CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

CNWRA
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CNWRA Subcontract 499883N
Task 02 - UDEC Validation

Sept. 14/2004.

This scientific notebook is a continuation of work summarized in scientific notebook SN654 Vol. 1 issued to Rodney Read (RSRead Consulting Inc.) by CNWRA.

Title: Validation of Universal Distinct Element Code (UDEC) Ver 3.1
Principal Investigator: Dr. Rodney S. Read, RSRead Consulting Inc.
CNWRA Personnel: Dr. Goodluck Ofoegbu, Dr. Asadul Chowdhury
Dr. Sui-min Hsiung

The objectives, approach, qualification requirements, and description of analyses are contained in SN654 Vol 1, along with details on computer platform, software, and in-process entries describing progress.
(R Nov 10/04) These are reproduced on pages 137 and 138.

Sep 14/04 R

Case 7.1 UDEC Horizontal transgressing joint (no slip)

Case 7.1 was re-run using input file U71INPUT.TXT (see page 2) and file U71FILL.TXT (see page 199 in SN654 Vol. 1.). Data exported from UDEC was imported into EXCEL file U71.XLS to create comparable plots to those created using FLAC. The sign convention for shear and normal stress on the joint were reversed to match those in FLAC.

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```
; Case 7.1 - UDEC 3.1 input file (Sep 9, 2004; RSR)
;
; Flat transgressing joint in a heated infinite rock mass.
Joint
; properties selected to prevent slippage.  Heat source 5x5 m
centered
; at x=50, y=45. Power is 2000 W/cu.m.
;
config thermal
set mech on
;
; Geometry
;
rou 0.001
bl 0,0 0,100 100,100 100,0
crack 0 50 100 50
crack 0 47.5 100 47.5
crack 47.5 42.5 47.5 47.5
crack 52.5 42.5 52.5 47.5
crack 0 42.5 100 42.5
gen quad 2.0
;
; Material properties
;
change jcons=5 range -0.2 100.2 49.8 50.2
prop m=1 de=2210.0 k=19.0e9 g=13.0e9
prop m=1 thexp=15.0e-6 cond=20.0 spec=1000.0
prop jm=1 jkn=19.0e11 jks=13.0e11
prop jm=1 jcoh=1.0e20 jfric=0.0 jten=1.0e20 jd=0
prop jm=1 jrescoh=1.0e20 jrfric=0.0 jrten=1.0e20
;
; Initial conditions
;
initem 34.0 0 100 0 100
;
; Boundary conditions
;
bound yvel 0.0 range (0,100) (-0.1, 0.1)
bound yvel 0.0 range (0,100) (99.1, 100.1)
bound xvel 0.0 range (-0.1, 0.1) (0,100)
bound xvel 0.0 range (99.1, 100.1) (0,100)
;
; Apply heat source
;
thapp source 50000 0 range 47.5 52.5 42.5 47.5
;
; Thermal histories
;
thist temp 50,45 ;1
thist temp 50,47 ;2
thist temp 50,50 ;3
thist temp 50,60 ;4
thist temp 50,75 ;5
thist temp 50,100 ;6
;
; Mechanical histories
;
hist ydisp 50,45  ;1
hist ydisp 50,47  ;2
hist ydisp 50,50  ;3
hist ydisp 50,60  ;4
hist ydisp 50,75  ;5
hist ydisp 50,100 ;6
;
hist xdisp 50,45  ;7
hist xdisp 50,47  ;8
hist xdisp 50,50  ;9
hist xdisp 50,60  ;10
hist xdisp 50,75  ;11
hist xdisp 50,100 ;12
;
hist unbalanced   ;13
hist ndis 50 50   ;14
hist sdis 50 50   ;15
;
; Thermal mechanical analysis
;
;
set nther 2500
set nmech 2000
run age 1000000 temp 50
;
cal dispmag.fis
disp_mag
save u71final.sav
;
set plot emf color
title
Case 7.1 Horizontal Transgressing Joint (UDEC, No Slip
Allowed)
;
; Geometry
;
set out u71grid.emf
set color iw
plo zone green blo iw
copy
; Joint condition plots
;
set out u71jndl.emf
set color iw
plot joint 0 50 100 50 ndisp 2
copy
;
set out u71jnsl.emf
set color iw
plot joint 0 50 100 50 nstr 2
copy
;
set out u71jsdl.emf
set color iw
plot joint 0 50 100 50 sdisp 2
copy
;
set out u71jssl.emf
set color iw
plot joint 0 50 100 50 sstr 2
copy
;
set out u71shear.emf
set color iw
plo blo iw shear red
copy
;
set out u71slip.emf
set color iw
plo blo iw slip red
copy
;
; Contour plots
;
set out u71temp.emf
set color iw
plot temp fill temp blo iw
copy
;
set out u71disp.emf
set color iw
plot gp_extra fill alias 'Displacement' gp_extra disp iw blo
iw
copy
;
set out u71xd.emf
set color iw
plot xd fill xd blo iw
copy
;
set out u71yd.emf
set color iw
plot yd fill yd blo iw
copy
;
set out u71sig1.emf
set color iw
plot sig1 fill sig1 blo iw
copy
;
set out u71sig2.emf
set color iw
plot sig2 fill sig2 blo iw
copy
;
set out u71sdif.emf
set color iw
plot sdiff fill sdiff blo iw
copy
;
set out u71thist.emf
set color iw
plo thist 1 2 3 4 5 6
copy
;
set out u71ydhist.emf
set color iw
plo hist 1 2 3 4 5 6
copy
;
set out u71xdhist.emf
set color iw
plo hist 7 8 9 10 11 12
copy
;
set out u71unbal.emf
set color iw
plo hist 13
copy
;
set out u71jns.emf
set color iw
plo hist 14 15
copy
;
ret
```

File U71INPUT.TXT

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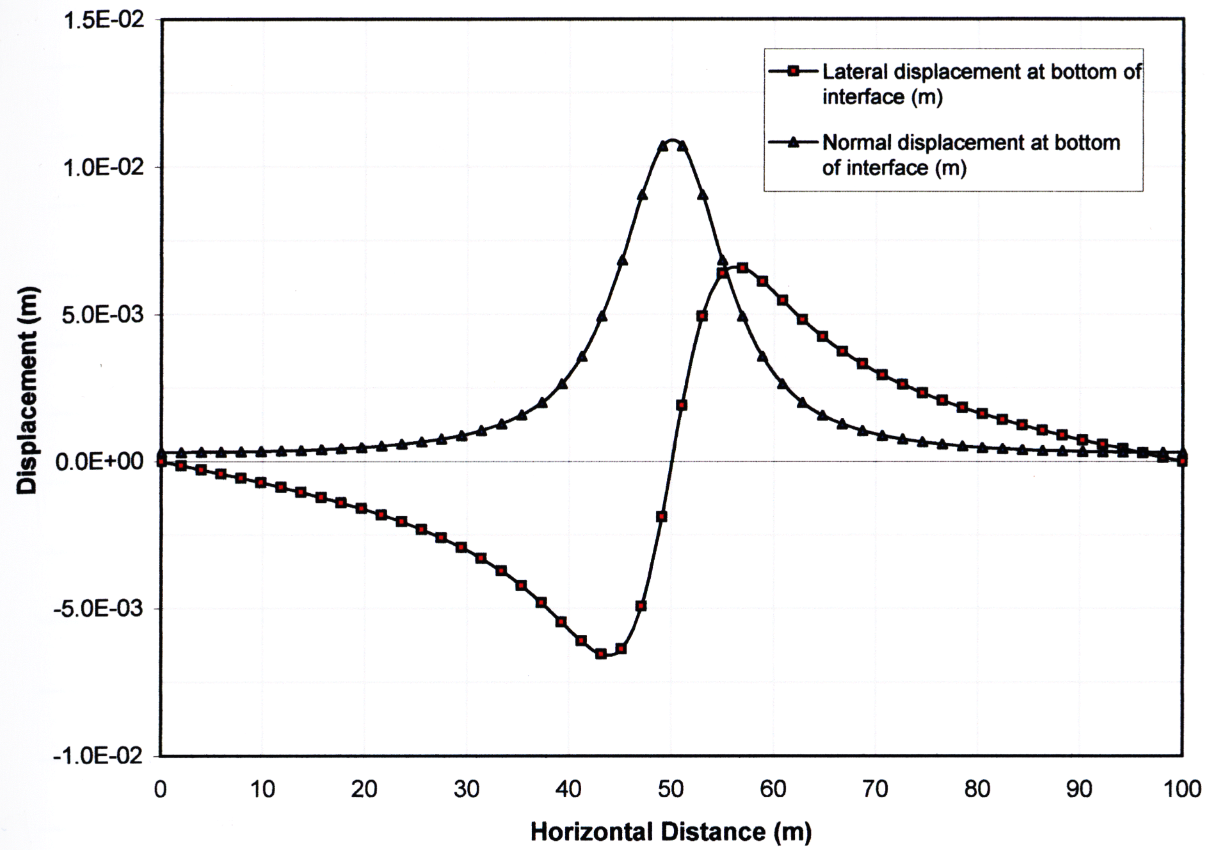
Case 7.1 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source



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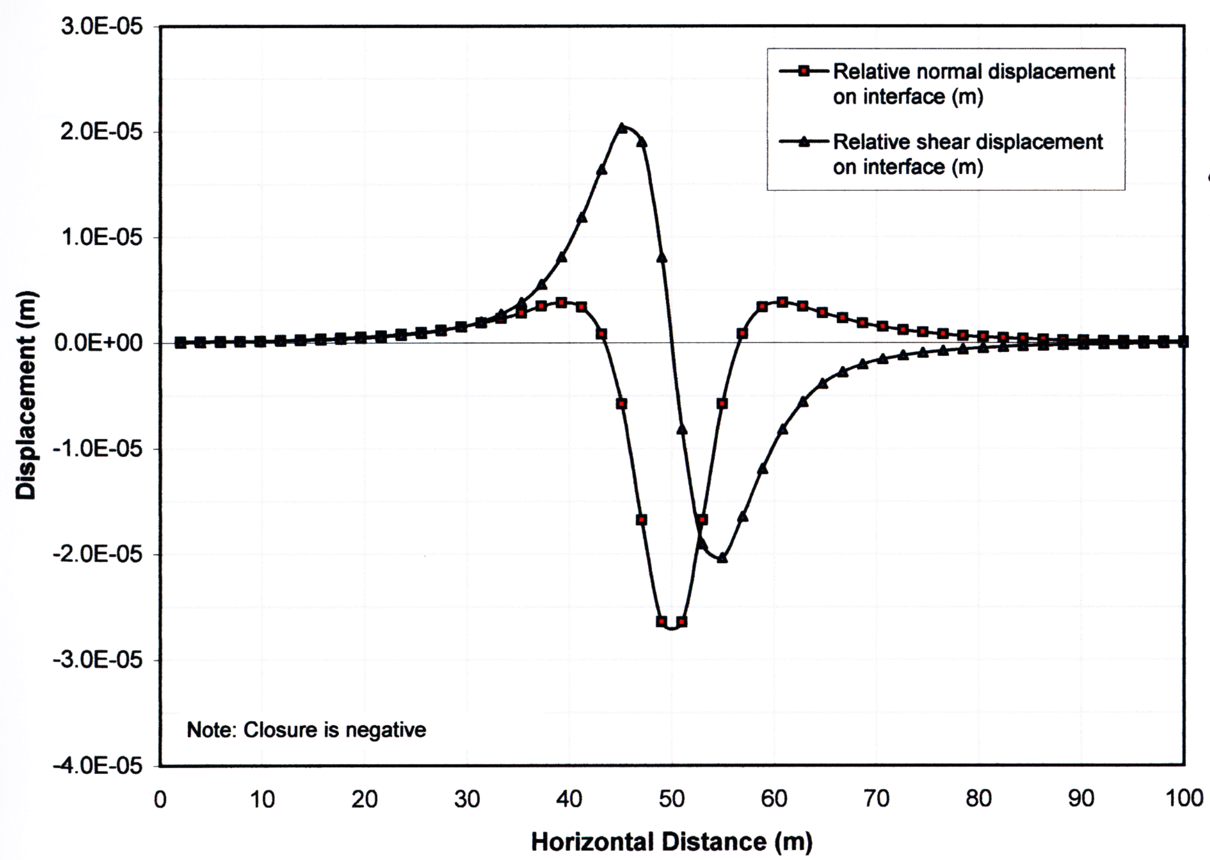
Case 7.1 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source



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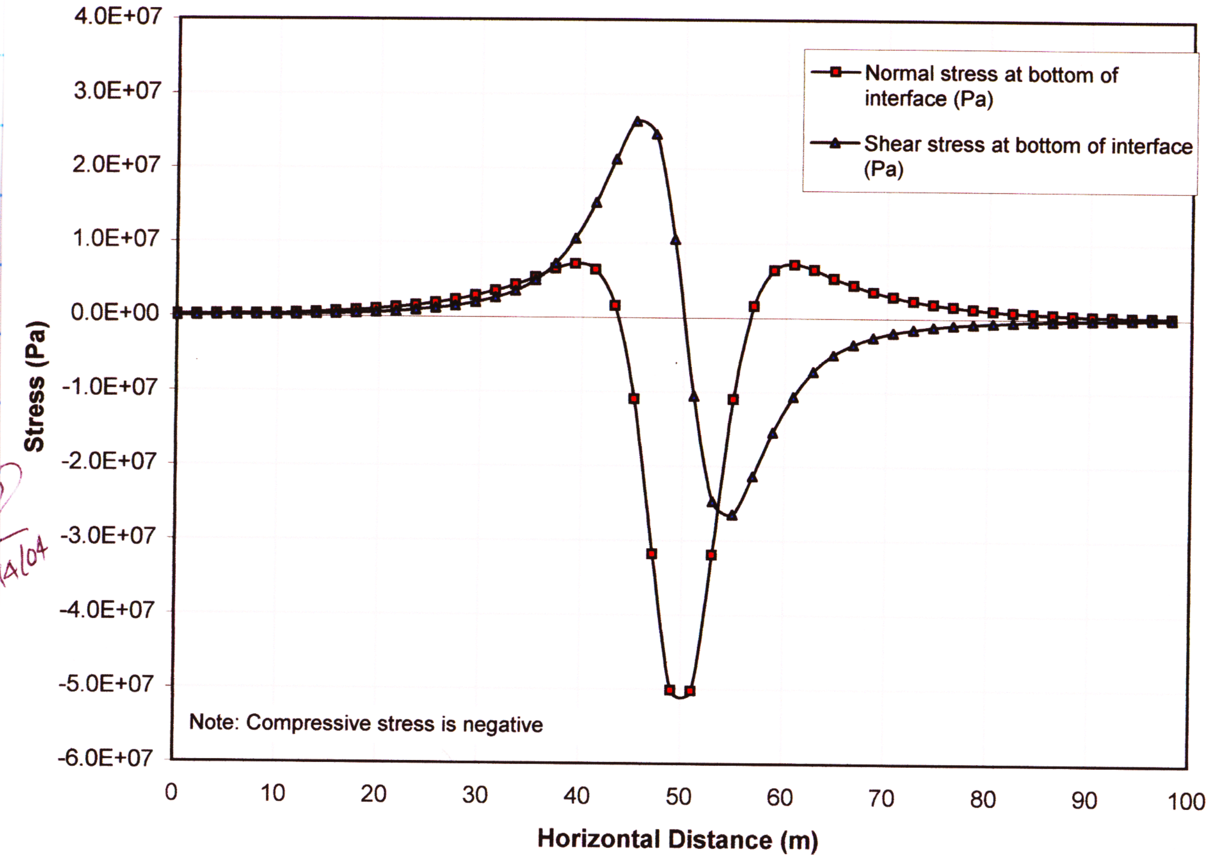
Case 7.1 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source



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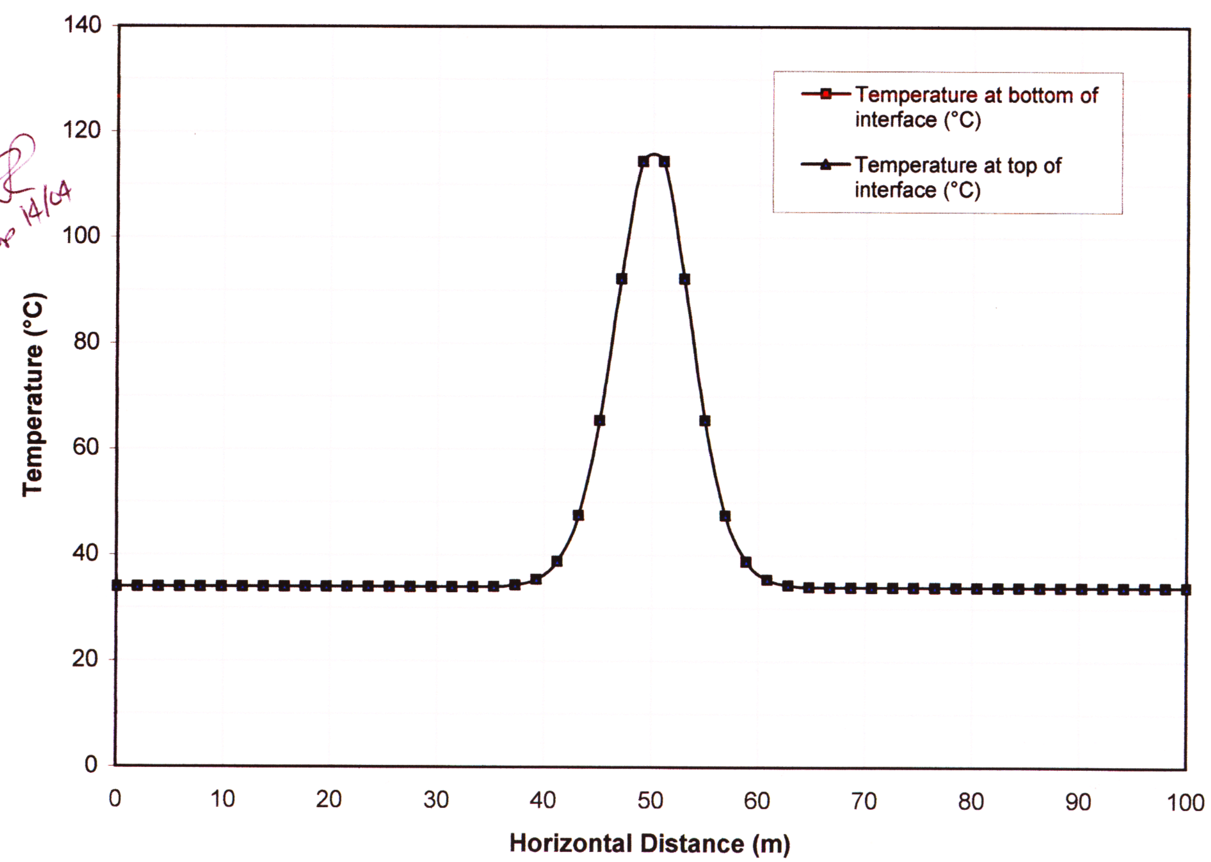
Case 7.1 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source



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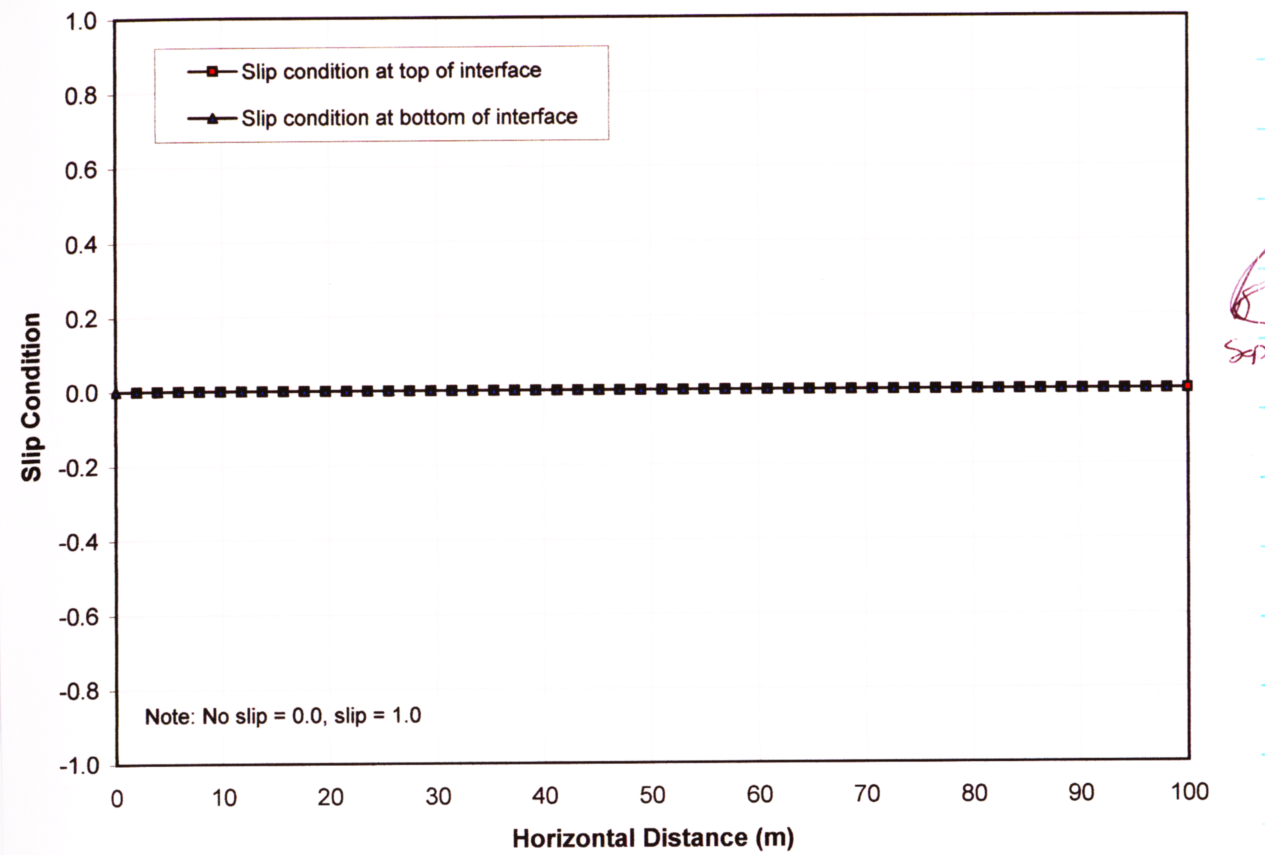
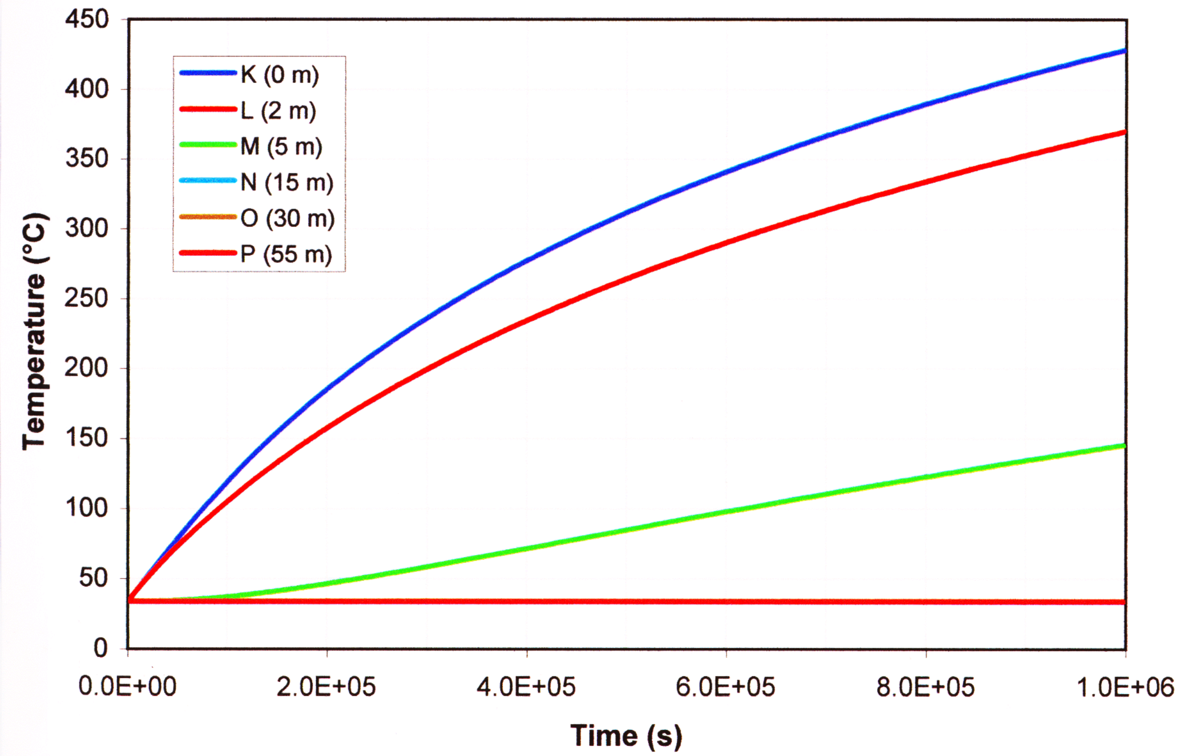
Case 7.1 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source



Sep 14/04.

Case 7.1 - UDEC Results for a Horizontal Bonded Interface Subjected to a Volumetric Heat Source



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From Excel Workbook U71 Temp.xls

File u71thist.txt

