.1348E+00	48
1.1250	0.1483E+00	66
1.1562	0.1530E+00	105
1.1719	0.1557E+00	129
1.1875	0.1720E+00	500

Estimated Factor of Safety = 1.19

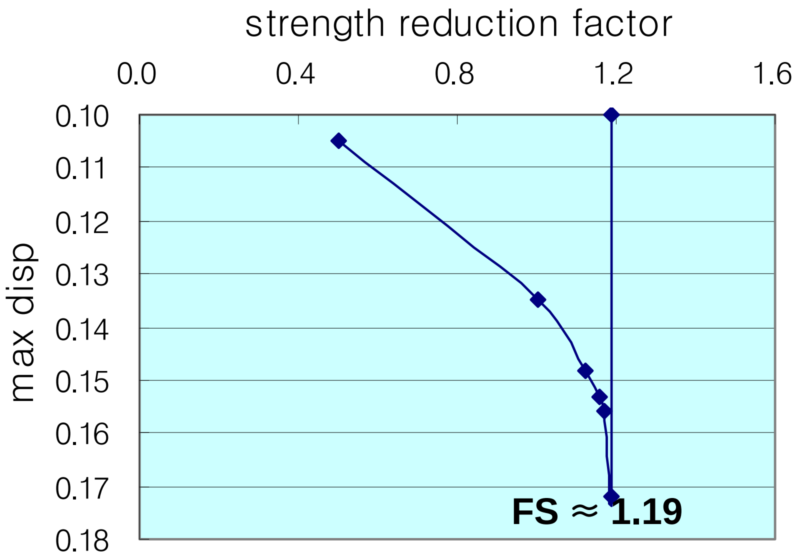


Fig 4.2 SRF vs d_{max} for Example 4

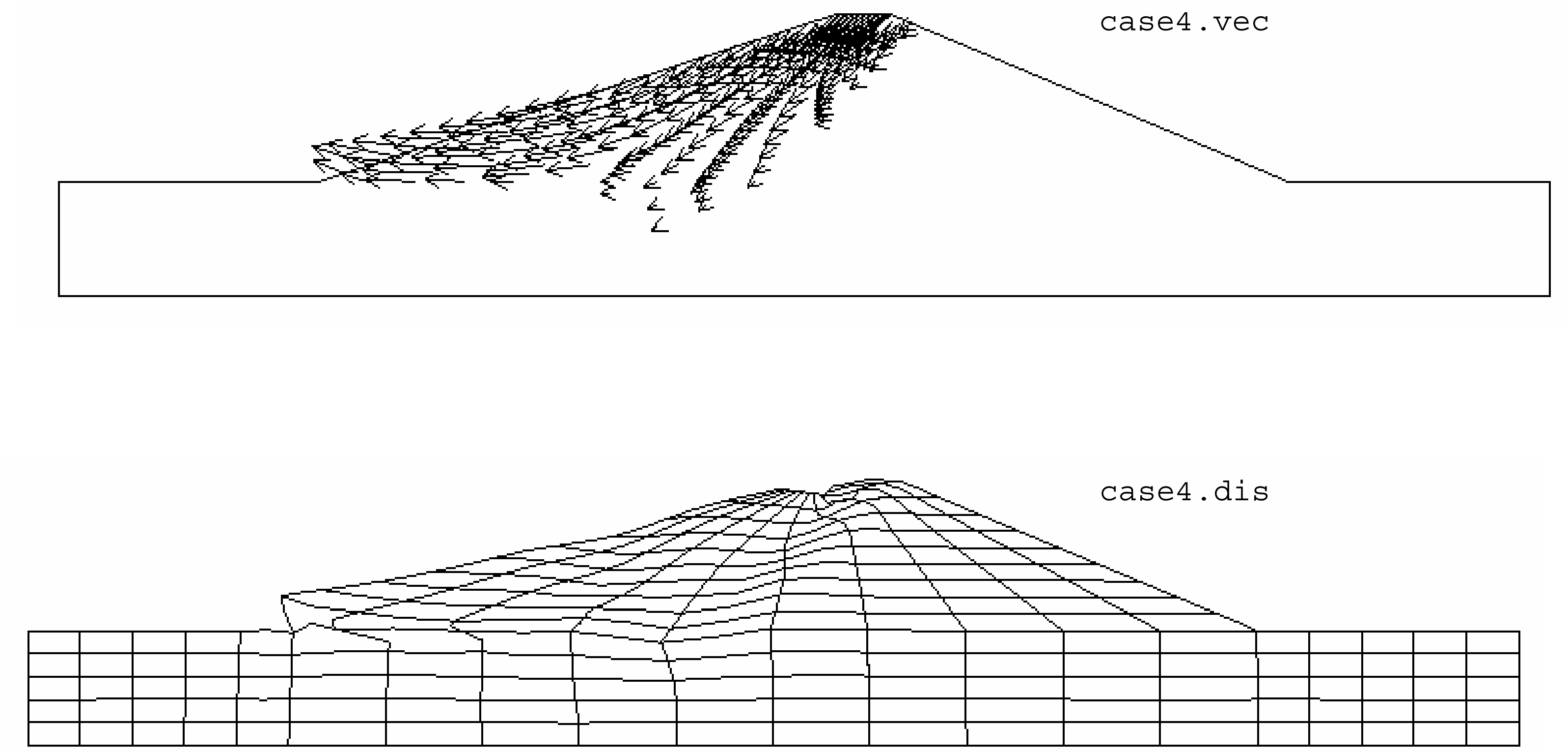


Fig. 4.3 Displacement vector and deformed mesh at failure for Example 4

Example 5: A a two-layer slope subjected to a horizontal acceleration

The stability analysis is of a two-layer c'- φ' slope subjected to a horizontal acceleration factor of 0.2g as shown in Figure 5.1.

Data for Example 5 (case5.dat)

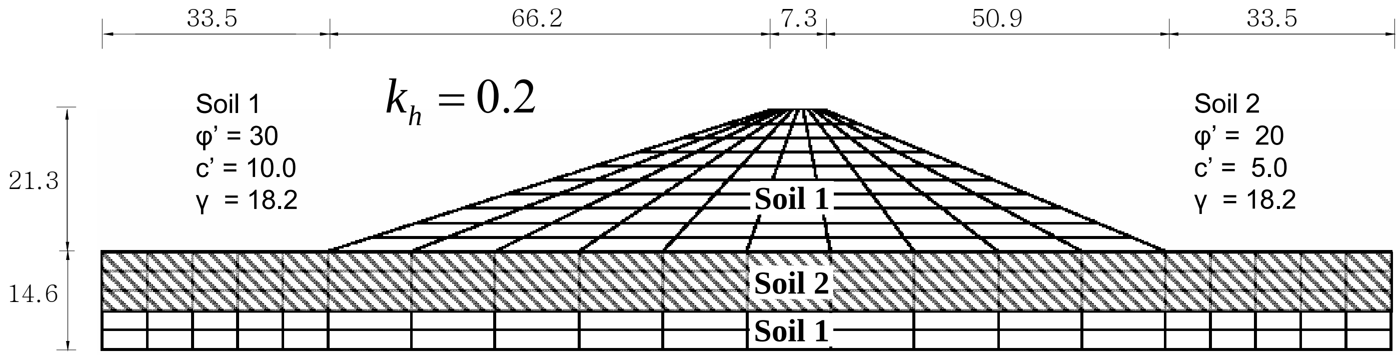


Fig. 5.1 Finite element mesh for example 5

"Example 5 A two-layer slope subjected to a horizontal pseudo-acceleration "
"Distance foundation extends to left of embankment toe (w1)"
33.5
"Width of sloping portion of embankment to the left (s1)"
66.2
"Width of top of embankent (w2)"
7.3
"Width of sloping portion of embankment to the right (s2)"
50.9
"Distance foundation extends to right of embankment toe (w3)"
33.5

```
"Height of embankment (h1)"
 21.3
"Thickness of foundation layer (h2)"
 14.6
"Number of x-elements to left of embankment (nx1)"
5
"Number of x-elements in embankment (nx2)"
10
"Number of x-elements to right of embankment (nx3)"
5
"Number of y-elements in embankment (ny1)"
10
"Number of y-elements in foundation (ny2)"
5
"Number of different property groups (np_types)"
2
"Material properties (phi,c,psi,gamma,e,v) for each group"
30.0  10.0  0.0  18.2  1.e5  0.3
20.0    5.0  0.0  18.2  1.e5  0.3
```

"Property group assigned to each element (etype, data not needed if np_types=1)[1]“

```
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
                    1   1   1   1   1   1   1   1   1   1
2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1
```

"Pseudo-static analysis: Horizontal acceleration factor (k_h)"
0.2
"Number of free surface points and their coordinates (nosurf, surf(:,nosurf))"
0
"Unit weight of water (gam_w)"
0.0
"Iteration ceiling (limit)"
500
"Factor of Safety accuracy tolerance (fos_tol)"
0.05

Output for Example 5 (case5.res)

trial factor	max displ	iterations
0.5000	0.8239E-01	22
0.7500	0.8703E-01	115
0.8750	0.1049E+00	182
0.8906	0.1180E+00	500

