Modelling rock slope behaviour and evolution with reference to Northern Spain and Southern Jordan

Nelis, Simon Brett

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MODELLING ROCK SLOPE BEHAVIOUR AND EVOLUTION WITH REFERENCE TO NORTHERN SPAIN AND SOUTHERN JORDAN

VOLUME 2

SIMON BRETT NELIS

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Ph.D. THESIS 2004
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The figures in this thesis include output from the UDEC computer simulation software and from the laboratory testing of rock. The output consists of two-dimensional block plots and filled contour block plots. The labelled notation (*10^1) indicates that the axes need to be multiplied by 10. On all UDEC plots, the horizontal and vertical axes are in meters. The plot legend includes an indication of the type of output plot, model cycle count, model time and also the contour intervals. In plots with displacement vectors, the scale presented is in meters. The notation 1 E 1 on the scale means that the scale is 1*10 m long. The values of displacement relate to actual displacements in the rock mass in meters. Where plots of unbalanced forces are presented, the x-axis is model time (s) and the y axis is force (kg m s^{-2}).

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- **50 m**
- **100 m**
- **200 m**
- **300 m**
- **400 m**
- **500 m**
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- 50 m
- 100 m
- 200 m
- 300 m
- 400 m
- 500 m

Deviatoric stress (MPa)

% lateral strain % Axial strain
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<th>Proposed slope form</th>
<th>Deformation / failure mode</th>
<th>Identifying characteristics</th>
<th>Rock mass characteristics</th>
<th>Failure mode</th>
<th>Examples</th>
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<td>Translational shear</td>
<td>High vertical cliffs enhanced by brittle failure.</td>
<td>Widely spaced joints, minimal joint normal closure, high stiffness, low shear strength.</td>
<td>Shear failure along persistent shear surfaces. Wide joint spacing limits depth of deformation</td>
<td>The Vaiont Dam failure, 1963. Large planar / translational slide.</td>
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<tr>
<td></td>
<td></td>
<td>Rotation and gradual deformation of slope with minimal shear</td>
<td>Relatively low angle slope profile with concave-convex profile</td>
<td>Closely spaced joints, high degree of joint normal closure, low stiffness, but high shear strength limits shear failure.</td>
<td>Rotation and ductile, time-dependent deformation of the rock mass. Deep-seated deformation pattern.</td>
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- 1. Ras el Naqab escarpment
- 2. Slopes in sandstone
- 3. Slopes in granite
- 4. Sandy plains
- 5. Dune systems
- 6. Alluvial fans
- 7. Inselbergs
- 8. Wadi beds
- 9. Escarpment plateau (?)
- 10. Playa
- 11. Rockfalls

Legend:
- + Aqaba granite complex
- Sandstones - Arkosic / Ismrin
- Sandstones - Disi
- Sandstones - Umm Samm
Figure 6.6: Contoured polar projection of the discontinuities at AL1, Wadi Rum, Jordan.
Figure 6.7: Contoured polar projection of the discontinuities at AL2, Wadi Rum, Jordan.
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Figure 6.10: Contoured polar projection of the discontinuities at AL5, Wadi Rum, Jordan.
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Figure 6.13: Contoured polar projection of the discontinuities at AL8, Wadi Rum, Jordan.
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Figure 6.15: Contoured polar projection of the discontinuities at AL10, Wadi Rum, Jordan.
Figure 6.16: Contoured polar projection of the discontinuities at AL11, Wadi Rum, Jordan.
Figure 6.17: Contoured polar projection of the discontinuities at AL12, Wadi Rum, Jordan.
Figure 6.18: Contoured polar projection of the discontinuities at AL13, Wadi Rum, Jordan.
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Figure 6.36: Axial strain plotted against Confining pressure, P'o (MPa) to help determine whether the sandstones are deforming in a very brittle, brittle, transitional or ductile manner.
Figure 7.1: Block plot of north section of the cirque wall of Torre de Salinas at equilibrium.

UDEC (Version 3.10)

LEGEND

17-Mar-03 19:11
cycle 10000
block plot

Department of Geography
University of Durham
### JOB TITLE: Total unbalanced forces for north-south profile of north cirque wall of Torre de Salinas at equilibrium.

#### UDEC (Version 3.10)

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Department of Geography  
University of Durham
JOE TITLE: Displacement vectors for north-south profile of north cirque wall of Torre de Salinas at 100 000 cycles.

UDEC (Version 3.10)

LEGEND

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block plot
displacement vectors
maximum = 4.295E+01
0 2E 2

Department of Geography
University of Durham
Figure 7.2b: Displacement vectors for the north-south profile of the northern cirque wall of Torre de Salinas at 200,000 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of north cirque wall of Torre de Salinas at 200,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

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- cycle 200000
- block plot
- displacement vectors
- maximum = 8.758E+01

Department of Geography
University of Durham
Displacement vectors for north-south profile of north cirque wall of Torre de Salinas at 350,000 cycles.

**UDEC (Version 3.10)***

**LEGEND**

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- block plot
- displacement vectors
  - maximum = 1.558E+02
- 0 5E 2

Department of Geography
University of Durham
Figure 7.3d: Displacement vectors for north-south profile of north cirque wall of Torre de Salinas at 600,000 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of north cirque wall of Torre de Salinas at 600,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

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Department of Geography
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Figure 7.4a: Horizontal displacement contours of north section of the cirque wall of Torre de Salinas at equilibrium.

**JOB TITLE:** Horizontal displacement contours of north section of the cirque wall of Torre de Salinas at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

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cycle  10000  
block plot  
X displacement contours  
contour interval= 5.000E-02  
-5.000E-02 to  1.500E-01  

Department of Geography  
University of Durham
Figure 7.4b: Horizontal displacement contours of the north section of the cirque wall of Torre de Salinas at 100,000 cycles.
Figure 7.4c: Horizontal displacement contours of the north section of the cirque wall of Torre de Salinas at 200,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

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<td>1.000E+01 to 2.000E+01</td>
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Department of Geography
University of Durham
Figure 7.4d: Horizontal displacement contours of the north section of Torre de Salinas wall at 350,000 cycles.

**JOB TITLE:** Horizontal displacement contours of north section of the cirque wall of Torre de Salinas at 350,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
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- X displacement contours contour interval = 2.000E+01 -6.000E+01 to 2.000E+01
- 0.000E+00
- 2.000E+01

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University of Durham
JOBTITLE: Horizontal displacement contours of north section of the cirque wall of Torre de Salinas at 600,000 cycles.

UDEC (Version 3.10)

LEGEND

18-Mar-03 10:51
cycle 600000
block plot
X displacement contours
contour interval= 2.000E+01
-1.400E+02 to 2.000E+01

-1.400E+02
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-1.000E+02
-8.000E+01
-6.000E+01
-4.000E+01
-2.000E+01
0.000E+00
2.000E+01

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Figure 7.5: Total unbalanced forces for north-south profile of north cirque wall of Torre de Salinas at 600,000 cycles.

**JOB TITLE:** Total unbalanced forces for north-south profile of north cirque wall of Torre de Salinas at 600,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

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Vs.

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Figure 7.6a: Block plot of the east-west profile of the central cirque headwall for Torre de Salinas, at equilibrium.

**LEGEND**
18-Mar-03 12:32
cycle 10000
block plot

Department of Geography
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**JOB TITLE**: Block plot of east-west profile of central cirque wall for Torre de Salinas at equilibrium.