```
; THIST.TXT
;
; Creates UDEC output files of temperature histories
;
thist write 1 u71t1.out
thist write 2 u71t2.out
thist write 3 u71t3.out
thist write 4 u71t4.out
thist write 5 u71t5.out
thist write 6 u71t6.out
;
ret
```

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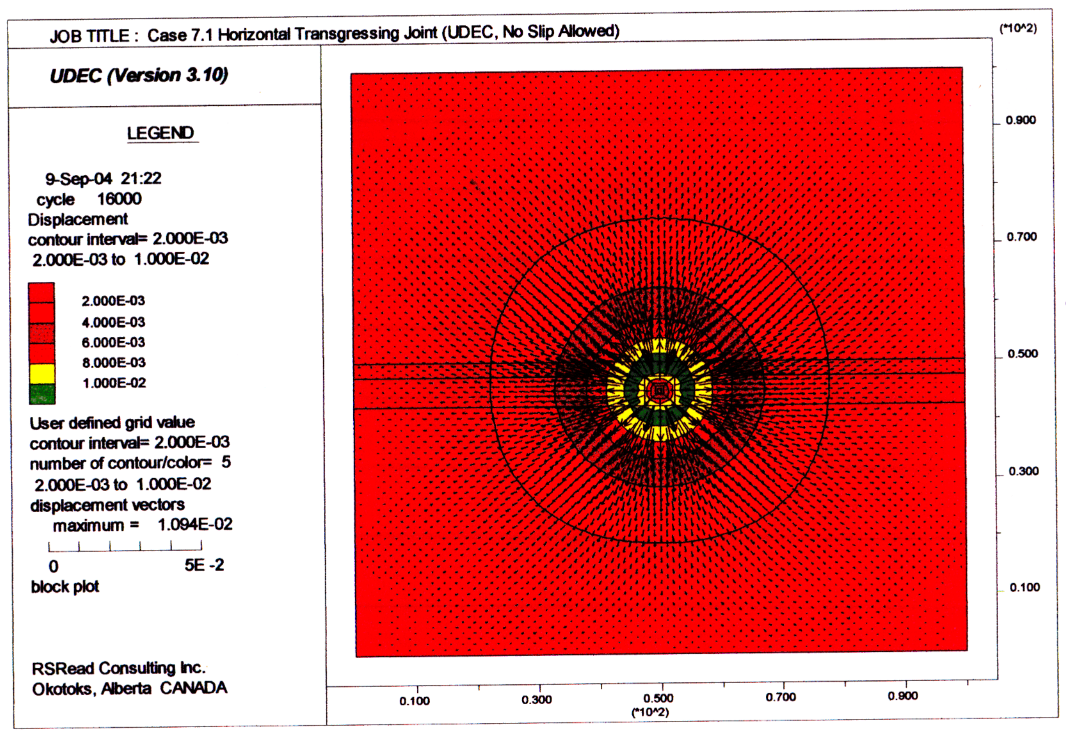
UDEC code used to produce temperature history output files. These files were imported into EXCEL file U71TEMP.XLS to create the plot on the bottom of page 5.



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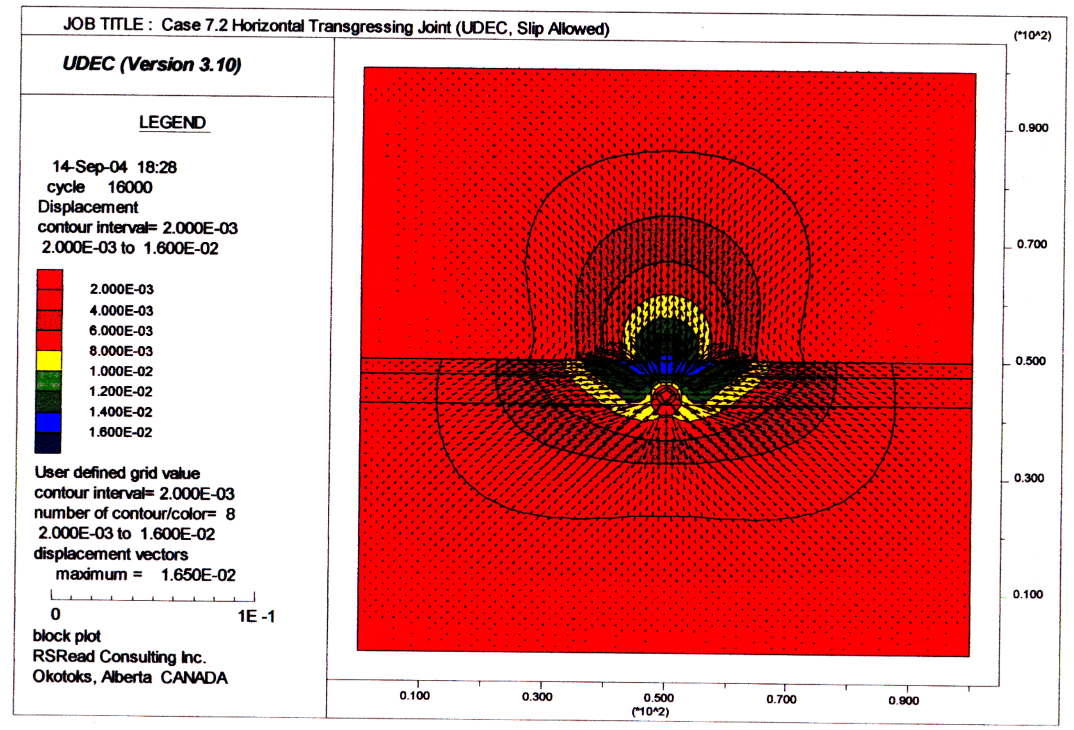
File u71disp.emf Total displacement contours and vectors.

Other plots contained in U71plots.doc, under Case 7/UDEC/

Case 7.2 Horizontal Transgressing Joint (Slip Allowed).

Case 7.2 was re-run using UDEC input file U72INPUT.TXT and importing exported UDEC data into EXCEL workbook U72.XLS. The code for U72INPUT.TXT is shown on pages 8 & 9. Note that the calculation of variable SLIPC produced all zeroes, indicating no slip. This contradicts the plot of slip showing all contacts at their shear limit. The plot of total displacement below illustrates the differences between Case 7.1 and 7.2. Plots generated in EXCEL for this case follow on pages 10-12.



Sept 14/04.

File U72disp.emf Total displacement contours and vectors

Other plots contained in U72plots.doc under Case 7/UDEC/