Estimated Factor of Safety = 0.89

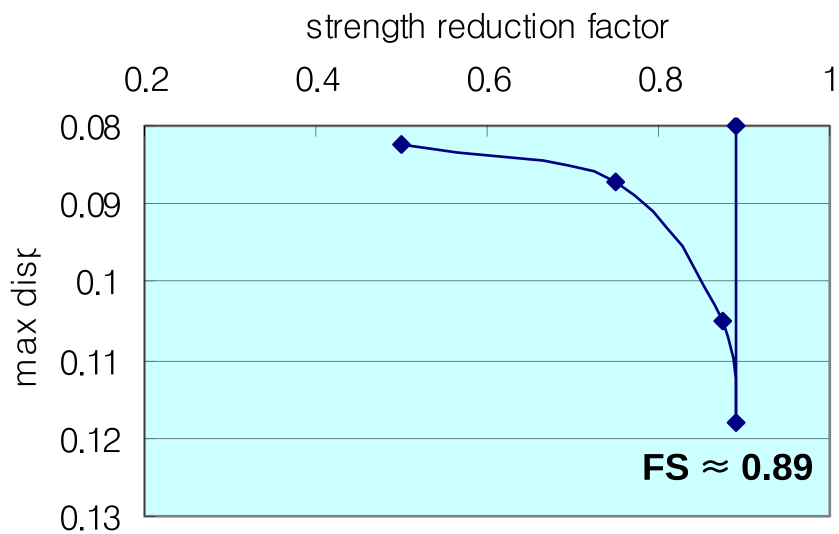
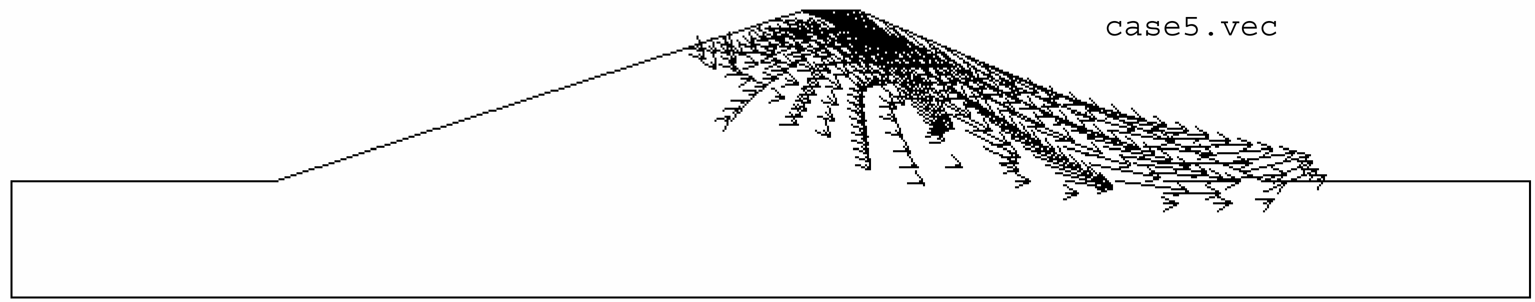


Fig 5.2 SRF vs d_{max} for Example 5



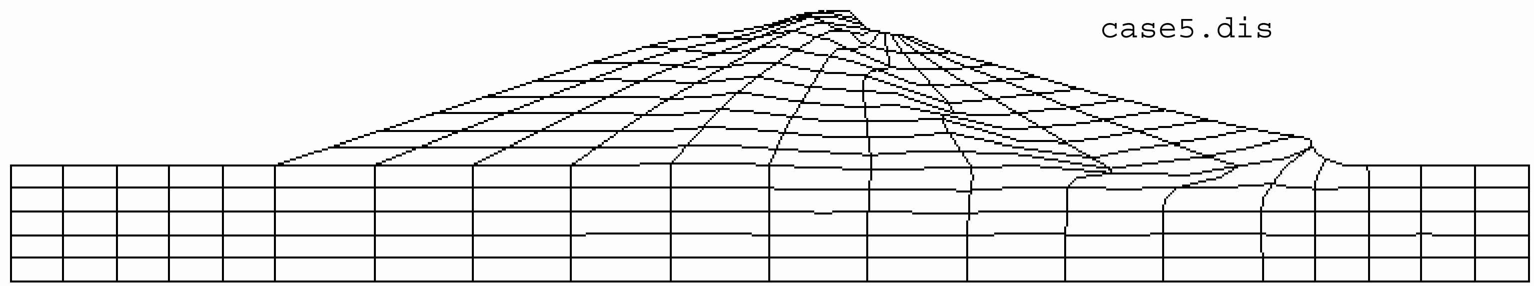


Fig. 5.3 Displacement vector and deformed mesh at failure for Example 5