**UDEC (Version 3.10)**

```plaintext
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3.500 2.500
0.500 0.500 0.500
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Figure 7.6(b): Displacement vectors for the east-west profile of the central cirque wall of Torre de Salinas at 100,000 cycles.

UDEC (Version 3.10)

LEGEND

18-Mar-03 13:54

cycle 100000

block plot

displacement vectors

maximum = 1.767E+01

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Figure 7.6c: Displacement vectors for east-west profile of central cirque wall of Torre de Salinas at 250,000 cycles.

UDEC (Version 3.10)

LEGEND
18-Mar-03 16:12
cycle 250000
block plot
displacement vectors
maximum = 5.129E+01

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Displacement vectors for east-west profile of central cirque wall of Torre de Salinas at 500,000 cycles.

**UDEC (Version 3.10)**

**Legend**
- 18-Mar-03 19:54 cycle 500000
- Block plot
- Displacement vectors
  - Maximum = 5.286E+01

Department of Geography
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Headwall for Torre de Salinas at Equilibrium.

Figure 7.1a: Horizontal displacement contours for the east-west profile of the cirque wall for Torre de Salinas at equilibrium.

Legend:
- 0.000E+00
- 1.000E-01
- 3.000E-01
- 5.000E-01
- 7.000E-01
- 9.000E-01

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**Figure 7.7b:** Horizontal displacement contours for the east-west profile of the cirque headwall for Torre de Salinas at 100,000 cycles.

**JOB TITLE:** Horizontal displacement contours for east-west profile of central cirque wall for Torre de Salinas at 100,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 18-Mar-03 13:54
- cycle 100000
- block plot
- X displacement contours
- contour interval: $2.000E+00$
- $-2.000E+00$ to $1.600E+01$

---

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Figure 7.7c: Horizontal displacement contours for the east-west profile of the cirque wall for Torre de Salinas at 250,000 cycles.

**JOB TITLE:** Horizontal displacement contours for east-west profile of central cirque wall for Torre de Salinas at 250,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

18-Mar-03 16:12

cycle 250000

block plot

X displacement contours

countour interval = 1.000E+01

0.000E+00 to 4.000E+01

- 0.000E+00
- 1.000E+01
- 2.000E+01
- 3.000E+01
- 4.000E+01

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Figure 7.7d: Horizontal displacement contours for east-west profile of central cirque wall for Torre de Salinas at 500,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 18-Mar-03 19:54 cycle 500,000
- Block plot
- X displacement contours
- Contour interval = 1.000E+01
- 0.000E+00 to 4.000E+01

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JOB TITLE: Total unbalanced forces for east-west profile of central cirque wall of Torre de Salinas at 500,000 cycles.

UDEC (Version 3.10)

LEGEND
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history plot
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Vs.
0.00E+00<time> 3.34E+02

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Figure 7.9a: Block plot of the east-west profile of the southern cirque headwall for Torre de Salinas, Picos de Europa, at equilibrium.
Figure 7.9b: Displacement vectors of the east-west profile of the southern cirque headwall for Torre de Salinas, Picos de Europa, at 200,000 cycles.

**JOB TITLE:** Displacement vectors of east-west profile of southern cirque wall for Torre de Salinas at 200,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 19-Mar-03 13:28 cycle 200000
- block plot
- displacement vectors
  - maximum = 2.140E+01

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University of Durham
Figure 7.9c: Displacement vectors of east-west profile of southern cirque wall for Torre de Salinas at 400,000 cycles.

**LEGEND**

- 19-Mar-03 16:50
- cycle 400,000
- block plot
- displacement vectors
- maximum = 4.344E+01

**UDEC (Version 3.10)**

Department of Geography
University of Durham
Headwall for Torre de Salinas, Picos de Europa, at 800,000 cycles.

Figure 7.9.d: Displacement vectors of the east-west profile of the southern circle wall for Torre de Salinas at 800,000 cycles.
JOE TITLE: Horizontal displacement contours for east-west profile of southern cirque wall for Torre de Salinas at equilibrium.

UDEC (Version 3.10)

LEGEND

19-Mar-03 10:11
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block plot
X displacement contours
contour interval= 1.000E-01
-2.000E-01 to 4.000E-01
-2.000E-01
-1.000E-01
0.000E+00
1.000E-01
2.000E-01
3.000E-01
4.000E-01

Department of Geography
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Figure 7.10b: Horizontal displacement contours for the east-west profile of the southern cirque headwall for Torre de Salinas at 200,000 cycles.

**JOB TITLE:** Horizontal displacement contours for east-west profile of southern cirque wall for Torre de Salinas at 200,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 19-Mar-03 13:26
- cycle 200,000
- block plot
- X displacement contours
- contour interval = 2.000E+00
- -1.400E+01 to 0.000E+00
- -4.000E+00
- -2.000E+00
- -1.000E+00
- -8.000E+00
- -6.000E+00
- -4.000E+00
- -2.000E+00
- 0.000E+00

Department of Geography
University of Durham
Figure 7.10c: Horizontal displacement contours for east-west profile of southern cirque wall for Torre de Salinas at 400,000 cycles.

UDEC (Version 3.10)

LEGEND

19-Mar-03 16:50
block plot
X displacement contours
contour interval = 5.000E+00
-3.500E+01 to 0.000E+00

Department of Geography
University of Durham
Figure 7.11a: Block plot of the north-south profile of the far western ridge of Pico de La Padierna at equilibrium.

**JOB TITLE:** Block plot of north-south profile of the far western ridge of Pico de La Padierna at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

29-Mar-03 20:21
cycle 10000
block plot

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JOB TITLE: Displacement vectors of north-south profile of the far western ridge of Pico de La Padierna at 530,000 cycles.

UDEC (Version 3.10)

LEGEND

30-Mar-03 2:03 cycle 530,000 block plot displacement vectors maximum = 2.038E+00

0 1E 1

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University of Durham
western section of the ridge of Pico de la Padrema at 530 000 cycles.

Figure 7.12: Horizontal displacement contours for the north-south profile of the ridge
Figure 7.13a: Block plot of the north-south profile of the central ridge of Pico de La Padierna at equilibrium.

**JOB TITLE:** Block plot of north-south profile of the central ridge of Pico de La Padierna at equilibrium.

**UDEC (Version 3.10)**

**LEGEND:**
- Date: 31-Mar-03 19:09
- Cycle: 10000
- Block plot

Department of Geography
University of Durham
Figure 7.13b: Displacement vectors for the north-south profile of the central ridge of Pico de la Pedrera at 150,000 cycles.
Figure 7.13c: Displacement vectors for the north-south profile of the central ridge of Pico de La Paderma at 550 000 cycles.
Figure 7.14: Block plot of the north-south profile of the central ridge of Pico de La Padierna at 500,000 cycles.

UDEC (Version 3.10)

LEGEND

1-Apr-03 8:10 cycle 550000 block plot

Department of Geography
University of Durham
Figure 7.15a: Horizontal displacement contours for north-south profile of the central ridge of Pico de La Padierna at equilibrium.

**JOB TITLE:** Horizontal displacement contours for north-south profile of the central ridge of Pico de La Padierna at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

31-Mar-03 19:09

- X displacement contours
- contour interval = 5.000E-01
- block plot
- -2.500E+00 to 1.000E+00
- -2.500E+00
- -2.000E+00
- -1.500E+00
- -1.000E+00
- -5.000E-01
- 0.000E+00
- 5.000E-01
- 1.000E+00

Department of Geography
University of Durham
Figure 7.15b: Horizontal displacement contours for north-south profile of the central ridge of Pico de La Padierna at 150,000 cycles.

**LEGEND**
- 3.500E+01
- -2.500E+01
- -1.500E+01
- -1.000E+01
- -5.000E+00
- 0.000E+00

Department of Geography
University of Durham
Central ridge of Pico de La Paderma at 550,000 cycles.

Figure 7.15c: Horizontal displacement contours for the north-south profile of the central ridge of Pico de La Paderma at 550,000 cycles.