```
; Case 7.2 - UDEC 3.1 input file (Sep 14, 2004; RSR)
;
; Flat transgressing joint in a heated infinite rock mass.
Joint
; properties selected to allow slippage.  Heat source 5x5 m
centered
; at x=50, y=45. Power is 2000 W/cu.m.
;
config thermal
set mech on
;
; Geometry
;
rou 0.001
bl 0,0 0,100 100,100 100,0
crack 0 50 100 50
crack 0 47.5 100 47.5
crack 47.5 42.5 47.5 47.5
crack 52.5 42.5 52.5 47.5
crack 0 42.5 100 42.5
gen quad 2.0
;
; Material properties
;
change jcons=5 range -0.2 100.2 49.8 50.2
prop m=1 de=2210.0 k=19.0e9 g=13.0e9
prop m=1 thexp=15.0e-6 cond=20.0 spec=1000.0
prop jm=1 jkn=19.0e11 jks=13.0e11
prop jm=1 jcoh=1.0e20 jfric=0.0 jten=1.0e20 jd=0
prop jm=1 jrescoh=1.0e20 jrfric=0.0 jrten=1.0e20
prop jm=2 jkn=19.0e10 jks=13.0e10
prop jm=2 jcoh=100.0e3 jfric=20.0 jten=1.0e6 jd=0
prop jm=2 jrescoh=100.0e3 jrfric=20.0 jrten=1.0e6
change jmat 2 range 0.0 100.0 49.9 50.1
;
; Initial conditions
;
initem 34.0 0 100 0 100
;
; Boundary conditions
;
bound yvel 0.0 range (0,100) (-0.1, 0.1)
bound yvel 0.0 range (0,100) (99.1, 100.1)
bound xvel 0.0 range (-0.1, 0.1) (0,100)
bound xvel 0.0 range (99.1, 100.1) (0,100)
;
; Apply heat source
;
thapp source 50000 0 range 47.5 52.5 42.5 47.5
;
; Thermal histories
;
thist temp 50,45 ;1
thist temp 50,47 ;2
thist temp 50,50 ;3
thist temp 50,60 ;4
thist temp 50,75 ;5
thist temp 50,100 ;6
;
; Mechanical histories
;
hist ydisp 50,45  ;1
hist ydisp 50,47  ;2
hist ydisp 50,50  ;3
hist ydisp 50,60  ;4
hist ydisp 50,75  ;5
hist ydisp 50,100 ;6
;
hist xdisp 50,45  ;7
hist xdisp 50,47  ;8
hist xdisp 50,50  ;9
hist xdisp 50,60  ;10
hist xdisp 50,75  ;11
hist xdisp 50,100 ;12
;
hist unbalanced   ;13
hist ndis 50 50   ;14
hist sdis 50 50   ;15
;
; Thermal mechanical analysis
;
;
set nther 2500
set nmech 2000
run age 1000000 temp 50
;
cal dispmag.fis
disp_mag
save u72final.sav
;
set plot emf color
title
Case 7.2 Horizontal Transgressing Joint (UDEC, Slip Allowed)
;
; Geometry
;
set out u72grid.emf
set color iw
plo zone green blo iw
copy

; Joint condition plots
;
set out u72jndl.emf
set color iw
plot joint 0 50 100 50 ndisp 2
copy
;
set out u72jnsl.emf
set color iw
plot joint 0 50 100 50 nstr 2
copy
;
set out u72jsdl.emf
set color iw
plot joint 0 50 100 50 sdisp 2
copy
;
set out u72jssl.emf
set color iw
plot joint 0 50 100 50 sstr 2
copy
;
set out u72shear.emf
set color iw
plo blo iw shear red
copy
;
set out u72slip.emf
set color iw
plo blo iw slip red
copy
;
; Contour plots
;
set out u72temp.emf
set color iw
plot temp fill temp iw blo iw
copy
;
set out u72disp.emf
set color iw
plot gp_extra fill alias 'Displacement' gp_extra iw disp iw
blo iw
copy
;
set out u72xd.emf
set color iw
plot xd fill xd iw blo iw
copy
;
set out u72yd.emf
set color iw
plot yd fill yd iw blo iw
copy
;
set out u72sig1.emf
set color iw
plot sig1 fill sig1 iw blo iw
copy
;
set out u72sig2.emf
set color iw
plot sig2 fill sig2 iw blo iw
copy
;
set out u72sdif.emf
set color iw
plot sdiff fill sdiff iw blo iw
copy
;
set out u72thist.emf
set color iw
plo thist 1 2 3 4 5 6
copy
;
set out u72ydhist.emf
set color iw
plo hist 1 2 3 4 5 6
copy
;
set out u72xdhist.emf
set color iw
plo hist 7 8 9 10 11 12
copy
;
set out u72unbal.emf
set color iw
plo hist 13
copy
```

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UDEC input file u72INPUT.TXT pg 1 of 2


```
;
set out u72jns.emf
set color iw
plo hist 14 15
copy
;
; Create output tables
;
def xxx
  nn=2000
end
xxx
def table_fill
  array u72c(13,nn)
  array u72b(9,nn)
  ic=contact_head
  ib=block_head
  ii=1
  thvalr=thvald*pi/180.0
  mval=tan(thvalr)
  bval=50.0-50.0*mval
;
; Contact information
;
  loop while ic # 0
    xval=c_x(ic)
    yval=c_y(ic)
    ycal=mval*xval+bval
    lval=sqrt(xval^2+(yval-bval)^2)
    blk1=c_b1(ic)
    blk2=c_b2(ic)
    clval=c_length(ic)
    dclos=c_ndis(ic)
    dride=c_sdis(ic)
    nfval=c_nforce(ic)
    sfval=c_sforce(ic)
    nsval=-nfval/clval
    ssval=-sfval/clval
    tyval=c_type(ic)
    slipc=fmem(c_jex(ic)+$rs_frac)
;
; Create table entries
;
    if abs(yval-ycal)<0.1 then
     table(1,ii)=yval
     table(2,ii)=xval
     table(3,ii)=lval
     table(4,ii)=blk1
     table(5,ii)=blk2
     table(6,ii)=nfval
     table(7,ii)=sfval
     table(8,ii)=dclos
     table(9,ii)=dride
     table(10,ii)=nsval
     table(11,ii)=ssval
     table(12,ii)=tyval
     table(13,ii)=slipc
;
; Array entries
;
     u72c(1,ii)=string(yval)
     u72c(2,ii)=string(xval)
     u72c(3,ii)=string(lval)
     u72c(4,ii)=string(blk1)
     u72c(5,ii)=string(blk2)
     u72c(6,ii)=string(nfval)
     u72c(7,ii)=string(sfval)
     u72c(8,ii)=string(dclos)
     u72c(9,ii)=string(dride)
     u72c(10,ii)=string(nsval)
     u72c(11,ii)=string(ssval)
     u72c(12,ii)=string(tyval)
     u72c(13,ii)=string(slipc)
     ii=ii+1
    end_if
    ic=c_next(ic)
  end_loop
  ii=1
;
; Gridpoints on joint
;
  loop while ib # 0
    cg=b_gp(ib)
    loop while cg # 0
      blkc=ib
      xval=gp_x(cg)
      yval=gp_y(cg)
      ycal=mval*xval+bval
      lval=sqrt(xval^2+(yval-bval)^2)
      dxval=gp_xdis(cg)
      dyval=gp_ydis(cg)
      dsval=dxval*cos(thvalr)-dyval*sin(thvalr)
      dnval=dxval*sin(thvalr)+dyval*cos(thvalr)
      gtemp=fmem(cg+$kgtemp)
;
; Create table entries
;
      if abs(yval-ycal)<0.1 then
        table(13,ii)=yval
        table(14,ii)=xval
        table(15,ii)=lval
        table(16,ii)=blkc
        table(17,ii)=dxval
        table(18,ii)=dyval
        table(19,ii)=dsval
        table(20,ii)=dnval
;
; Array entries
;
        u72b(1,ii)=string(yval)
        u72b(2,ii)=string(xval)
        u72b(3,ii)=string(lval)
        u72b(4,ii)=string(blkc)
        u72b(5,ii)=string(dxval)
        u72b(6,ii)=string(dyval)
        u72b(7,ii)=string(dsval)
        u72b(8,ii)=string(dnval)
        u72b(9,ii)=string(gtemp)
        ii=ii+1
      end_if
      cg=gp_next(cg)
    end_loop
    ib=b_next(ib)
  end_loop
  status=open('u72cdata.out',1,1)
  status=write(u72c,2000)
  status=close
  status=open('u72bdata.out',1,1)
  status=write(u72b,2000)
end
;
set thvald=0.0
cal contact.fin
cal jmat.fin
table_fill
;
; Write thermal histories to files
;
thist write 1 u72t1.out
thist write 2 u72t2.out
thist write 3 u72t3.out
thist write 4 u72t4.out
thist write 5 u72t5.out
thist write 6 u72t6.out
;
ret
```

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U72INPUT.TXT Page 2 of 2

UDEC Code used for Case 7.2.

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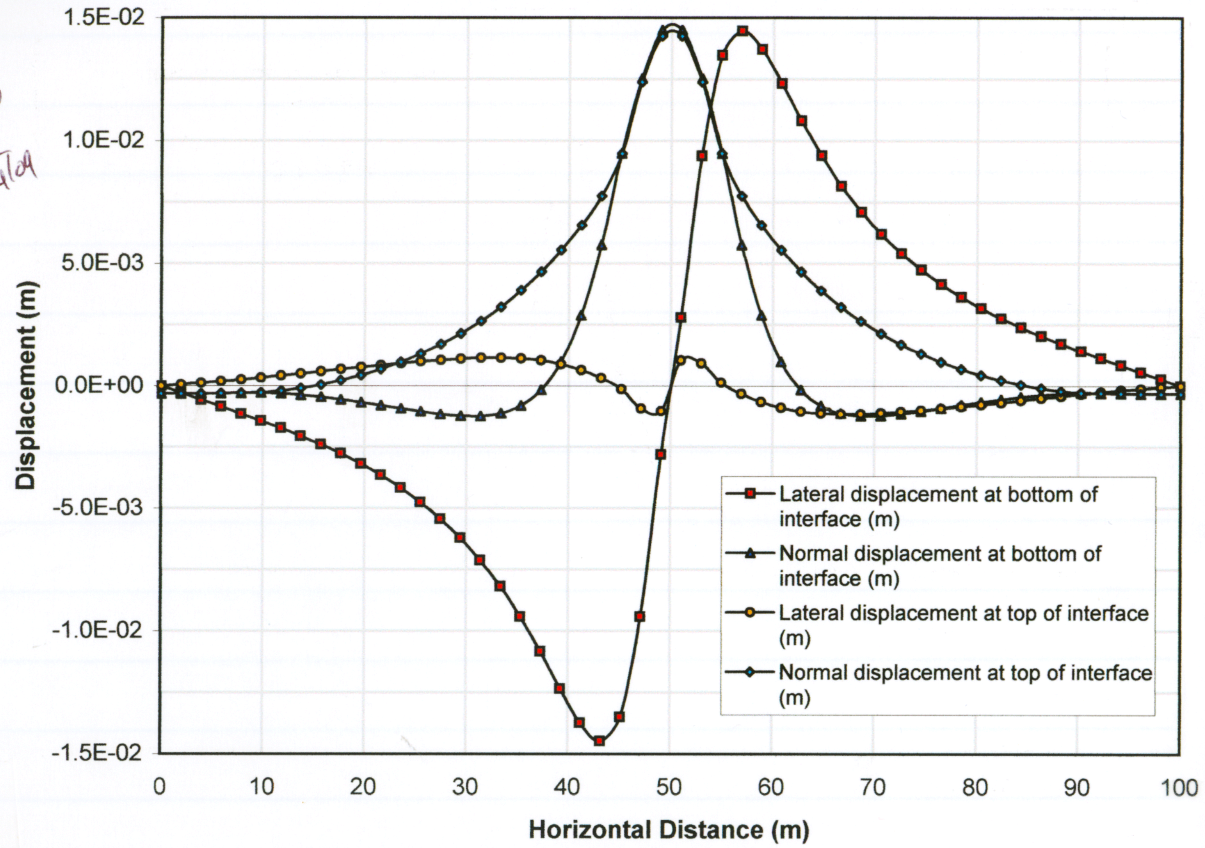
Case 7.2 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



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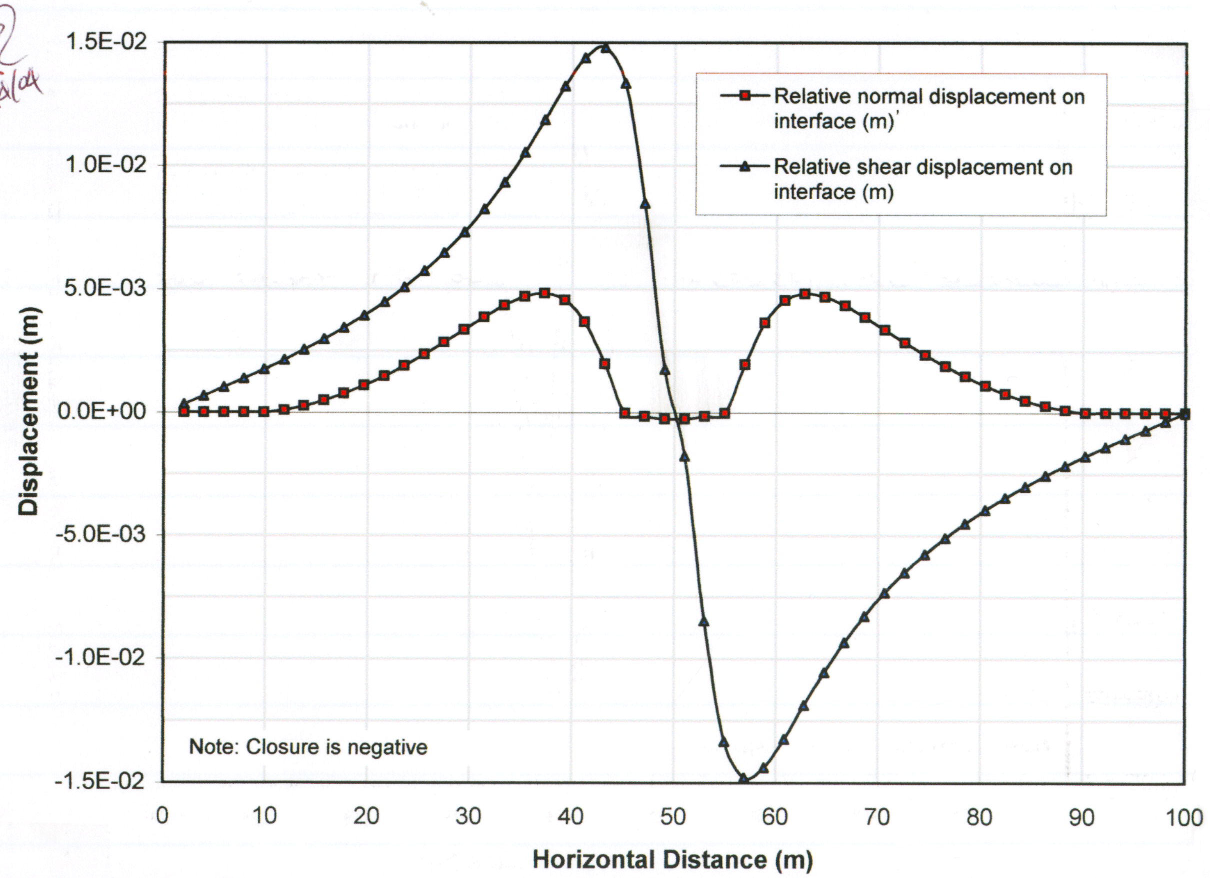
Case 7.2 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



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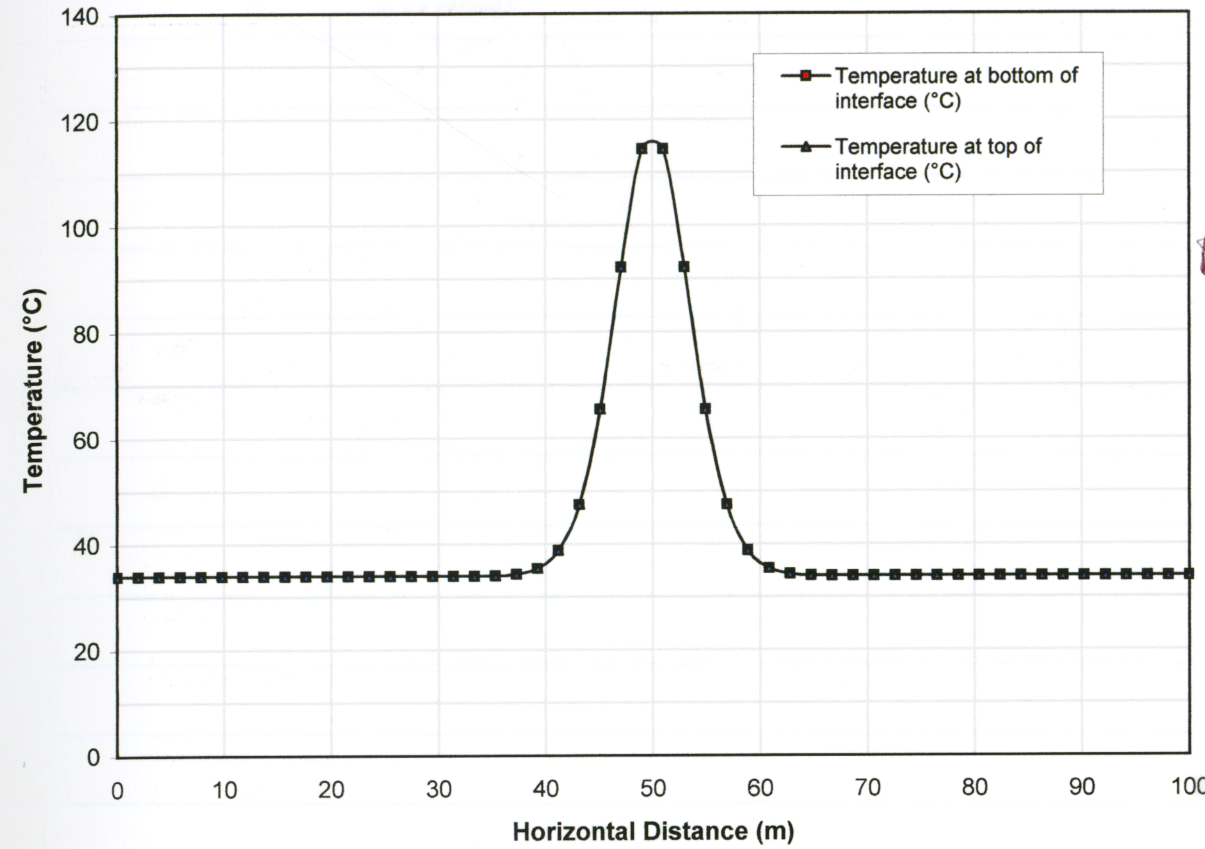
Case 7.2 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



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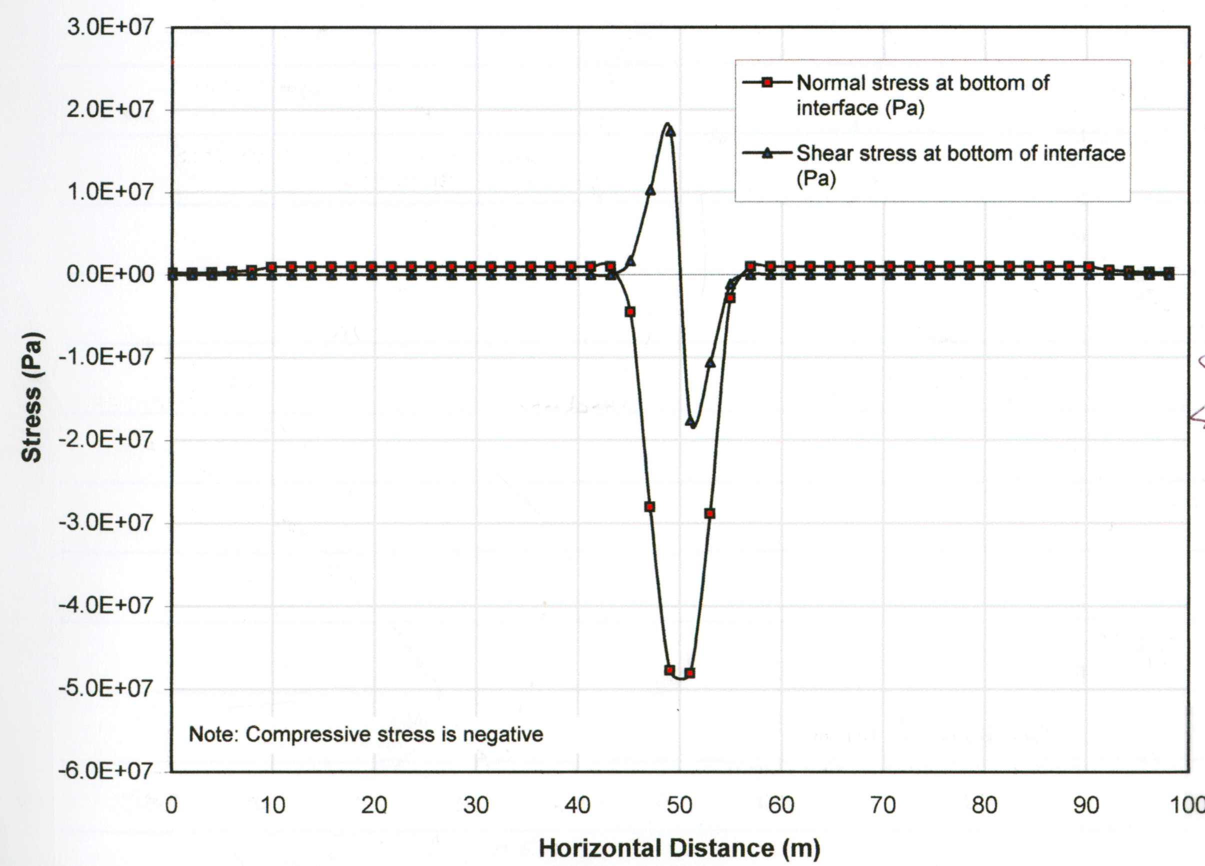
Case 7.2 - UDEC Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



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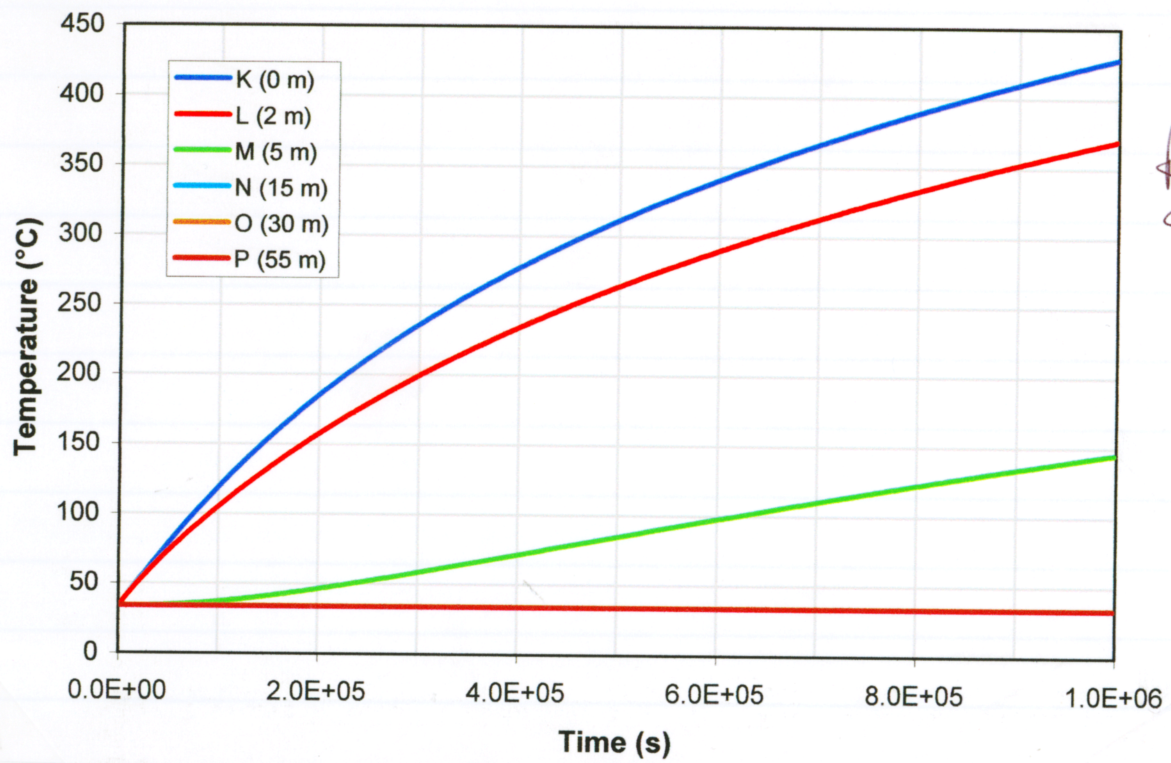
Case 7.2 - UDEC Results for a Horizontal Bonded Interface Subjected to a Volumetric Heat Source (Slip Allowed)



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From EXCEL workbook U72TEMP.XLS

Summary of Cases 7.1 and 7.2 using UDEC vs FLAC

The major points of comparison between the FLAC and UDEC runs for cases 7.1 and 7.2 include the following:

Lateral displacement - max and min values and corresponding X values on top and bottom of interface.

Normal displacement - as above

Relative Shear displacement - max, min and related X-values

Relative Normal displacement - max, min and related X-values

Normal Stress - as for normal displacement

Shear stress - as above

Temperature - as above. + max temperature at source center.

Case 7.1 Summary of Results (FLAC)

Parameter	Maximum		Minimum		Mean
	X	Value	X	Value	Value
Lateral displacement at bottom of interface (m)	56.00	7.40E-03	44.00	-7.40E-03	5.84E-08
Lateral displacement at top of interface (m)	56.00	7.39E-03	44.00	-7.38E-03	6.02E-08
Normal displacement at bottom of interface (m)	50.00	1.12E-02	0.00	3.92E-04	2.15E-03
Normal displacement at top of interface (m)	50.00	1.12E-02	0.00	3.92E-04	2.15E-03
Relative normal displacement on interface (m)	60.00	3.89E-06	50.00	-2.83E-05	-9.00E-07
Relative shear displacement on interface (m)	46.00	2.32E-05	54.00	-2.32E-05	1.13E-10
Total displacement at bottom of interface (m)	50.00	1.12E-02	0.00	3.92E-04	3.88E-03
Total displacement at top of interface (m)	50.00	1.12E-02	0.00	3.92E-04	3.87E-03
Normal stress at bottom of interface (Pa)	60.00	7.40E+06	50.00	-5.36E+07	-1.72E+06
Normal stress at top of interface (Pa)	60.00	7.40E+06	50.00	-5.36E+07	-1.72E+06
Shear stress at bottom of interface (Pa)	46.00	3.01E+07	54.00	-3.01E+07	2.93E+02
Shear stress at top of interface (Pa)	46.00	3.01E+07	54.00	-3.01E+07	2.93E+02
Temperature at bottom of interface (°C)	50.00	119.30	0.00	34.00	40.90
Temperature at top of interface (°C)	50.00	124.44	0.00	34.00	41.45
Maximum temperature at source (°C)	50.00	425.24	-	-	-
Number of Contacts	51				
Number of Contacts at Slip Condition	0				

Case 7.1 Summary of Results (UDEC, Interpolated)

Parameter	Maximum		Minimum		Mean
	X	Value	X	Value	Value
Lateral displacement at bottom of interface (m)	56.00	6.49E-03	44.00	-6.47E-03	6.33E-06
Lateral displacement at top of interface (m)	56.00	6.47E-03	44.00	-6.45E-03	6.33E-06
Normal displacement at bottom of interface (m)	50.00	1.07E-02	100.00	3.03E-04	1.91E-03
Normal displacement at top of interface (m)	50.00	1.07E-02	100.00	3.03E-04	1.91E-03
Relative normal displacement on interface (m)	40.00	3.62E-06	50.00	-2.64E-05	-7.56E-07
Relative shear displacement on interface (m)	46.00	1.97E-05	54.00	-1.97E-05	3.85E-11
Total displacement at bottom of interface (m)	50.00	1.09E-02	100.00	3.03E-04	3.42E-03
Total displacement at top of interface (m)	50.00	1.08E-02	100.00	3.03E-04	3.42E-03
Normal stress at bottom of interface (Pa)	60.00	6.89E+06	50.00	-5.02E+07	-1.43E+06
Normal stress at top of interface (Pa)	40.00	6.89E+06	50.00	-5.02E+07	-1.43E+06
Shear stress at bottom of interface (Pa)	46.00	2.56E+07	54.00	-2.56E+07	-1.71E+03
Shear stress at top of interface (Pa)	46.00	2.56E+07	54.00	-2.56E+07	6.41E+02
Temperature at bottom of interface (°C)	50.00	114.50	0.00	34.00	40.97
Temperature at top of interface (°C)	50.00	114.50	0.00	34.00	40.97
Maximum temperature at source (°C)	50.00	428.20	-	-	-
Number of Contacts	51				
Number of Contacts at Slip Condition	0				

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Case 7.1 Relative Error between UDEC and FLAC Results*

Parameter	Maximum		Minimum		Mean
	X	Error	X	Value	Value
Lateral displacement at bottom of interface (m)	56.00	13%	44.00	13%	0%
Lateral displacement at top of interface (m)	56.00	13%	44.00	13%	0%
Normal displacement at bottom of interface (m)	50.00	7%	100.00	1%	-2%
Normal displacement at top of interface (m)	50.00	6%	100.00	1%	-2%
Relative normal displacement on interface (m)	40.00	0%	50.00	0%	0%
Relative shear displacement on interface (m)	46.00	0%	54.00	0%	0%
Total displacement at bottom of interface (m)	50.00	4%	100.00	1%	-4%
Total displacement at top of interface (m)	50.00	4%	100.00	1%	-4%
Normal stress at bottom of interface (Pa)	54.00	1%	46.00	7%	1%
Normal stress at top of interface (Pa)	40.00	1%	50.00	7%	1%
Shear stress at bottom of interface (Pa)	58.00	15%	50.00	15%	0%
Shear stress at top of interface (Pa)	46.00	15%	54.00	15%	0%
Temperature at bottom of interface (°C)	50.00	6%	0.00	0%	0%
Temperature at top of interface (°C)	50.00	12%	0.00	0%	0%
Maximum temperature at source (°C)	50.00	1%	-	-	-
Number of Contacts	0%				
Number of Contacts at Slip Condition	0%				

* Relative error calculated as difference between UDEC and FLAC values normalized to maximum deviation from mean along interface in either total displacement, stress, or temperature

Results compiled in EXCEL file C71.XLS comparing UDEC and FLAC for Case 7.1.

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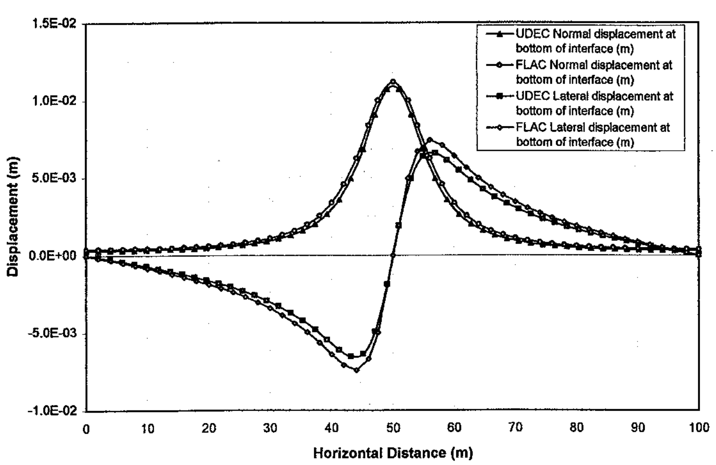
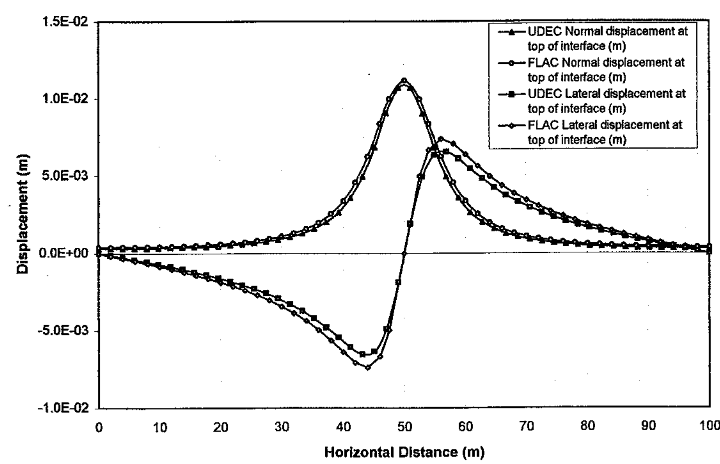
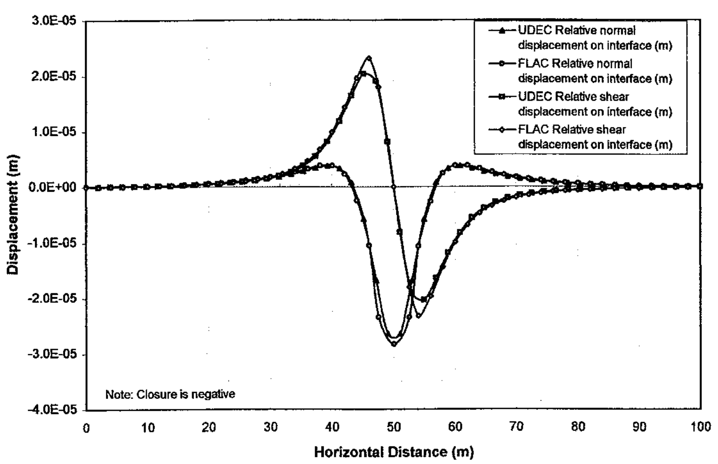
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



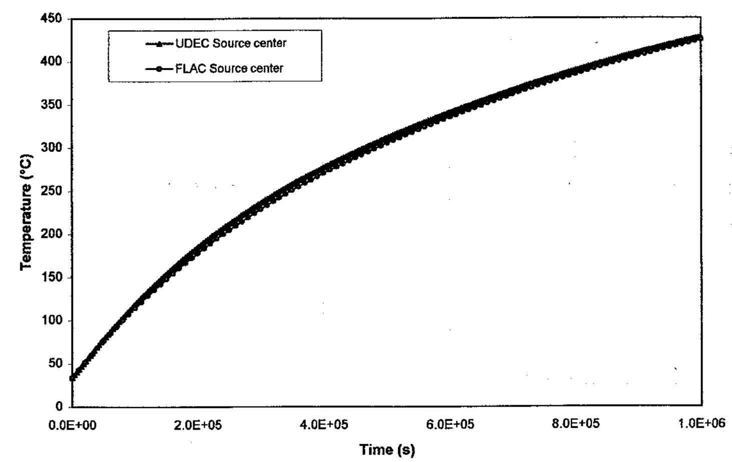
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



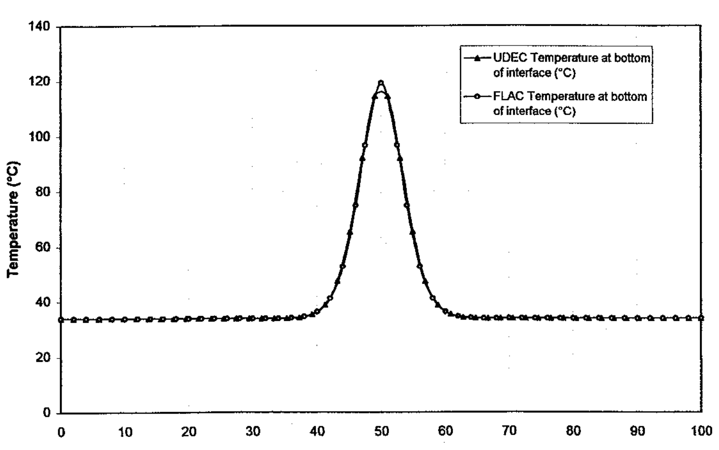
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



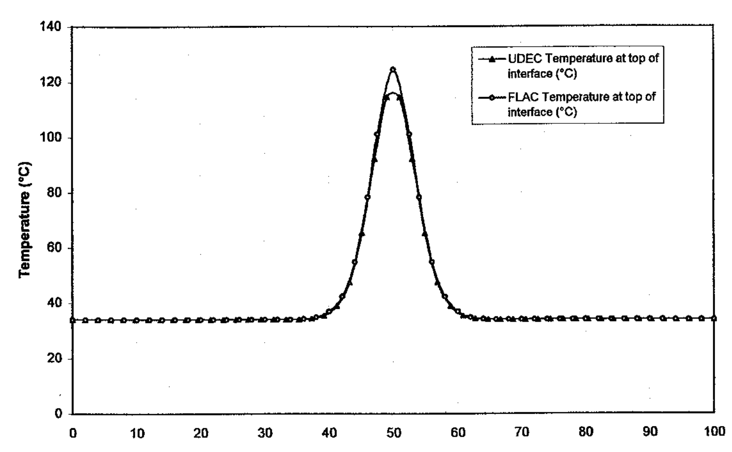
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Results from EXCEL file C71.XLS for Case 7.1
/Case 7/Comparison/C71.xls

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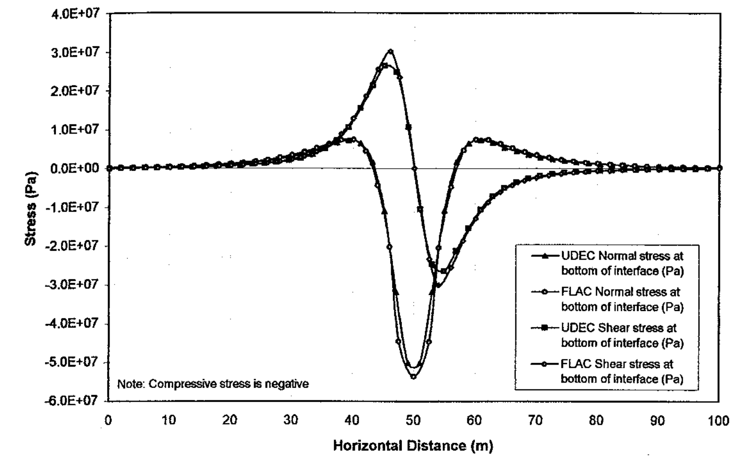
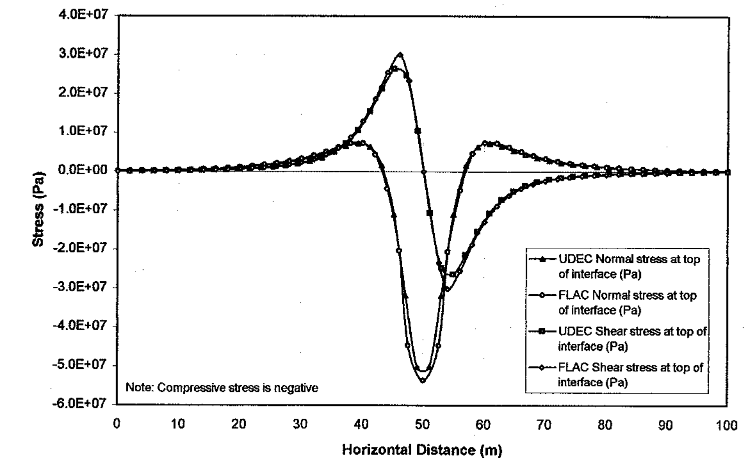
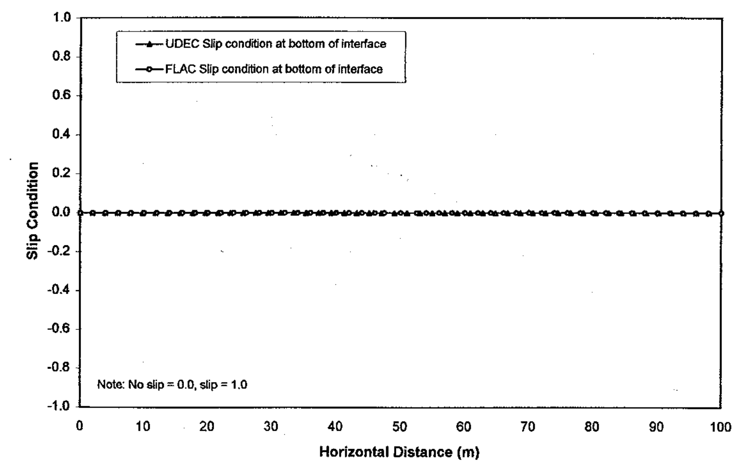
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



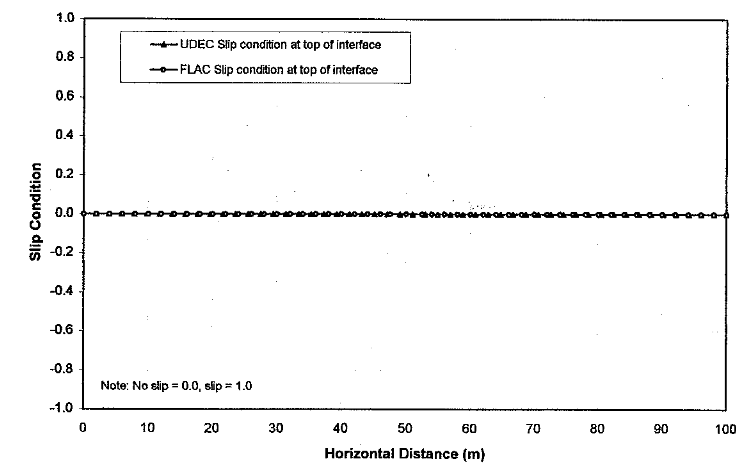
Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Case 7.1 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (No Slip Allowed)



Summary of Case 7.1

- general trends the same between UDEC & FLAC
- differences primarily at sharp changes in gradient.
- temperature responses similar in time and space.
- max temperature difference 12%
- max displacement difference 13%
- max normal stress difference 7%
- max shear stress difference 15%
- same slip condition response

Maximum difference is 15%; larger than 10% envisioned in test plan. Sept 17/04

Case 7.2 Summary of Results (FLAC)

Parameter	Maximum		Minimum		Mean
	X	Value	X	Value	Value
FLAC Lateral displacement at bottom of interface (m)	58.00	1.32E-02	42.00	-1.32E-02	-4.36E-08
FLAC Lateral displacement at top of interface (m)	54.00	7.05E-03	46.00	-7.05E-03	-4.83E-09
FLAC Normal displacement at bottom of interface (m)	50.00	1.32E-02	72.00	-2.38E-03	3.07E-04
FLAC Normal displacement at top of interface (m)	50.00	1.29E-02	100.00	7.38E-04	4.09E-03
FLAC Relative normal displacement on interface (m)	36.00	7.21E-03	50.00	-2.64E-04	3.79E-03
FLAC Relative shear displacement on interface (m)	40.00	1.10E-02	60.00	-1.10E-02	2.67E-08
FLAC Total displacement at bottom of interface (m)	44.00	1.44E-02	0.00	1.33E-03	6.51E-03
FLAC Total displacement at top of interface (m)	47.50	1.30E-02	100.00	7.38E-04	4.29E-03
Normal stress at bottom of interface (Pa)	0.00	0.00E+00	50.00	-5.01E+07	0.00E+00
Normal stress at top of interface (Pa)	0.00	0.00E+00	50.00	-5.01E+07	0.00E+00
Shear stress at bottom of interface (Pa)	46.00	6.32E+07	54.00	-6.32E+07	0.00E+00
Shear stress at top of interface (Pa)	46.00	6.32E+07	54.00	-6.32E+07	0.00E+00
FLAC Temperature at bottom of interface (°C)	50.00	119.30	0.00	34.00	40.90
FLAC Temperature at top of interface (°C)	50.00	124.44	0.00	34.00	41.45
Maximum temperature at source (°C)	50.00	425.24	-	-	-
Number of Contacts	51				
Number of Contacts at Slip Condition	46				

Case 7.2 Summary of Results (UDEC, Interpolated)

Parameter	Maximum		Minimum		Mean
	X	Value	X	Value	Value
UDEC Lateral displacement at bottom of interface (m)	58.00	1.40E-02	42.00	-1.41E-02	-3.57E-06
UDEC Lateral displacement at top of interface (m)	32.00	1.14E-03	68.00	-1.14E-03	4.63E-07
UDEC Normal displacement at bottom of interface (m)	50.00	1.45E-02	30.00	-1.23E-03	1.27E-03
UDEC Normal displacement at top of interface (m)	50.00	1.43E-02	100.00	-3.21E-04	2.90E-03
UDEC Relative normal displacement on interface (m)	36.00	4.75E-03	50.00	-2.52E-04	1.62E-03
UDEC Relative shear displacement on interface (m)	42.00	1.46E-02	58.00	-1.45E-02	4.57E-06
UDEC Total displacement at bottom of interface (m)	46.00	1.61E-02	0.00	3.22E-04	6.41E-03
UDEC Total displacement at top of interface (m)	50.00	1.43E-02	0.00	3.20E-04	3.26E-03
UDEC Normal stress at bottom of interface (Pa)	14.00	1.00E+06	50.00	-4.79E+07	-2.13E+06
UDEC Normal stress at top of interface (Pa)	14.00	1.00E+06	50.00	-4.79E+07	-2.13E+06
UDEC Shear stress at bottom of interface (Pa)	47.50	1.19E+07	52.50	-1.22E+07	8.97E+02
UDEC Shear stress at top of interface (Pa)	47.50	1.22E+07	52.50	-1.19E+07	-1.32E+03
UDEC Temperature at bottom of interface (°C)	50.00	114.50	0.00	34.00	41.12
UDEC Temperature at top of interface (°C)	50.00	114.50	0.00	34.00	41.10
Maximum temperature at source (°C)	50.00	428.20	-	-	-
Number of Contacts	51				
Number of Contacts at Slip Condition	51				

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Case 7.2 Relative Error between UDEC and FLAC Results*

Parameter	Maximum		Minimum		Mean
	X	Error	X	Value	Value
Lateral displacement at bottom of interface (m)	56.00	11%	44.00	11%	0%
Lateral displacement at top of interface (m)	56.00	75%	44.00	75%	0%
Normal displacement at bottom of interface (m)	50.00	17%	100.00	15%	7%
Normal displacement at top of interface (m)	50.00	17%	100.00	13%	-9%
Relative normal displacement on interface (m)	40.00	31%	50.00	0%	-17%
Relative shear displacement on interface (m)	46.00	45%	54.00	44%	0%
Total displacement at bottom of interface (m)	50.00	22%	100.00	13%	-1%
Total displacement at top of interface (m)	50.00	16%	100.00	5%	-8%
Normal stress at bottom of interface (Pa)	54.00	2%	46.00	4%	-4%
Normal stress at top of interface (Pa)	40.00	2%	50.00	4%	-4%
Shear stress at bottom of interface (Pa)	58.00	81%	50.00	81%	0%
Shear stress at top of interface (Pa)	46.00	81%	54.00	81%	0%
Temperature at bottom of interface (°C)	50.00	6%	0.00	0%	0%
Temperature at top of interface (°C)	50.00	12%	0.00	0%	0%
Maximum temperature at source (°C)	50.00	1%	-	-	-
Number of Contacts	0%				
Number of Contacts at Slip Condition	10%				

* Relative error calculated as difference between UDEC and FLAC values normalized to maximum deviation from mean along interface in either total displacement, stress, or temperature

Results compiled in EXCEL File C72.XLS
Comparing UDEC and FLAC for Case 7.2

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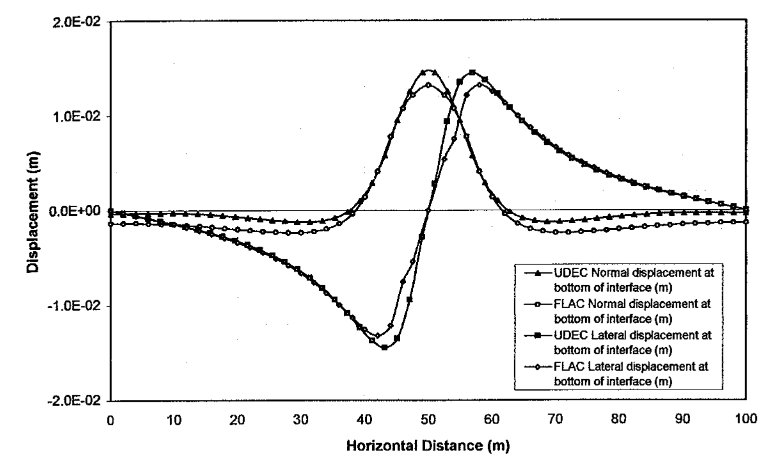
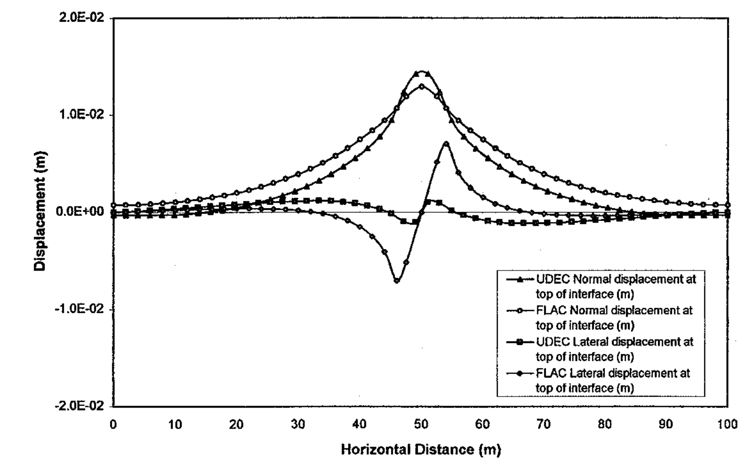
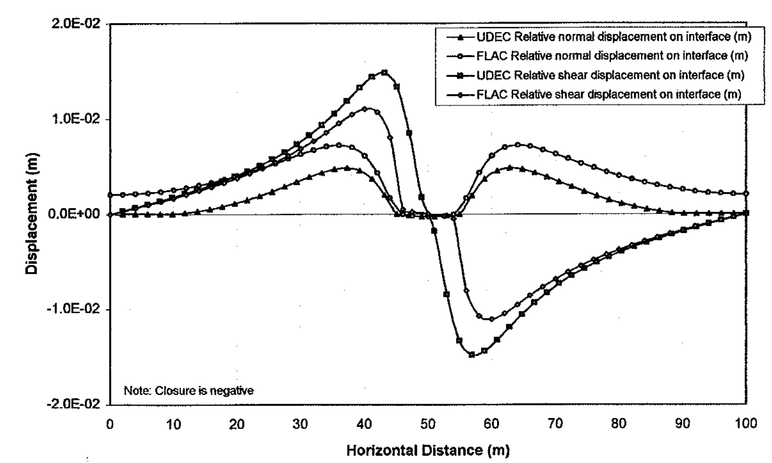
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



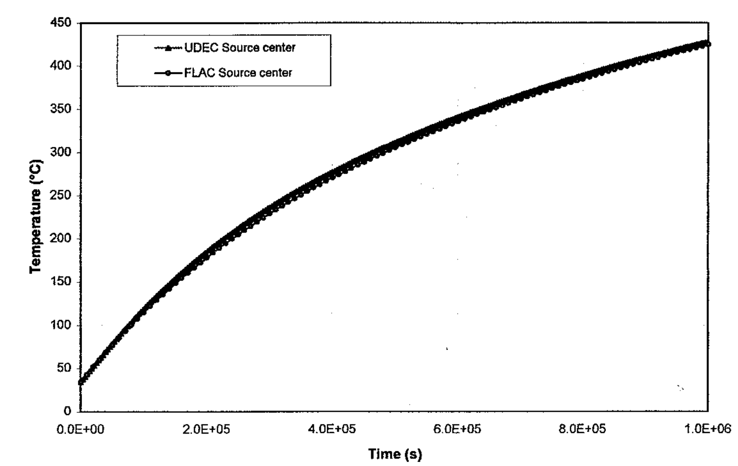
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



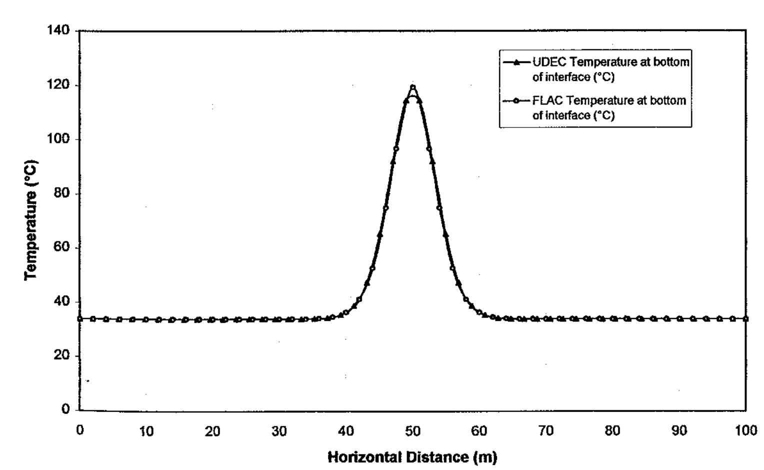
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



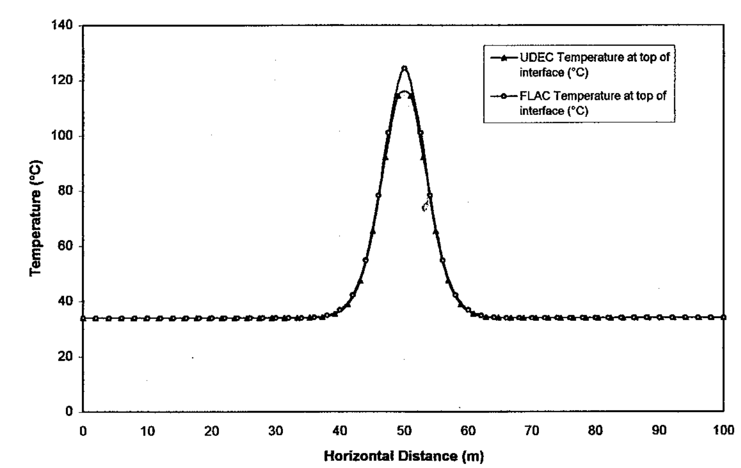
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



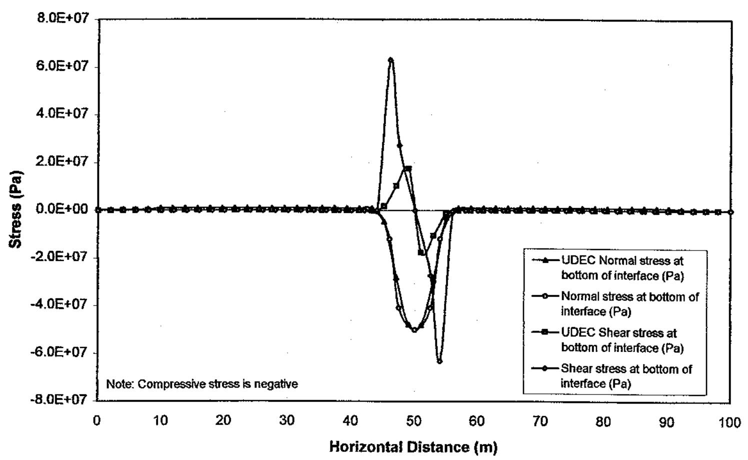
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



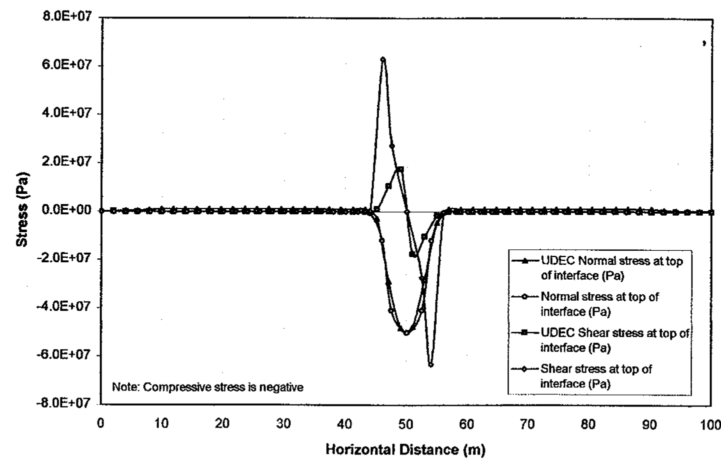
Results from EXCEL file C72.xls for case 7.2
/Case 7 / Comparison /C72.xls

[signature] Sep 18/04

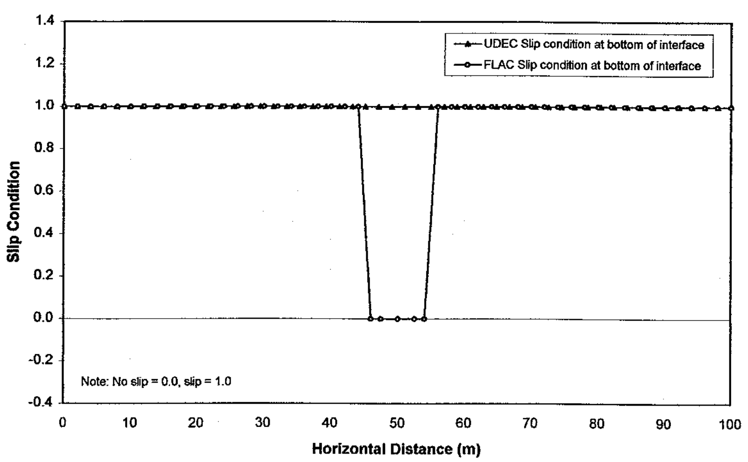
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



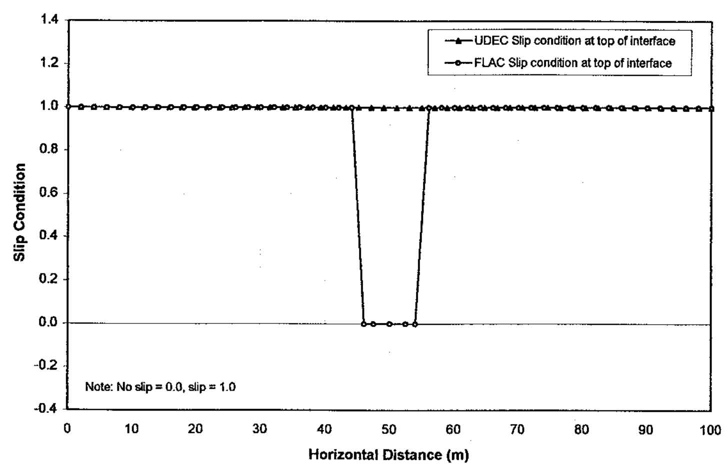
Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



Case 7.2 - Comparison of Results for a Horizontal Weak Interface Subjected to a Volumetric Heat Source (Slip Allowed)



Results from EXCEL file C72.xls for Case 7.2
/case 7 /Comparison / C72.xls.

Summary of Case 7.2

- UDEC model slips along entire interface → differences in shear stress and shear displacement up to 81%
- the fact that the entire interface slips may introduce unrealistic boundary conditions.
- temperature profiles are very similar.

[signature] Sept 18/04.

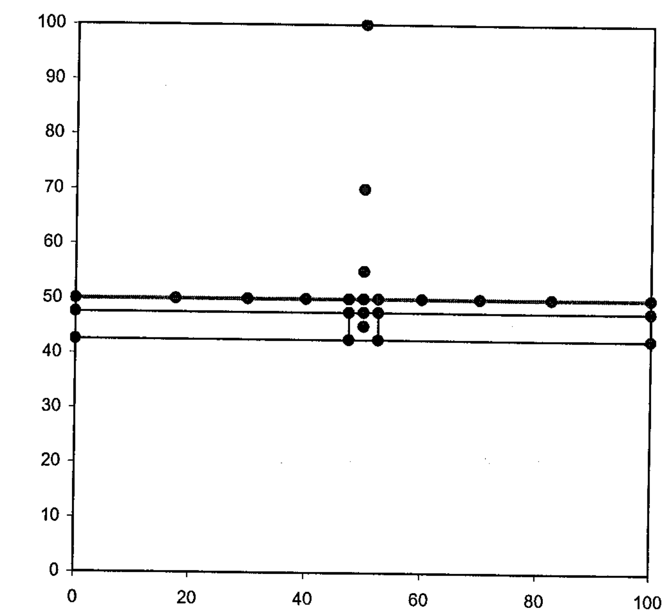
Case 7.3 (FLAC) - build grid using rotated coordinates calculated using EXCEL routine ROTATE.XLS. Rotated coordinates given below.

Case 7.3 Rotation of Coordinate System

	Original			Rotated	
Point	x	y		x*	y*
A	0.000	50.000	A	0.000	25.000
B	100.000	50.000	B	100.000	75.000
C	0.000	47.500	C	0.000	22.205
D	100.000	47.500	D	100.000	72.205
E	0.000	42.500	E	0.000	16.615
F	100.000	42.500	F	100.000	66.615
G	47.500	47.500	G	48.882	46.646
H	47.500	42.500	H	51.118	42.174
I	52.500	47.500	I	53.354	48.882
J	52.500	42.500	J	55.590	44.410
K	50.000	45.000	K	52.236	45.528
L	50.000	47.500	L	51.118	47.764
M	50.000	50.000	M	50.000	50.000
N	50.000	55.000	N	47.764	54.472
O	50.000	70.000	O	41.056	67.889
P	50.000	100.000	P	25.000	100.000
Q	0.000	50.000	Q	0.000	25.000
R	17.500	50.000	R	20.931	35.466
S	30.000	50.000	S	32.111	41.056
T	40.000	50.000	T	41.056	45.528
U	47.500	50.000	U	47.764	48.882
V	50.000	50.000	V	50.000	50.000
W	52.500	50.000	W	52.236	51.118
X	60.000	50.000	X	58.944	54.472
Y	70.000	50.000	Y	67.889	58.944
Z	82.500	50.000	Z	79.069	64.534
AA	100.000	50.000	AA	100.000	75.000

Line	x	y		x*	y*
A-B	0.000	50.000		0.000	25.000
	100.000	50.000		100.000	75.000
C-D	0.000	47.500		0.000	22.205
	100.000	47.500		100.000	72.205
E-F	0.000	42.500		0.000	16.615
	100.000	42.500		100.000	66.615
G-H	47.500	47.500		48.882	46.646
	47.500	42.500		51.118	42.174
I-J	52.500	47.500		53.354	48.882
	52.500	42.500		55.590	44.410

Rotation angle (°) 26.6



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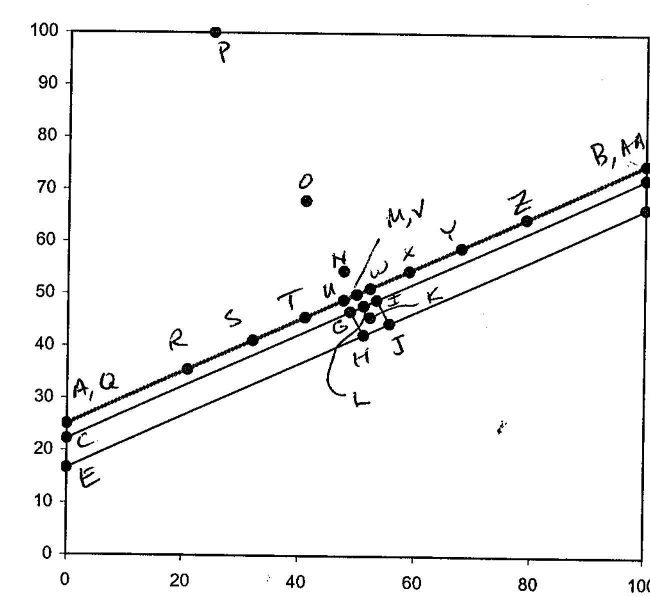