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Job Title: Horizontal displacement contours for north-south profile of the central ridge of Pico de La Paderma at 550,000 cycles.

UDEC (Version 3.10)

Legend

-1.200E+02
-1.000E+02
-8.000E+01
-6.000E+01
-4.000E+01
-2.000E+01
0.000E+00
2.000E+01
4.000E+01
6.000E+01
8.000E+01
1.000E+02
1.200E+02

X-displacement contour interval = 2,000E+01

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Figure 7.16: Total unbalanced forces for north-south profile of central ridge of Pico de la Padierna at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**
- 30-Mar-03 2:03 cycle 530000 history plot
- $0.00E+00<$hist 1> $8.33E+08$ Vs
- $0.00E+00<$time$>$ $3.50E+02$

Department of Geography
University of Durham
JOB TITLE: Block plot of north-south profile of the far eastern ridge of Pico de La Padrena at equilibrium.

UDEC (Version 3.10)

LEGEND

28-Mar-03 18:02
cycle 10000
block plot

Department of Geography
University of Durham

Figure 7.17a: Block plot of the north-south profile of the far eastern section for the ridge of Pico de La Padrena at equilibrium.
Figure 7.17b: Displacement vectors for the north-south profile of the far eastern ridge of Pico de La Padierna at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 29-Mar-03 3:22
- cycle 500000
- block plot
- displacement vectors
- maximum = 2.623E+00

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University of Durham
JOB TITLE: Horizontal displacement contours for north-south profile of eastern ridge of Pico de La Padierna at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 29-Mar-03  3.22 cycle  500000
- block plot
- X displacement contours
- contour interval: 4.000E-01
- -1.200E+00 to 4.000E-01

Department of Geography
University of Durham
Figure 7.19: Total unbalanced forces for north-south profile of eastern section of Pico de la Padierna at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

29-Mar-03 3:22
cycle 500000
history plot
0.00E+00<hist 1> 1.50E+08
Vs.
0.00E+00<time> 3.69E+02

Department of Geography
University of Durham
Figure 7.20a: Block plot of north-south profile for Tiro Pedabejo at equilibrium.

JOB TITLE: Block plot of north-south profile for Tiro Pedabejo at equilibrium.

UDEC (Version 3.10)

LEGEND

25-Mar-03 21:44
cycle 10000
block plot

Department of Geography
University of Durham
JOB TITLE: Displacement vectors for north-south profile for Tiro Pedabeio at 500 000 cycles.

UDEC (Version 3.10)

LEGEND

26-Mar-03 0:31
cycle 500000
block plot
displacement vectors
maximum = 5.134E+00
0 2E 1

Department of Geography
University of Durham
Figure 7.21: Total unbalanced forces for north-south profile of Tiro Pedabejo at 500 000 cycles.

**LEGEND**

26-Mar-03 0:31

- cycle 500000
- history plot
- 0.00E+00 < hist 1 > 1.56E+09
- Vs.
- 0.00E+00 < time > 5.89E+02

Department of Geography
University of Durham
Figure 7.22: Horizontal displacement contours for the north-south profile of Tiro Pedabejo at equilibrium.

**JOB TITLE**: Horizontal displacement contours for north-south profile of Tiro Pedabejo at equilibrium.

**UDEC** (Version 3.10)

**LEGEND**
- 25-Mar-03 21:44
- cycle 10000
- block plot
- X displacement contours
- contour interval= 1.000E-02 to 3.000E-02
- -6.000E-02
- -5.000E-02
- -4.000E-02
- -3.000E-02
- -2.000E-02
- -1.000E-02
- 0.000E+00
- 1.000E-02
- 2.000E-02
- 3.000E-02
- 4.000E-02
- 5.000E+00

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University of Durham
Figure 7.22b: Horizontal displacement contours for north-south profile of Tiro Pedabejo at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 26-Mar-03  0:31 cycle 500 000
- black plot
- x displacement contours
- contour interval= 5.000E-01
- -1.500E+00 to 2.500E+00

Department of Geography
University of Durham
Figure 7.23a: Block plot of east-west profile for Tiro Pedabejo at equilibrium.

UDEC (Version 3.10)

LEGEND

30-Jun-03 17:05
cycle 11000
block plot

Department of Geography
University of Durham
Figure 7.23b: Displacement vectors for the north-south profile for Tiro Pedabejo, at 201000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile for Tiro Pedabejo at 201000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 30-Jun-03 18:51 cycle 201000
- block plot displacement vectors
- maximum = 3.017E+01
- 0 1E 2

Department of Geography
University of Durham
Figure 7.33c: Displacement vectors for the north-south profile for Tiro Pedabejo, Picos de Europa, at 351,000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile for Tiro Pedabejo at 351,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 30-Jun-03 20:18
- cycle 351000
- block plot
- displacement vectors
  - maximum = 1.293E+02

Department of Geography
University of Durham
Figure 7.23d: Displacement vectors for the north-south profile for Tiro Pedabejo, at 601000 cycles.

Department of Geography
University of Durham
Figure 7.24a: Horizontal displacement contours for east-west profile of Tiro Pedabejo at 201 000 cycles.

UDEC (Version 3.10)

LEGEND

30-Jun-03 18:51
cycle 201000
block plot
X displacement contours
contour interval = 4.000E+00
-2.000E+01 to 0.000E+00

Department of Geography
University of Durham
Figure 7.24b: Horizontal displacement contours for east-west profile of Tiro Pedabejo at 351000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 30-Jun-03 20:18
- cycle 351000
- block plot
- X displacement contours
- contour interval = 1.000E+01
- -5.000E+01 to 0.000E+00
- -5.000E+01
- -4.000E+01
- -3.000E+01
- -2.000E+01
- -1.000E+01
- 0.000E+00

Department of Geography
University of Durham
Figure 7.24c: Horizontal displacement contours for east-west profile of Tiro Pedabejo at 601 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 30-Jun-03 22:46
- cycle 601000
- block plot
- X displacement contours
- contour interval = 2.000E+01
- -1.00E+02 to 0.000E+00

Department of Geography
University of Durham
JOB TITLE: Total unbalanced forces for east-west profile of Tiro Pedabejo at 601000 cycles.

**UDEC (Version 3.10)**

---

**Legend**
- 30-Jun-03 22:46
- Cycle 601000
- History plot
- 0.00E+00 < hist 1 > 1.37E+09
  - Vs.
- 0.00E+00 < time > 7.51E+02

---

Department of Geography
University of Durham

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Figure 7.25: Total unbalanced forces for the north-south profile of Tiro Pedabejo at 601000 cycles.
Figure 7.26a: Block plot of north-south profile for Canchorrall de Hormas at equilibrium.

**LEGEND**

2-Apr-03 10:34
cycle 10000
block plot

Department of Geography
University of Durham
Figure 7.28b: Displacement vectors of the north-south profile of Canchorral de Hormas at 100,000 cycles.

**JOB TITLE:** Displacement vectors of north-south profile of Canchorral de Hormas at 100,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 2-Apr-03 11:41
- Cycle 100,000
- Block plot
- Displacement vectors
  - Maximum = 5.475E+00

Department of Geography
University of Durham
Figure 7.26c: Displacement vectors of north-south profile of Canchorral de Hormas at 250,000 cycles.

**UDEC (Version 3.10)**

**JOB TITLE:** Displacement vectors of north-south profile of Canchorral de Hormas at 250,000 cycles.

**LEGEND**
- 2-Apr-03 13:32
- cycle 250000
- block plot
- displacement vectors
- maximum = 2.895E+01
- 0-1E 2

Department of Geography
University of Durham
Figure 7.26d: Block plot of the north-south profile of Canchorral de Hormas at 500,000 cycles.

JOB TITLE: Block plot of north-south profile for Canchorral de Hormas at 500,000 cycles.

UDEC (Version 3.10)

LEGEND

2-Apr-03 16:34
cycle 500000
block plot

Department of Geography
University of Durham
Figure 7.27a: Horizontal displacement contours for north-south profile of Canchoral de Hormas at equilibrium.

**JOB TITLE**: Horizontal displacement contours for north-south profile of Canchoral de Hormas at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

2-Apr-03 10:34
Cycle 10000
Block plot
X displacement contours
Contour interval = 5.000E-02
-2.500E-01 to 1.000E-01

-2.500E-01
-2.000E-01
-1.500E-01
-1.000E-01
-5.000E-02
0.000E+00
5.000E-02
1.000E-01

Department of Geography
University of Durham
Figure 7.27b: Horizontal displacement contours for north-south profile of Canchorral de Hormas at 100,000 cycles.

JOB TITLE: Horizontal displacement contours for north-south profile of Canchorral de Hormas at 100,000 cycles.

**UDEC (Version 3.10)**

**LEGEND:**
- 2-Apr-03 11:41 cycle 100000 block plot
- X displacement contours
- contour interval = 5.000E-01
- -4.000E+00 to 5.000E-01

Department of Geography
University of Durham
Figure 7.2.7c: Horizontal displacement contours for north-south profile of Canchorral de Hormas at 500,000 cycles.

**LEGEND**

- 2-Apr-03 16:34 cycle 500000
- block plot
- horizontal displacement contours
- contour interval = $5.000E+00$
- $-4.000E+01$ to $0.000E+00$

Department of Geography
University of Durham
Figure 7.28: Total unbalanced forces for the north-south profile of Canchorral de Hormas at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 2-Apr-03 16:34
- cycle 500000
- history plot
- 0.00E+00<hist 1> 1.14E+09
- Vs.
- 0.00E+00<time> 3.05E+02

Department of Geography
University of Durham
Figure 7.29a: Block plot of the east-west profile of Canchorral de Hormas at equilibrium.

**UDEC (Version 3.10)**

**JOBTITLE:** Block plot of east-west profile for Canchorral de Hormas at equilibrium.

**LEGEND**

1-Apr-03 19:10

**Department of Geography**
**University of Durham**
Figure 7.29b: Displacement vectors for the east-west profile of Canchorral de Hormas at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 1-Apr-03 20:29 cycle 100000 block plot
- Displacement vectors
  - Maximum = 9.213E+00

Department of Geography
University of Durham
Figure 7.28c: Displacement vectors for the east-west profile of Canchorrail de Hormas at 200000 cycles.

**UDEC** (Version 3.10)

**LEGEND**

1-Apr-03 22:00

cycle 200000

block plot

displacement vectors

maximum = 3.721E+01

0 2E 2

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Figure 7.29d: Displacement vectors for the east-west profile of Canchorral de Hormas, Picos de Europa at 500 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 2-Apr-03 2:27 cycle 500000 block plot displacement vectors maximum = 7.139E+01

Department of Geography
University of Durham
Figure 7.30: Horizontal displacement contours for east-west profile of Canchorral de Hormas at equilibrium.

**JOB TITLE:** Horizontal displacement contours for east-west profile of Canchorral de Hormas at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

- 1-Apr-03 19:10
- cycle 10000
- block plot
- X displacement contours
- contour interval = 2.000E-01
- -6.000E-01 to 4.000E-01

Department of Geography
University of Durham
Figure 7.30b: Horizontal displacement contours for east-west profile of Canchorral de Hormas at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 1-Apr-03 20:29
- cycle 100000
- block plot
- X displacement contours
- contour interval= 1.000E+00
- -7.000E+00 to 0.000E+00

- -7.000E+00
- -6.000E+00
- -5.000E+00
- -4.000E+00
- -3.000E+00
- -2.000E+00
- -1.000E+00
- 0.000E+00

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University of Durham
Figure 7.30c: Horizontal displacement contours for east-west profile of Canchorral de Hormas at 200,000 cycles.

UDEC (Version 3.10)

Legend

1-Apr-03 22:00
cycle 200000
block plot
X displacement contours
contour interval= 5.000E+00
-2.500E+01 to 0.000E+00

Department of Geography
University of Durham
Figure 7.31: Total unbalanced forces for east-west profile of Canchorral de Hormas at 500,000 cycles.

**UDEC (Version 3.10)**

<table>
<thead>
<tr>
<th>JOB TITLE</th>
<th>Total unbalanced forces for east-west profile of Canchorral de Hormas at 500,000 cycles.</th>
</tr>
</thead>
</table>

**CONCLUSION**

2-Apr-03 2:27

| cycle 500000 |
| history plot |
| 0.00E+00<hist 1: 1.93E+08 Vs. 0.00E+00<time> 3.10E+02 |

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Figure 7.32a: Block plot of the east-west profile of Los Montes at equilibrium.

**LEGEND**

- 7-Apr-03 11:07
- cycle 10000
- block plot

Department of Geography
University of Durham
Figure 7.32b: Displacement vector plot for the east-west profile of Los Montes, Picos de Europa at 300,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 7-Apr-03 16:24
- cycle 300000
- block plot
- displacement vectors
- maximum = 1.112E+02
- 0 5E 2

Department of Geography
University of Durham
Figure 7.3: Total unbalanced forces for east-west profile of Los Montes at 300,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

7-Apr-03 16:24
cycle 300000
history plot
0.00E+00<hist 1> 2.96E+08
Vs
0.00E+00<time> 2.75E+02

Department of Geography
University of Durham
Figure 7.34: Horizontal displacement contours for the east-west profile of Los Montes at 300,000 cycles.

JOB TITLE: Horizontal displacement contours for east-west profile of Los Montes at 300,000 cycles.

UDEC (Version 3.10)

LEGEND

7-Apr-03 16:24
cycle 300000
block plot
X displacement contours
contour interval= 1.000E+01
-5.000E+01 to 3.000E+01

-5.000E+01
-4.000E+01
-3.000E+01
-2.000E+01
-1.000E+01
0.000E+00
1.000E+01
2.000E+01
3.000E+01

Department of Geography
University of Durham
Figure 7.35a: Block plot of the east-west profile of Los Montes. Picos de Europa with a simulated road cut at equilibrium.

JOB TITLE: Block plot of east-west profile for Los Montes with simulated road cut at equilibrium.

UDEC (Version 3.10)

LEGEND

8-Apr-03 10:11
Cycle 10000
Block plot

Department of Geography
University of Durham
Figure 7.35b: Displacement vectors for east-west profile for Los Montes with simulated road-cut at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 8-Apr-03 11:29
- cycle 100000
- block plot
- displacement vectors
  - maximum = 1.199E+02

Department of Geography
University of Durham
JOB TITLE: Displacement vectors for east-west profile for Los Montes with simulated road-cut at 300 000 cycles.

UDEC (Version 3.10)

LEGEND

8-Apr-03 14:45
cycle 300000
block plot
displacement vectors
maximum = 2.581E+02

0 1E 3

Department of Geography
University of Durham
Figure 7.36a: Horizontal displacement contours for the east-west profile of Los Montes with simulated road cut at 100,000 cycles.

**JOB TITLE:** Horizontal displacement contours for east-west profile of Los Montes with simulated road cut at 100,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 6-Apr-03 11:29
- cycle 100,000
- block plot
- X displacement contours
- contour interval = 1.00E+01
- -2.00E+01 to 6.00E+01
- 2.00E+01
- 1.00E+01
- 0.00E+00
- 3.00E+01
- 4.00E+01
- 5.00E+01
- 6.00E+01

Department of Geography
University of Durham
Figure 7.36b: Horizontal displacement contours for the east-west profile of Los Montes with simulated road cut at 300,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 8-Apr-03 14:45
- cycle 300000
- block plot
- X displacement contours
- contour interval = 2.000E+01
- -2.000E+01 to 1.200E+02

- -2.000E+01
- 0.000E+00
- 2.000E+01
- 4.000E+01
- 6.000E+01
- 8.000E+01
- 1.000E+02
- 1.200E+02

Department of Geography
University of Durham
Figure 7.37a: Block plot of the north-south profile of Los Montes, Picos de Europa at equilibrium.

JOB TITLE: Block plot of north-south profile for Los Montes at equilibrium.

UDEC (Version 3.10)

LEGEND

11-Apr-03 19:08
cycle 10000
block plot

Department of Geography
University of Durham
Figure 7.37b: Displacement vectors for north-south profile for Los Montes at 100,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 11-Apr-03 20:43
- cycle 100000
- block plot
- displacement vectors
- maximum = 1.829E+01

Department of Geography
University of Durham
Figure 7.37c: Displacement vectors for north-south profile for Los Montes at 300,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 12-Apr-03 0:16
- cycle 300000
- block plot
- displacement vectors
- maximum = 6.502E+01
- 0 2E 2

Department of Geography
University of Durham
Figure 7.38a: Horizontal displacement contours for north-south profile of Los Montes at 100,000 cycles.

**UDEC (Version 3.10)**

LEGEND

11-Apr-03 20:43
cycle 100000
block plot
X displacement contours
contour interval = 2.000E+00
0.000E+00 to 1.600E+01

- 0.000E+00
- 2.000E+00
- 4.000E+00
- 6.000E+00
- 8.000E+00
- 1.000E+01
- 1.200E+01
- 1.400E+01
- 1.600E+01

Department of Geography
University of Durham
Figure 7.38: Horizontal displacement contours for north-south profile of Los Montes at 300,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 12-Apr-03 0:16 cycle 300,000
- block plot
- X displacement contours
- contour interval: 1.000E+01
- 0.000E+00 to 5.000E+01

Department of Geography
University of Durham
Figure 7.39a: Block plot of east-west profile for Allende at equilibrium.

**LEGEND**

4-Apr-03 17:17  
cycle 10000  
block plot