```
; Case 7.3 - FLAC 4.0 input file (Sep 18,
2004; RSR)
;
; Inclined transgressing joint in a heated
infinite rock mass.  Joint
; properties selected to disallow slippage.
Heat source 5x5 m centered
; at x=52.236, y=45.528. Power is 2000 W/cu.m.
;
config thermal extra 10
call dispmag.fis
;
; Geometry
;
;Points
;A 0.000 25.000
;B 100.000 75.000
;C 0.000 22.205
;D 100.000 72.205
;E 0.000 16.615
;F 100.000 66.615
;G 48.882 46.646
;H 51.118 42.174
;I 53.354 48.882
;J 55.590 44.410
;K 52.236 45.528
;L 51.118 47.764
;M 50.000 50.000
;N 47.764 54.472
;O 41.056 67.889
;P 25.000 100.000
;Q 0.000 25.000
;R 20.931 35.466
;S 32.111 41.056
;T 41.056 45.528
;U 47.764 48.882
;V 50.000 50.000
;W 52.236 51.118
;X 58.944 54.472
;Y 67.889 58.944
;Z 79.069 64.534
;AA 100.000 75.000
;
;Line
;A-B 0.000 25.000 100.000 75.000
;C-D 0.000 22.205 100.000 72.205
;E-F 0.000 16.615 100.000 66.615
;G-H 48.882 46.646 51.118 42.174
;I-J 53.354 48.882 55.590 44.410
;
grid 50 29
model elastic th_isotropic
mod null j=16
gen 0.0,22.205 0.0,25.0 100.0,75.0
100.0,72.205 i=1,51 j=14,16
gen 0.0,16.615 0.0,22.205 48.882,46.646
51.118,42.174 i=1,25 j=10,14
gen 55.590,44.410 53.354,48.882 100.000,72.205
100.000,66.615 i=27,51 j=10,14
gen 0.0,25.0 0.0,100.0 100.0,100.0 100.0 75.0
i=1,51 j=17,30
int 1 aside from 1,16 to 51,16 bside from 1,17
to 51,17
gen 51.118,42.174 48.882,46.646 53.354,48.882
55.590,44.410 i=25,27 j=10,14
mark i=25,27 j=10,14
gen 0.0,0.0 0.0,16.615 100.0,66.615 100.0,0.0
i=1,51 j=1,10
gen 0.0,16.615 0.0,22.205 48.882,46.646
51.118,42.174 i=1,25 j=10,14
gen 55.590,44.410 53.354,48.882 100.000,72.20!
100.000,66.615 i=27,51 j=10,14
gen 51.118,42.174 48.882,46.646 53.354,48.882
55.590,44.410 i=25,27 j=10,14
mark j=10,14
gen adjust
unmark
mark i=25,27 j=10,14
ini x=47.764 y=54.472 i=25 j=19
ini x=41.056 y=67.889 i=22 j=23
ini x=25.0 y=100.0 i=14 j=30
;
; Material properties
;
prop de=2210.0 b=19.0e9 s=13.0e9
prop thexp=15.0e-6 cond=20.0 spec=1000.0
int 1 kn=19.0e10 ks=13.0e10
int 1 c=1.0e20 f=0.0 t=1.0e20 di=0 ; no slip
;
;int 1 c=100.0e3 f=20.0 t=1.0e6 di=0 ; slip
;
; Initial conditions
;
ini tem 34.0
;
; Boundary conditions
;
;apply yvel 0.0 j=1
;apply yvel 0.0 j=30
;apply xvel 0.0 i=1 j=1,16
;apply xvel 0.0 i=1 j=17,30
;apply xvel 0.0 i=51 j=1,16
;apply xvel 0.0 i=51 j=17,30
;
fix y j=1
fix y j=30
fix x i=1 j=1,16
fix x i=1 j=17,30
fix x i=51 j=1,16
fix x i=51 j=17,30
;
; Apply heat source
;
interior source 2000 i=25,26 j=10,13
;
set mech on therm off
step 2000
ini xd 0
ini yd 0
ini xv 0
ini yv 0
;
; Time and force history
;
hist unbalanced ;1
hist thtime ; 2
;
; Thermal histories
;
hist temp i=26 j=12 ;3
hist temp i=26 j=14 ;4
hist temp i=26 j=16 ;5
hist temp i=25 j=19 ;6
hist temp i=22 j=23 ;7
hist temp i=14 j=30 ;8
;
; Mechanical histories
;
hist ydisp i=26 j=12 ;9
hist ydisp i=26 j=14 ;10
hist ydisp i=26 j=16 ;11
```

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FLAC input file f73input.txt for Case 7.3 (pg 1 of 3)