Department of Geography  
University of Durham
JOB TITLE: Displacement vectors for east-west profile of Allende at 100 000 cycles.

UDEC (Version 3.10)

LEGEND:
4-Apr-03 18:48
cycle 100000
block plot
displacement vectors
maximum = 3.733E+01
0 2E 2

Department of Geography
University of Durham
Displacement vectors for east-west profile of Allende at 250,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 4-Apr-03 21:17
- cycle 250000
- block plot
- displacement vectors
  - maximum = 7.810E+01
  - 0 2E 2

Department of Geography
University of Durham
Figure 7.39d: Displacement vectors for the east-west profile of Allende at 500,000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of Allende at 500,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 5-Apr-03 1:22
- cycle 500,000
- block plot
- displacement vectors
- maximum = 1.332E+02

Department of Geography
University of Durham
JOB TITLE: Horizontal displacement contours for east-west profile of Allende at 100,000 cycles.

UDEC (Version 3.10)

LEGEND

4-Apr-03 18:48
cycle 100000
block plot
X displacement contours
contour interval = 5.000E+00
-2.000E+01 to 2.500E+01

Department of Geography
University of Durham
Figure 7.40b: Horizontal displacement contours for the east-west profile of Allende at 250,000 cycles.

JOB TITLE: Horizontal displacement contours for east-west profile of Allende at 250,000 cycles.

UDEC (Version 3.10)

LEGEND

4-Apr-03 21:17
cycle 250000
block plot
X displacement contours
contour interval= 1.000E+01
-5.000E+01 to 3.000E+01

Department of Geography
University of Durham
Figure 7.40c: Horizontal displacement contours for the east-west profile of Allende at 500,000 cycles.

UDEC (Version 3.10)

LEGEND

-1.00E+02
-8.00E+01
-6.00E+01
-4.00E+01
-2.00E+01
0.00E+00
2.00E+01

Department of Geography
University of Durham
Figure 7.4.1: Total unbalanced forces for east-west profile of Allende at 500,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

5-Apr-03 1:22
500000 cycles
history plot
0.00E+00<hist 1> 6.20E+08
Vs.
0.00E+00<time> 4.81E+02

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Figure 7.42a: Block plot of north-south profile for Allende at equilibrium.

**JOB TITLE:** Block plot of north-south profile for Allende at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

3-Apr-03 18:07  
cycle 10000  
block plot

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0.500 1.500  
2.500 3.500 4.500 5.500 6.500  
(-10^2)  
5.000 4.000 3.000 2.000 1.000 0.000 -1.000  
(-10^2)
Displacement vectors for the north-south profile of Allende, Picos de Europa at 100,000 cycles.

**JOB TITLE:** Displacement vectors for N-S profile of Allende at 100,000 cycles

**UDEC (Version 3.10)**

**LEGEND:**
- 3-Apr-03 18:39
- cycle: 100,000
- block plot
- displacement vectors
- maximum = 4.606E+01
- 0 2E 2

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Figure 7.42c: Displacement vectors for the north-south profile of Allende at 300 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 3-Apr-03 19:47
- cycle 300000
- block plot
- displacement vectors
- maximum = 1.339E+02

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Figure 7.42d: Displacement vectors for the north-south profile of Allende, Picos de Europa at 401 040 cycles.

**JOB TITLE**: Displacement vectors for north-south profile for Allende at 401 040 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 4-Apr-03 11:26
cycle 401040
block plot
displacement vectors
maximum = 3.629E+02

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Figure 7.43a: Horizontal displacement contours for the north-south profile of Allende at 100,000 cycles.

JOB TITLE: Horizontal displacement contours for north-south profile of Allende at 100,000 cycles.

UDEC (Version 3.10)

LEGEND

3-Apr-03 18:39
cycle 100000
block plot
X displacement contours
contour interval = 5.000E+00
-2.000E+01 to 1.500E+01

Legend:
-2.000E+01
-1.500E+01
-1.000E+01
-5.000E+00
0.000E+00
5.000E+00
1.000E+01
1.500E+01

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JOB TITLE: Horizontal displacement contours for north-south profile of Allende at 300 000 cycles.

UDEC (Version 3.10)

LEGEND

3-Apr-03 19:47
cycle 300000
block plot
X displacement contours
contour interval= 1.000E+01
-7.000E+01 to 2.000E+01

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Figure 7.46: Comparison of the half-way time for all failures in the Picos de Europa models.
Figure 7.47: Exponential asymptotic model (dashed line) applied to x-displacement data for the failures at Torre de Salinas.
Figure 7.48: Exponential asymptotic model (dashed line) applied to x-displacement data for the failure on the north-south profile of Pico de la Padierna.
Figure 7.49: Exponential asymptotic (dashed line) applied to x-displacement data (circles) for the east-west profile of Tiro Pedabejo.
Figure 7.50: Exponential asymptotic model (dashed line) applied to x-displacement data for the failures at Canchorral de Hormas.
Figure 7.51: Exponential asymptotic model (dashed line) applied to x-displacement data for the failures at Los Montes.
Figure 7.52: Exponential asymptotic model (dashed line) applied to x-displacement data for the failures at Allende.
Figure 7.53: Summary of the two main patterns of failure in $\lambda$-$t$ space associated with brittle, catastrophic failure and self-stabilising flexural toppling failure.
Figure 7.54: Results of erosion rate modelling on the samples selected for $^{36}$Cl dating. As the erosion rate increases, the applied erosion rate correction decreases the ages of the boulder.
Figure 7.55: Calculated $^{36}$Cl dates for rock slope failures in the Picos de Europa. The dates indicate one failure event, with almost synchronous timing.
Figure 7.56: Exhaustion model for paraglacial rock slope failure in the Picos de Europa, compared with data from Cruden and Hu (1993) in the Canadian Rockies.
Figure 7.57: Proposed model of paraglacial rock slope evolution for the Picos de Europa based on UDEC modelling, assessment of paraglacial exhaustion models and cosmogenic dating.
Figure 8.1: Block plot of north-south profile of AL9 at equilibrium.

**JOB TITLE:** Block plot of north-south profile of AL9 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

30-May-03 10:59  
cycle 10000  
block plot

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Figure 8.2: Total unbalanced forces for the north-south profile of AL9 at equilibrium.

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UDEC (Version 3.10)

LEGEND

CQ: 1.20

C: 0.80

C: 0.60

C: 0.40

C: 0.20

E: 0.00

0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60

0.00 0.20 0.40 0.60 0.80

0.00 0.20 0.40 0.60

0.00 0.20 0.40 0.60

0.00 0.20 0.40 0.60
Figure 8.3a: Displacement vectors for north-south profile of AL9 at 15,000 cycles.

**JOBS TITLE:** Displacement vectors for north-south profile of AL9 at 15,000 cycles.

**UDEC (Version 3.10)**

<table>
<thead>
<tr>
<th>JOB TITLE</th>
<th>Displacement vectors for north-south profile of AL9 at 15,000 cycles.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEGEND</strong></td>
<td>30-May-03 10:59 cycle 15000 block plot displacement vectors maximum = 4.20E+00</td>
</tr>
<tr>
<td>0</td>
<td>2E 1</td>
</tr>
</tbody>
</table>

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---

Figure 8.3a: Displacement vectors for the north-south profile of AL9 at 15,000 cycles.
Figure 8.3b: Displacement vectors for the north-south profile of AL9 at 17000 cycles.

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Figure 8.3c: Displacement vectors for the north-south profile of AL9 at 40,000 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of AL9 at 40,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 30-May-03 11:00
- cycle 40,000
- block plot
- displacement vectors
- maximum = 3.242E+01
- 0 1E 2

Department of Geography
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Figure 8.4: Total unbalanced forces for north-south profile of AL9 at 40,000 cycles.

JOB TITLE: Total unbalanced forces for north-south profile of AL9 at 40,000 cycles.

UDEC (Version 3.10)

LEGEND

30-May-03 11:00
cycle 40000
history plot
0.00E+00<hist 1> 2.72E+06
Vs.
0.00E+00<time> 6.33E+01

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University of Durham
Figure 8.5a: Horizontal displacement contours for the north-south profile of AL9 at equilibrium.

UDEC (Version 3.10)

LEGEND

30-May-03 10:59
cycle 10000
block plot
X displacement contours
contour interval = 5.000E-03
-1.000E-02 to 2.000E-02

-1.000E-02
-5.000E-03
0.000E+00
5.000E-03
1.000E-02
1.500E-02
2.000E-02

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Figure 8.5b: Horizontal displacement contours for the north-south profile of AL9 at 15,000 cycles.

UDEC (Version 3.10)

LEGEND

30-May-03 10:59
Cycle 15000
Block plot
X displacement contours
Contour interval = 5.000E-01
-4.000E+00 to 5.000E-01

Department of Geography
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Figure 8.5c: Horizontal displacement contours for the north-south profile of AL9 at 17 000 cycles.

UDEC (Version 3.10)

LEGEND

30-May-03 10:59
cycle 17000
block plot
X displacement contours
contour interval= 2.000E+00
-1.000E+01 to 0.000E+00

0.100 0.300 0.500 0.700 0.900

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JOB TITLE: Horizontal displacement contours for north-south profile of AL9 at 40,000 cycles.

UDEC (Version 3.10)

LEGEND

30-May-03 11:00
cycle 40000
block plot
X displacement contours
contour interval = 4.000E+00
-2.000E+01 to 0.000E+00

Department of Geography
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Figure 8.6a: Block plot of the east-west profile of AL9 at equilibrium.

JOB TITLE: Block plot of east-west profile of AL9 at equilibrium.

UDEC (Version 3.10)

LEGEND

30-May-03 14:52
cycle 10000
block plot

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Figure 8.6b: Displacement vectors for the east-west profile of AL9 at 50,000 cycles.
Figure 8.7: Total unbalanced forces for the east-west profile of AL9 at 50,000 cycles.

**LEGEND**
- 30-May-03 14:58
- Cycle 50000
- History plot
- 0.00E+00<hist 1> 2.10E+06
- Vs.
- 0.00E+00<time> 7.90E+01

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JOB TITLE: Block plot of north-south profile of AL12 at equilibrium.

UDEC (Version 3.10)

LEGEND

10-Jun-03 10:34

cycle 10000
block plot

Department of Geography
University of Durham
JOB TITLE: Displacement vectors for north-south profile of AL12 at 12 000 cycles.

UDEC (Version 3.10)

LEGEND

10-Jun-03 10:34
cycle 12000
block plot
displacement vectors
maximum = $4.734E+00$

Department of Geography
University of Durham
Figure 8.8c: Displacement vectors for north-south profile of AL12 at 15,000 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of AL12 at 15,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 10-Jun-03 10:34 cycle 15000 block plot displacement vectors
- maximum = 1.078E+01

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Department of Geography
University of Durham
Figure 8.8d: Displacement vectors for the north-south profile of AL12 at 25,000 cycles.
**Figure 8.9:**
Total unbalanced forces for north-south profile of AL12 at 25 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
10-Jun-03 10:34
cycle 25000
history plot
0.00E+00< hist 1 > 1.82E+06
Vs.
0.00E+00< time > 8.33E+01

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JOB TITLE: Horizontal displacement contours for north-south profile of AL12 at 12 000 cycles.

UDEC (Version 3.10)

LEGEND

10-Jun-03 10:34
cycle 12000
block plot
X displacement contours
contour interval= 4.000E-01
0.000E+00 to 2.000E+00

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Figure 8.10b: Horizontal displacement contours for the north-south profile of AL 12 at 15,000 cycles.

**JOB TITLE**: Horizontal displacement contours for north-south profile of AL 12 at 15,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 10-Jun-03 10:34 cycle 15000
- Block plot X displacement contours
- Contour interval: $1.000E+00$
- $0.000E+00$ to $8.000E+00$

Department of Geography
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Figure 8.10c: Horizontal displacement contours for north-south profile of AL12 at 25 000 cycles.

**JOB TITLE:** Horizontal displacement contours for north-south profile of AL12 at 25 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 10-Jun-03 10:34
- cycle 25000
- block plot
- X displacement contours
- contour interval = 4.00E+00
- 0.000E+00 to 2.000E+01

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JOB TITLE: Block plot of east-west profile of AL12 at equilibrium.

UDEC (Version 3.10)

Legend:
10-Jun-03 11:19
Cycle 10000
Block plot

Department of Geography
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Figure 8.11b: Displacement vectors for the east-west profile of AL12 at 100 000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL12 at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

10-Jun-03 11:23
cycle 100000
block plot
displacement vectors
maximum = 3.103E-01
0 1E 0

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Horizontal displacement contours for the east-west profile of AL12 at 100,000 cycles.

LEGEND

- Cycle: 100,000
- X-displacement contours
- Contour interval: 2.000E-02
- Minimum: -4.000E-02
- Maximum: 4.000E-02

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Figure 8.13a: Block plot of north-south profile of AL10 at equilibrium.

**JOB TITLE**: Block plot of north-south profile of AL10 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

9-Jun-03 12:59
cycle 10000
block plot

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Figure 6.13b: Displacement vectors for the north-south profile of AL10 at 13,000 cycles.

JOB TITLE: Displacement vectors for north-south profile of AL10 at 13,000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 13:00
cycle 13000
block plot
displacement vectors
maximum = 1.656E+01

Department of Geography
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Figure 8.13c: Displacement vectors for north-south profile of AL10 at 15,000 cycles.

**JOB TITLE**: Displacement vectors for north-south profile of AL10 at 15,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

9-Jun-03 13:01

cycle 15000

block plot

displacement vectors

maximum = 3.399E+01

0 2E 2

Department of Geography
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Figure 8.13d: Displacement vectors for the north-south profile of AL10 at 21000 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of AL10 at 21000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 9-Jun-03 13:08
- cycle 21000
- block plot
- displacement vectors
- maximum = 6.941E+01
- 0 2E 2

Department of Geography
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JOB TITLE: Horizontal displacement contours for north-south profile of AL10 at 13 000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 13:00
cycle 13000
block plot
X displacement contours
contour interval= 5.000E+00
-1.000E+01 to 1.000E+01

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University of Durham
Figure 8.14b: Horizontal displacement contours for the north-south profile of AL10 at 15 000 cycles.

**JOB TITLE:** Horizontal displacement contours for north-south profile of AL10 at 15 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 9-Jun-03 13:01
- cycle 15000
- block plot
- X displacement contours
- contour interval = 1.000E+01 to 2.000E+01

Department of Geography
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Horizontal displacement contours for the north-south profile of AL10 at 21,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- X displacement contours
  - contour interval: 1.000E+01
  - -5.000E+01 to 4.000E+01

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Figure 8.15: Total unbalanced forces for north-south profile of AL10 at 21,000 cycles.

JOB TITLE: Total unbalanced forces for north-south profile of AL10 at 21,000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 13:08
cycle 21000
history plot
0.00E+00<hist 1> 8.70E+06 
Vs.
0.00E+00<time> 4.03E+01

Department of Geography
University of Durham
Figure 8.16a: Block plot of the east-west profile of AL10 at equilibrium.

**JOB TITLE:** Block plot of east-west profile of AL10 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

9-Jun-03 9:25  
cyCLE 10000  
block plot

Department of Geography  
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Figure 8.16b: Displacement vectors for east-west profile of AL10 at 100 000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL10 at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 9-Jun-03 10:11
- cycle 100000
- block plot
- displacement vectors
  - maximum = 2.398E+00
  - 0 to 1E1