```
hist ydisp i=25 j=19 ;12
hist ydisp i=22 j=23 ;13
hist ydisp i=14 j=30 ;14
;
hist xdisp i=26 j=12 ;15
hist xdisp i=26 j=14 ;16
hist xdisp i=26 j=16 ;17
hist xdisp i=25 j=19 ;18
hist xdisp i=22 j=23 ;19
hist xdisp i=14 j=30 ;20
;
; Thermal mechanical analysis
;
set mech off therm on
set thdt 1e2
solve age 100000
set mech on therm off
step 2000
set mech off therm on
solve age 200000
set mech on therm off
step 2000
set mech off therm on
solve age 300000
set mech on therm off
step 2000
set mech off therm on
solve age 400000
set mech on therm off
step 2000
set mech off therm on
solve age 500000
set mech on therm off
step 2000
set mech off therm on
solve age 600000
set mech on therm off
step 2000
set mech off therm on
solve age 700000
set mech on therm off
step 2000
set mech off therm on
solve age 800000
set mech on therm off
step 2000
set mech off therm on
solve age 900000
set mech on therm off
step 2000
set mech off therm on
solve age 1000000
set mech on therm off
step 2000
disp_mag
save f73final.sav
;
set plot emf color
title
Case 7.3 Inclined Transgressing Joint (FLAC,
No Slip Allowed)
;
set out f73grid.emf
plot gri bou iw
copy
;
; Joint condition plots
;
set out f73jnd.emf
plot if 1 ndisp
copy
;
set out f73jsd.emf
plot if 1 sdisp
copy
;
set out f73jss.emf
plot if 1 ss
copy
;
set out f73jns.emf
plot if 1 ns
copy
;
set out f73jrnd.emf
plot if 1 closure
copy
;
set out f73jrsd.emf
plot if 1 ride
copy
;
; Contour plots
;
set out f73temp.emf
plot temp fill temp iw bou iw
copy
;
set out f73disp.emf
plot ex_1 fill alias 'Displacement' ex_1 iw
disp iw bou iw
copy
;
set out f73xd.emf
plot xd fill xd iw bou iw
copy
;
set out f73yd.emf
plot yd fill yd iw bou iw
copy
;
set out f73sig1.emf
plot sig1 fill sig1 iw bou iw
copy
;
set out f73sig2.emf
plot sig2 fill sig2 iw bou iw
copy
;
set out f73sdif.emf
plot sdiff fill sdiff iw bou iw
copy
;
set out f73thist.emf
plo hist 3 4 5 6 7 8 vs 2
copy
;
set out f73ydhist.emf
plo hist 9 10 11 12 13 14 vs 2
copy
;
set out f73xdhist.emf
plo hist 15 16 17 18 19 20 vs 2
copy
;
set out f73unbal.emf
plo hist 1
copy
;
set hisfile f73temp.his
his write 3 4 5 6 7 8 vs 2 begin 1 skip 10
;
```

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FLAC input file f73input.txt (pg 2 of 3)