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-0.250 -0.750 -1.250

0.250 0.750 1.250 1.750 2.250 2.750 3.250 3.750 (10^2)

-0.250 -0.750 -1.250

0.250 0.750 1.250 1.750 2.250 2.750 3.250 3.750 (10^2)
JOB TITLE: Horizontal displacement contours for east-west profile of AL10 at 100 000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 10:11
cycle 100000
block plot
X displacement contours
contour interval= 2.000E-01
-1.400E+00 to 2.000E-01

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Figure 8.18a: Block plot of the north-south profile of AL11 at equilibrium.

**JOB TITLE**: Block plot of north-south profile of AL11 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

10-Jun-03 8:45  
Cycle 10000  
Block plot

Department of Geography  
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Figure 6.18b: Displacement vectors for north-south profile of AL11 at 100 000 cycles.

**JOB TITLE**: Displacement vectors for north-south profile of AL11 at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

10-Jun-03 9:12
cycle 100000
block plot
displacement vectors
maximum = 2.392E+01

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Figure 8.19: Total unbalanced forces for north-south profile of AL11 at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

10-Jun-03 9:12
cycle 100000
history plot
0.00E+00<hist 1> 5.59E+06
Vs.
0.00E+00<time> 2.07E+02

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JOB TITLE: Horizontal displacement contours for north-south profile of AL11 at 100 000 cycles.

UDEC (Version 3.10)

LEGEND

10-Jun-03  9:12
cycle  100000
block plot
X displacement contours
contour interval= 2.000E+00
-4.000E+00 to 4.000E+00
-4.000E+00
-2.000E+00
0.000E+00
2.000E+00
4.000E+00

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Figure 8.21a: Block plot of the east-west profile of AL11 at equilibrium.

JOB TITLE: Block plot of east-west profile of AL11 at equilibrium.

UDEC (Version 3.10)

LEGEND

9-Jun-03 13:56
cycle 10000
block plot

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0.500 1.500 2.500 3.500 (10^2)

0.000 1.000 2.000 3.000

-1.000 -2.000
JOB TITLE: Displacement vectors for east-west profile of AL11 at 20 000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 14:12
cycle 20000
block plot
displacement vectors
maximum = 3.954E+01

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Figure 8.21c: Displacement vectors for the east-west profile of AL11 at 40 000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL11 at 40 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

9-Jun-03 14:31

cycle 40000

block plot
displacement vectors

maximum = 5.897E+01

0 2E 2
Figure 8.22a: Horizontal displacement contours for the east-west profile of AL11 at 20,000 cycles.

JOBTITLE: Horizontal displacement contours for east-west profile of AL11 at 20,000 cycles.

UDEC (Version 3.10)

LEGEND

9-Jun-03 14:12
cycle 20000
block plot
X displacement contours
contour interval = 5.000E+00
0.000E+00 to 3.000E+01

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University of Durham
Figure 8.22b: Horizontal displacement contours for the east-west profile of AL 11 at 40,000 cycles.
Figure 8.22: Total unbalanced forces for the east-west profile of AL11 at 40,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

9-Jun-03 14:31
cycle 40000
history plot
0.00E+00<hist 1> 6.08E+06
Vs.
0.00E+00<time> 8.73E+01

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JOB TITLE: Block plot of north-south profile of AL3 at equilibrium.

UDEC (Version 3.10)

LEGEND

15-May-03 18:21
cycle 10000
block plot

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Figure 8.24b: Displacement vectors for the north-south profile of AL3 at 13000 cycles.
Figure 8.24c: Displacement vectors for the north-south profile of AL3 at 15,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 15-May-03 18:25
- cycle 15000
- block plot
- displacement vectors
- maximum = 7.286E+01
- 0 2E 2

Department of Geography
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Figure 8.24d: Displacement vectors for the north-south profile of AL3 at 20,000 cycles.

**JOE TITLE:** Displacement vectors for north-south profile of AL3 at 20,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

15-May-03 18:31
cycle 20000
block plot
displacement vectors
maximum = 1.268E+02

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Figure 25a: Horizontal displacement contours for north-south profile of AL3 at 13 000 cycles.

UDEC (Version 3.10)

LEGEND

15-May-03 18.23 cycle 13000 block plot
X displacement contours contour interval= 1.000E+01 -2.000E+01 to 3.000E+01

-2.000E+01
-1.000E+01
0.000E+00
1.000E+01
2.000E+01
3.000E+01

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Figure 8.25b: Horizontal displacement contours for north-south profile of AL3 at 20,000 cycles.

JOB TITLE: Horizontal displacement contours for north-south profile of AL3 at 20,000 cycles.

UDEC (Version 3.10)

LEGEND

15-May-03 18:31
cycle 20000
block plot
X displacement contours
contour interval=2.000E+01
-6.000E+01 to 8.000E+01
-6.000E+01
-4.000E+01
-2.000E+01
0.000E+00
2.000E+01
4.000E+01
6.000E+01
8.000E+01

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Figure B.26a: Block plot of the east-west profile of AL3 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

13-May-03 18:26
cycle 10000
block plot

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---

**JOB TITLE:** Block plot of east-west profile of AL3 at equilibrium.
Figure 2.26b: Displacement vectors for AL3a at 20,000 cycles.

**JOB TITLE:** Displacement vectors for AL3a at 20,000 cycles

**UDEC (Version 3.10)**

**LEGEND**

13-May-03 18:56

- cycle 20000
- block plot
- displacement vectors
  - maximum = 4.958E+01
  - 0 2E 2

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Figure 8.26c: Displacement vectors for the east-west profile of AL3 at 150,000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL3 at 150,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

14-May-03 16:23

Cycle 150000

Block plot

Displacement vectors

Maximum = 4.471E+01

Department of Geography

University of Durham
Figure 8.27a: Horizontal displacement contours for east-west profile of AL3 at 20 000 cycles.

UDEC (Version 3.10)

LEGEND

13-May-03 18:56
cycle 20000
block plot
X displacement contours
contour interval= 5.000E+00
-5.000E+00 to 4.000E+01

Department of Geography
University of Durham
Figure 8.27b: Horizontal displacement contours for east-west profile of AL3 at 150,000 cycles.

LEGEND
14-May-03 16:23
cycle 150000
block plot
X displacement contours
contour interval= 1.000E+01
0.000E+00 to 4.000E+01

Department of Geography
University of Durham
Figure 8.28: Total unbalanced forces for the east-west profile of AL3 at 150 000 cycles.

**JOB TITLE**: Total unbalanced forces for east-west profile of AL3 at 150 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

14-May-03 16:23
cycle 150000
history plot
0.00E+00<hist 1> 3.25E+07
Vs.
0.00E+00<time> 4.40E+02

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University of Durham
JOB TITLE: Block plot of north-south profile of AL2 at equilibrium.

UDEC (Version 3.10)

LEGEND

12-May-03 18:19
cycle 10000
block plot

Department of Geography
University of Durham
Figure 8.29b: Displacement vectors for the north-south profile of AL2 at 20,000 cycles.

**JOB TITLE**: Displacement vectors for north-south profile of AL2 at 20,000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 12-May-03 18:38
- cycle 20000
- block plot
- displacement vectors
- maximum = 1.322E+02

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JOB TITLE: Displacement vectors for north-south profile of AL2 at 68,502 cycles.

UDEC (Version 3.10)

LEGEND

13-May-03 12:32

cycle 68502
block plot
displacement vectors
maximum = 2.223E+02

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20 000 cycles. Figure 8.30a: Horizontal displacement contours for the north-south profile of AL2 at 20 000 cycles.
68 502 cycles

Figure 8.30b: Horizontal displacement contours for north-south profile of AL2 at 68 502 cycles.

JOE TITLE: Horizontal displacement contours for north-south profile of AL2 at 68 502 cycles.

UDEC (Version 3.10)

LEGEND

13-May-03 12:32
1 cycle 68502
block plot
X displacement contours
contour interval= 5.000E+01
-1.500E+02 to 1.000E+02

-1.500E+02
-1.000E+02
-5.000E+01
0.000E+00
5.000E+01
1.000E+02

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University of Durham
Figure 8.31: Total unbalanced forces for north-south profile of AL2 at 68,502 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 13-May-03 12:32 cycle 68502 history plot
- 0.00E+00<hist 1> 9.05E+07 Vs.
- 0.00E+00<time> 1.43E+02

Department of Geography
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Figure 8.32a: Block plot of the east-west profile of AL2 at equilibrium.

**JOB TITLE:** Block plot of east-west profile of AL2 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

13-May-03 15:21

- cycle 10000
- block plot

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Figure 8.32b: Displacement vectors for the east-west profile of AL2 at 100 000 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL2 at 100 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

13-May-03 16:11
cycle 100000
block plot
displacement vectors
maximum = 2.718E+00
0 1E 1

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JOB TITLE: Horizontal displacement contours for east-west profile of AL2 at 100 000 cycles.

UDEC (Version 3.10)

LEGEND

13-May-03 16:11
cycle 100000
block plot
X displacement contours
contour interval= 2.000E-01
-1.000E+00 to 4.000E-01

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Figure 8.34a: Block plot of north-south profile of AL7 at equilibrium.

**JOB TITLE:** Block plot of north-south profile of AL7 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

20-May-03 10:25
cycle 10000
block plot

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Figure 8.34b: Displacement vectors for north-south profile of AL7 at 15403 cycles.

**UDEC (Version 3.10)**

<table>
<thead>
<tr>
<th>JOB TITLE</th>
<th>Displacement vectors for north-south profile of AL7 at 15403 cycles.</th>
</tr>
</thead>
</table>

**LEGEND**

- 20-May-03 14:28
- cycle 15403
- block plot
- displacement vectors
- maximum = 6.192E+01

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Figure 8.34c: Displacement vectors for the north-south profile of AL7 at 17403 cycles.

**UDEC (Version 3.10)**

**JOB TITLE:** Displacement vectors for north-south profile of AL7 at 17403 cycles.

**LEGEND:**
- 20-May-03 14:47 cycle 17403 block plot displacement vectors maximum = 7.697E+01
- 0 2E 2

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Figure 8.34d: Displacement vectors for the north-south profile of AL7 at 30 403 cycles.

**JOB TITLE:** Displacement vectors for north-south profile of AL7 at 30 403 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 20-May-03 15:56
- Cycle: 30403
- Block plot
- Displacement vectors
- Maximum: 2.029E+02

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Figure 8.35a: Horizontal displacement contours for the north-south profile of AL7 at 15,403 cycles.

**JOB TITLE:** Horizontal displacement contours for north-south profile of AL7 at 15,403 cycles.

**UDEC (Version 3.10)**

**LEGEND**

20-May-03 14:28
cycle 15403
block plot
X displacement contours
contour interval= 1.000E+01
-3.000E+01 to 3.000E+01

-3.000E+01
-2.000E+01
-1.000E+01
0.000E+00
1.000E+01
2.000E+01
3.000E+01

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Figure 8.35b: Horizontal displacement contours for north-south profile of AL7 at 30,403 cycles.

**JOB TITLE:** Horizontal displacement contours for north-south profile of AL7 at 30,403 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 20-May-03 15:56
- cycle 30403
- block plot
- X displacement contours
- contour interval = 2.000E+01
- -8.000E+01 to 6.000E+01
- -8.000E+01
- -6.000E+01
- -4.000E+01
- -2.000E+01
- 0.000E+00
- 2.000E+01
- 4.000E+01
- 6.000E+01

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JOB TITLE: Block plot of east-west profile of AL7 at equilibrium.

UDEC (Version 3.10)

LEGEND
19-May-03 10:27
cycle 10000
block plot

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Figure 8.36b: Displacement vectors for the east-west profile of AL7 at 13 000 cycles.

** Legend **
- 19-May-03 10:31
- cycle 13000
- block plot
- displacement vectors
- maximum = 2.452E+01

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Figure 8.36c: Displacement vectors for east-west profile of AL7 at 20 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 19-May-03 10:54
- cycle 20000
- block plot
- displacement vectors
- maximum = 9.926E+01

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JOB TITLE: Displacement vectors for east-west profile of AL7 at 25 056 cycles.

UDEC (Version 3.10)

LEGEND

19-May-03 12:24
cycle 25056
block plot
displacement vectors
maximum = 1.652E+02

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JOB TITLE: Horizontal displacement contours for east-west profile of AL7 at 13000 cycles.

UDEC (Version 3.10)

LEGEND
19-May-03 10:31
cycle 13000
block plot
X displacement contours
contour interval = 5.000E+00
-5.000E+00 to 1.500E+01

-5.00E+00
0.00E+00
5.00E+00
1.00E+01
1.50E+01

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Figure 8.37b: Horizontal displacement contours for east-west profile of AL7 at 20 000 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 19-May-03 10:54
- cycle 20000
- block plot
- X displacement contours
- contour interval = 1.000E+01
- -1.000E+01 to 6.000E+01

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**Figure 8.37c:** Horizontal displacement contours for the east-west profile of AL7 at 25,056 cycles.

**JOB TITLE:** Horizontal displacement contours for east-west profile of AL7 at 25,056 cycles.

**UDEC (Version 3.10)**

**LEGEND**

19-May-03 12:24

cycle 25056
block plot
X displacement contours
contour interval= 2.000E+01
-2.000E+01 to 8.000E+01

-2.000E+01
0.000E+00
2.000E+01
4.000E+01
6.000E+01
8.000E+01
Figure 8.38a: Block plot of east-west profile of AL17 at equilibrium.

**JOB TITLE:** Block plot of east-west profile of AL17 at equilibrium.

**UDEC (Version 3.10)**

**LEGEND**

12-Jun-03 13:21
cycle 10000
block plot

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Figure 8.38b: Displacement vectors for the east-west profile of AL17 at 34 360 cycles.
Figure 6.38c: Displacement vectors for east-west profile of AL17 at 334 360 cycles.

**JOB TITLE:** Displacement vectors for east-west profile of AL17 at 334 360

**UDEC (Version 3.10)**

**LEGEND**

13-Jun-03 12:02
cycle 334360
block plot
displacement vectors
maximum = 1.204E+02

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JOB TITLE: Displacement vectors for east-west profile of AL17 at 404 360 cycles.

UDEC (Version 3.10)

LEGEND

13-Jun-03 12:55
cycle 404360
block plot
displacement vectors
maximum = 1.823E+02

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JOB TITLE: Total unbalanced forces for east-west profile of AL17 at 404 360 cycles.

**UDEC (Version 3.10)**

**LEGEND**
- 13-Jun-03 12:55
- cycle 404360
- history plot
  - 0.00E+00<hist 1> 2.65E+09
  - Vs.
  - 0.00E+00<time> 1.14E+03

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Figure 8.40a: Horizontal displacement contours for east-west profile of AL17 at 34 360 cycles.

**UDEC (Version 3.10)**

**LEGEND**

- 12-Jun-03 13:55 cycle 34360 block plot
- X displacement contours
- Contour interval = 2.000E+01 -2.000E+01 to 8.000E+01

-2.000E+01
0.000E+00
2.000E+01
4.000E+01
6.000E+01
8.000E+01

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Figure 8.49b: Horizontal displacement contours for east-west profile of AL17 at 334 360 cycles.

**UDEC (Version 3.10)**

**LEGEND**

13-Jun-03 12:02
Cycle 334360
Block plot
X displacement contours
Contour interval= 2.000E+01
-2.000E+01 to 1.000E+02

-2.000E+01
0.000E+00
2.000E+01
4.000E+01
6.000E+01
8.000E+01
1.000E+02

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404 360 cycles.

Figure 8.40c: Horizontal displacement contours for the east-west profile of AL17 at 404 360 cycles.

JOB TITLE: Horizontal displacement contours for east-west profile of AL17 at 404 360 cycles.

UDEC (Version 3.10)

LEGEND

13-Jun-03 12:55
cycle 404360
block plot
X displacement contours
contour interval= 4.000E+01
-4.000E+01 to 1.600E+02

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Figure 8.55: Smoothed total unbalanced forces for $\text{AL}_{10} \text{Be}$ ages and $\sigma_1$ error have been overlaid on the graph, based on one model cycle representing 2.3 years.
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