```
set hisfile f73yd.his
his write 9 10 11 12 13 14 vs 2 begin 1 skip
10
;
set hisfile f73xd.his
his write 15 16 17 18 19 20 vs 2 begin 1 skip
10
;
def xxx
  nn=561
end
xxx
def table_fill
  array f73(11,nn)
;
; Bottom of interface
;
thvalr=thvald*pi/180.0
  loop i (1,igp)
    xnot=x(1,16)
    ynot=y(1,16)
    xval=x(i,16)
    yval=y(i,16)
    lval=sqrt(((xval-xnot)*(xval-
xnot))+((yval-ynot)*(yval-ynot)))
    dxvalb=xdisp(i,16)
    dyvalb=ydisp(i,16)
    dsvalb=dxvalb*cos(thvalr)-
dyvalb*sin(thvalr)

dnvalb=dxvalb*sin(thvalr)+dyvalb*cos(thvalr)
;
; Top of interface
;
    dxvalt=xdisp(i,17)
    dyvalt=ydisp(i,17)
    dsvalt=dxvalt*cos(thvalr)-
dyvalt*sin(thvalr)

dnvalt=dxvalt*sin(thvalr)+dyvalt*cos(thvalr)
;
; Interface
;
    dclos=dnvalt-dnvalb
    dride=dsvalt-dsvalb
    tempvalb=temp(i,16)
    tempvalt=temp(i,17)
;
; Create table entries
;
    table(1,i)=yval
    table(2,i)=xval
    table(3,i)=lval
    table(4,i)=dsvalb
    table(5,i)=dnvalb
    table(6,i)=dsvalt
    table(7,i)=dnvalt
    table(8,i)=dclos
    table(9,i)=dride
    table(10,i)=tempvalb
    table(11,i)=tempvalt
;
; Array entries
;
    f73(1,i)=string(yval)
    f73(2,i)=string(xval)
    f73(3,i)=string(lval)
    f73(4,i)=string(dsvalb)
    f73(5,i)=string(dnvalb)
    f73(6,i)=string(dsvalt)
    f73(7,i)=string(dnvalt)
    f73(8,i)=string(dclos)
    f73(9,i)=string(dride)
    f73(10,i)=string(tempvalb)
    f73(11,i)=string(tempvalt)
  endLoop
  status=open('f73data.out',1,1)
  status=write(f73,561)
end
;
set thvald=26.565051
table_fill
;
set log f73slip.out
pr if 1
set log f73sr.out
pr sratio j=16,17
ret
```

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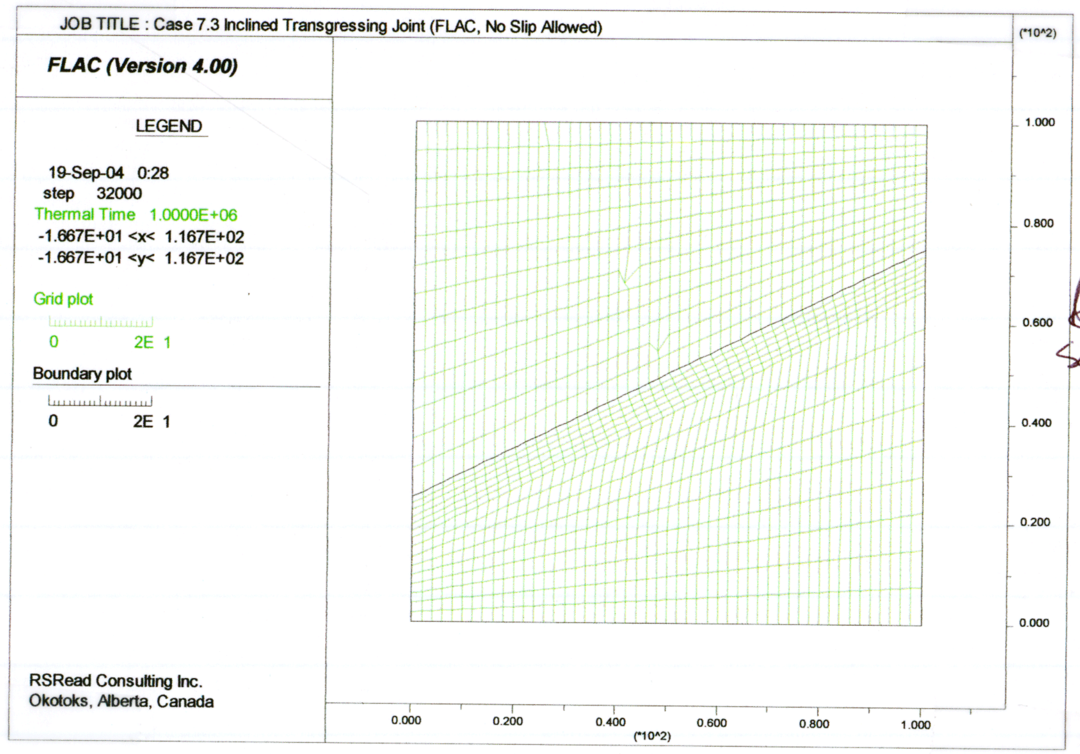
FLAC Input File f73input.txt (page 3 of 3)

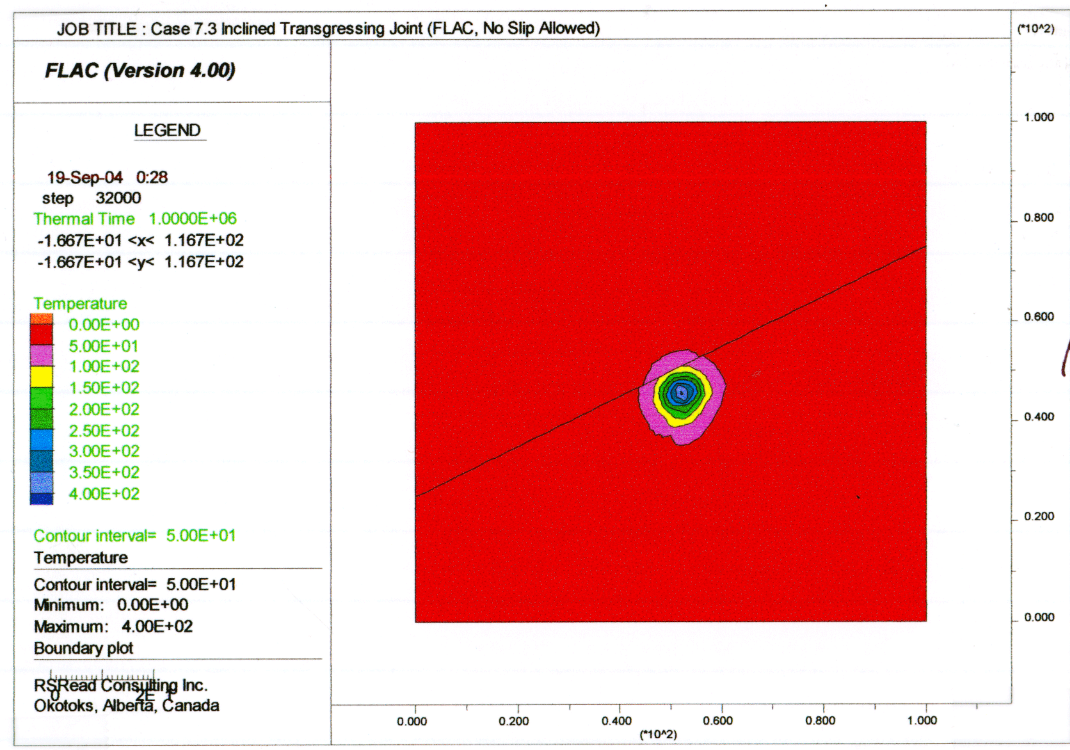
Flac input file f73input.txt was run with FLAC 4.0 (Double Precision) to produce standard plots, contained in WORD file f73plots.doc. The grid is the same density as that for UDEC case 7.3.

Maximum displacement is $1.135e^{-2}$ m compared to $1.143e^{-2}$ for UDEC (see SN 654 Vol 1, pg 78). Sep 18/04.
Error is 0.7%.



Sep 18/04.

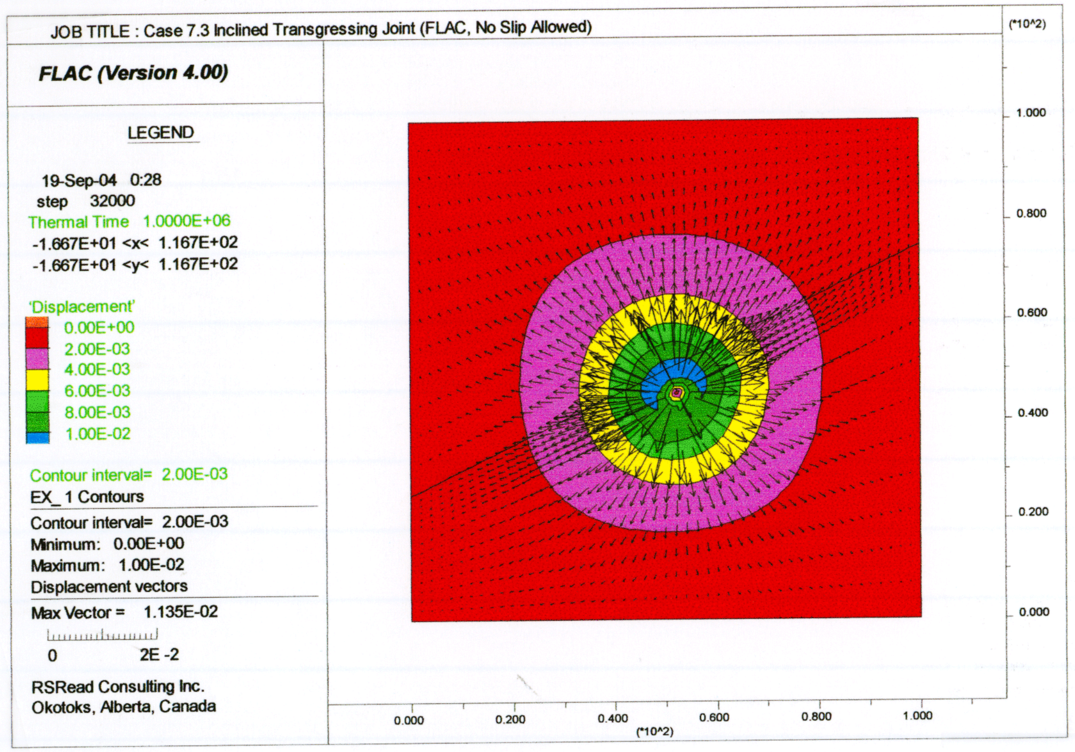
File f73grid.emf Grid used for Case 7.3.



Sep 18/04

File f73temp.emf Temperature contours for case 7.3

Plots stored in file f73plots.doc (WORD) in /Case7/FLAC



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File f73disp.emf Displacement contours and Vectors for Case 7.3.

Data from FLAC run using f73input.txt imported into f73.xls to create table and plots along interface. For comparison with UDEC run for same case. File stored under /Case 7/FLAC/f73.xls. Temperature history also imported into EXCEL file f73temp.XLS.

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Modified f73input.txt to increase joint stiffnesses to match those used in UDEC run. Normal stiffness increased to 19.0e11 and shear stiffness increased to 13.0e11. Results saved as f73a.xls. Input file f73inputa.txt.

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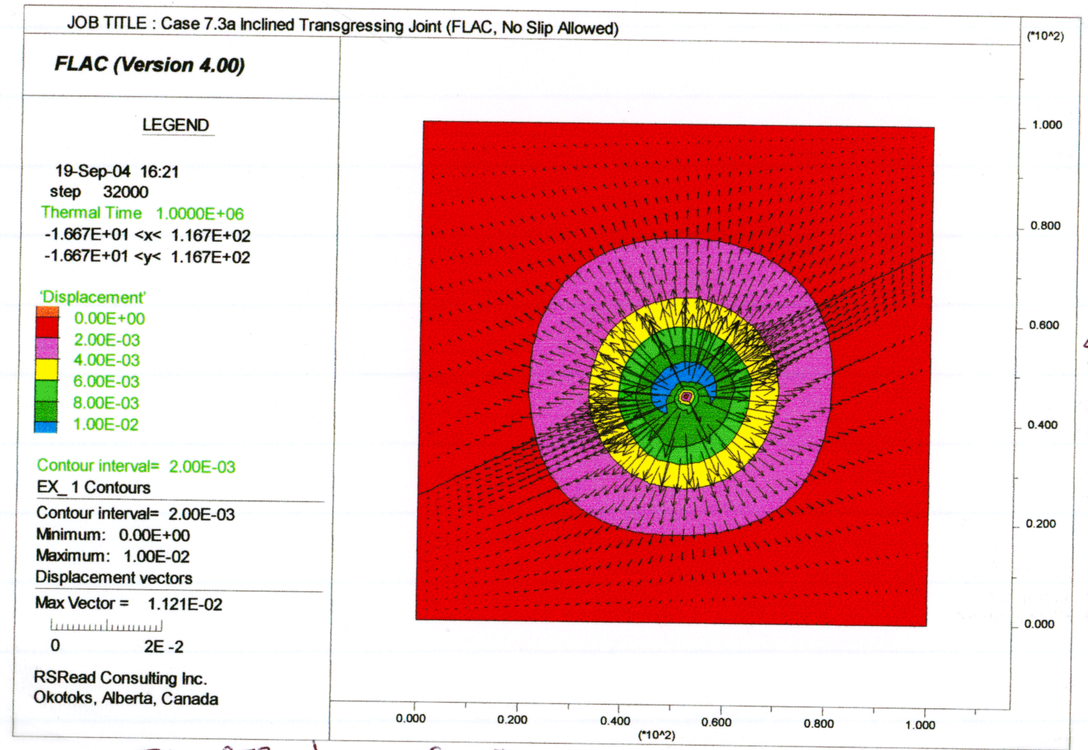
Case 7.3a FLAC - maximum vector for total displacement 1.121e-2 m.



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File f73adisp.emf Displacement contours and vectors for Case 7.3a.

/Case 7/FLAC/f73aplots.doc.

```
;
; Material properties
;
prop de=2210.0 b=19.0e9 s=13.0e9
prop thexp=15.0e-6 cond=20.0 spec=1000.0
int 1 kn=19.0e11 ks=13.0e11 ; increased stiffness
int 1 c=1.0e20 f=0.0 t=1.0e20 di=0 ; no slip
;
;int 1 c=100.0e3 f=20.0 t=1.0e6 di=0 ; slip
;
```

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modification in f73inputa.txt.

All plots for this case are stored in /Case 7/FLAC/f73aplots.doc and the corresponding EXCEL files are f73a.xls and f73atemp.xls. No slip along interface. Temperature differential across interface.

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```
; Case 7.4 - FLAC 4.0 input file (Sep 19, 2004; RSR)
;
; Inclined transgressing joint in a heated infinite rock
mass.  Joint
; properties selected to allow slippage.  Heat source 5x5 m
centered
; at x=52.236, y=45.528. Power is 2000 W/cu.m.
;
config thermal extra 10
call dispmag.fis
;
; Geometry
;
;Points
;A 0.000 25.000
;B 100.000 75.000
;C 0.000 22.205
;D 100.000 72.205
;E 0.000 16.615
;F 100.000 66.615
;G 48.882 46.646
;H 51.118 42.174
;I 53.354 48.882
;J 55.590 44.410
;K 52.236 45.528
;L 51.118 47.764
;M 50.000 50.000
;N 47.764 54.472
;O 41.056 67.889
;P 25.000 100.000
;Q 0.000 25.000
;R 20.931 35.466
;S 32.111 41.056
;T 41.056 45.528
;U 47.764 48.882
;V 50.000 50.000
;W 52.236 51.118
;X 58.944 54.472
;Y 67.889 58.944
;Z 79.069 64.534
;AA 100.000 75.000
;
;Line
;A-B 0.000 25.000 100.000 75.000
;C-D 0.000 22.205 100.000 72.205
;E-F 0.000 16.615 100.000 66.615
;G-H 48.882 46.646 51.118 42.174
;I-J 53.354 48.882 55.590 44.410
;
grid 50 29
model elastic th_isotropic
mod null j=16
gen 0.0,22.205 0.0,25.0 100.0,75.0 100.0,72.205 i=1,51
j=14,16
gen 0.0,16.615 0.0,22.205 48.882,46.646 51.118,42.174 i=1,25
j=10,14
gen 55.590,44.410 53.354,48.882 100.000,72.205 100.000,66.615
i=27,51 j=10,14
gen 0.0,25.0 0.0,100.0 100.0,100.0 100.0 75.0 i=1,51 j=17,30
int 1 aside from 1,16 to 51,16 bside from 1,17 to 51,17
gen 51.118,42.174 48.882,46.646 53.354,48.882 55.590,44.410
i=25,27 j=10,14
mark i=25,27 j=10,14
gen 0.0,0.0 0.0,16.615 100.0,66.615 100.0,0.0 i=1,51 j=1,10
gen 0.0,16.615 0.0,22.205 48.882,46.646 51.118,42.174 i=1,25
j=10,14
gen 55.590,44.410 53.354,48.882 100.000,72.205 100.000,66.615
i=27,51 j=10,14
gen 51.118,42.174 48.882,46.646 53.354,48.882 55.590,44.410
i=25,27 j=10,14
mark j=10,14
gen adjust
unmark
mark i=25,27 j=10,14
ini x=47.764 y=54.472 i=25 j=19
ini x=41.056 y=67.889 i=22 j=23
ini x=25.0 y=100.0 i=14 j=30
;
; Material properties
;
prop de=2210.0 b=19.0e9 s=13.0e9
prop thexp=15.0e-6 cond=20.0 spec=1000.0
int 1 kn=19.0e11 ks=13.0e11
;int 1 c=1.0e20 f=0.0 t=1.0e20 di=0 ; no slip
;
int 1 c=100.0e3 f=20.0 t=1.0e6 di=0 ; slip
;
; Initial conditions
;
ini tem 34.0
;
; Boundary conditions
;
;apply yvel 0.0 j=1
;apply yvel 0.0 j=30
;apply xvel 0.0 i=1 j=1,16
;apply xvel 0.0 i=1 j=17,30
;apply xvel 0.0 i=51 j=1,16
;apply xvel 0.0 i=51 j=17,30
;
fix y j=1
fix y j=30
fix x i=1 j=1,16
fix x i=1 j=17,30
fix x i=51 j=1,16
fix x i=51 j=17,30
;
; Apply heat source
;
interior source 2000 i=25,26 j=10,13
;
set mech on therm off
step 2000
ini xd 0
ini yd 0
ini xv 0
ini yv 0
;
; Time and force history
;
hist unbalanced ;1
hist thtime ; 2
;
; Thermal histories
;
hist temp i=26 j=12 ;3
hist temp i=26 j=14 ;4
hist temp i=26 j=16 ;5
hist temp i=25 j=19 ;6
hist temp i=22 j=23 ;7
hist temp i=14 j=30 ;8
;
; Mechanical histories
;
hist ydisp i=26 j=12 ;9
hist ydisp i=26 j=14 ;10
hist ydisp i=26 j=16 ;11
hist ydisp i=25 j=19 ;12
hist ydisp i=22 j=23 ;13
hist ydisp i=14 j=30 ;14
;
hist xdisp i=26 j=12 ;15
hist xdisp i=26 j=14 ;16
hist xdisp i=26 j=16 ;17
hist xdisp i=25 j=19 ;18
hist xdisp i=22 j=23 ;19
hist xdisp i=14 j=30 ;20
;
; Thermal mechanical analysis
;
set mech off therm on
set thdt 1e2
solve age 100000
set mech on therm off
step 2000
set mech off therm on
solve age 200000
set mech on therm off
step 2000
set mech off therm on
solve age 300000
set mech on therm off
step 2000
set mech off therm on
solve age 400000
set mech on therm off
step 2000
set mech off therm on
solve age 500000
set mech on therm off
step 2000
set mech off therm on
solve age 600000
set mech on therm off
step 2000
set mech off therm on
solve age 700000
set mech on therm off
step 2000
set mech off therm on
solve age 800000
set mech on therm off
step 2000
set mech off therm on
solve age 900000
set mech on therm off
step 2000
set mech off therm on
solve age 1000000
set mech on therm off
```

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File f74input.txt (FLAC input file for Case 7.4)

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```
step 2000
disp_mag
save f74final.sav
;
set plot emf color
title
Case 7.4 Inclined Transgressing Joint (FLAC, Slip Allowed)
;
set out f74grid.emf
plot gri bou iw
copy
;
; Joint condition plots
;
set out f74jnd.emf
plot if 1 ndisp
copy
;
set out f74jsd.emf
plot if 1 sdisp
copy
;
set out f74jss.emf
plot if 1 ss
copy
;
set out f74jns.emf
plot if 1 ns
copy
;
set out f74jrnd.emf
plot if 1 closure
copy
;
set out f74jrsd.emf
plot if 1 ride
copy
;
; Contour plots
;
set out f74temp.emf
plot temp fill temp iw bou iw
copy
;
set out f74disp.emf
plot ex_1 fill alias 'Displacement' ex_1 iw disp iw bou iw
copy
;
set out f74xd.emf
plot xd fill xd iw bou iw
copy
;
set out f74yd.emf
plot yd fill yd iw bou iw
copy
;
set out f74sig1.emf
plot sig1 fill sig1 iw bou iw
copy
;
set out f74sig2.emf
plot sig2 fill sig2 iw bou iw
copy
;
set out f74sdif.emf
plot sdiff fill sdiff iw bou iw
copy
;
set out f74thist.emf
plo hist 3 4 5 6 7 8 vs 2
copy
;
set out f74ydhist.emf
plo hist 9 10 11 12 13 14 vs 2
copy
;
set out f74xdhist.emf
plo hist 15 16 17 18 19 20 vs 2
copy
;
set out f74unbal.emf
plo hist 1
copy
;
set hisfile f74temp.his
his write 3 4 5 6 7 8 vs 2 begin 1 skip 10
;
set hisfile f74yd.his
his write 9 10 11 12 13 14 vs 2 begin 1 skip 10
;
set hisfile f74xd.his
his write 15 16 17 18 19 20 vs 2 begin 1 skip 10
;
def xxx
  nn=561
end
xxx
def table_fill
  array f74(11,nn)
;
; Bottom of interface
;
thvalr=thvald*pi/180.0
  loop i (1,igp)
    xnot=x(1,16)
    ynot=y(1,16)
    xval=x(i,16)
    yval=y(i,16)
    lval=sqrt(((xval-xnot)*(xval-xnot))+((yval-ynot)*(yval-
ynot)))
    dxvalb=xdisp(i,16)
    dyvalb=ydisp(i,16)
    dsvalb=dxvalb*cos(thvalr)-dyvalb*sin(thvalr)
    dnvalb=dxvalb*sin(thvalr)+dyvalb*cos(thvalr)
;
; Top of interface
;
    dxvalt=xdisp(i,17)
    dyvalt=ydisp(i,17)
    dsvalt=dxvalt*cos(thvalr)-dyvalt*sin(thvalr)
    dnvalt=dxvalt*sin(thvalr)+dyvalt*cos(thvalr)
;
; Interface
;
    dclos=dnvalt-dnvalb
    dride=dsvalt-dsvalb
    tempvalb=temp(i,16)
    tempvalt=temp(i,17)
;
; Create table entries
;
    table(1,i)=yval
    table(2,i)=xval
    table(3,i)=lval
    table(4,i)=dsvalb
    table(5,i)=dnvalb
    table(6,i)=dsvalt
    table(7,i)=dnvalt
    table(8,i)=dclos
    table(9,i)=dride
    table(10,i)=tempvalb
    table(11,i)=tempvalt
;
; Array entries
;
    f74(1,i)=string(yval)
    f74(2,i)=string(xval)
    f74(3,i)=string(lval)
    f74(4,i)=string(dsvalb)
    f74(5,i)=string(dnvalb)
    f74(6,i)=string(dsvalt)
    f74(7,i)=string(dnvalt)
    f74(8,i)=string(dclos)
    f74(9,i)=string(dride)
    f74(10,i)=string(tempvalb)
    f74(11,i)=string(tempvalt)
  endLoop
  status=open('f74data.out',1,1)
  status=write(f74,561)
end
;
set thvald=26.565051
table_fill
;
set log f74slip.out
pr if 1
set log f74sr.out
pr sratio j=16,17
ret
```

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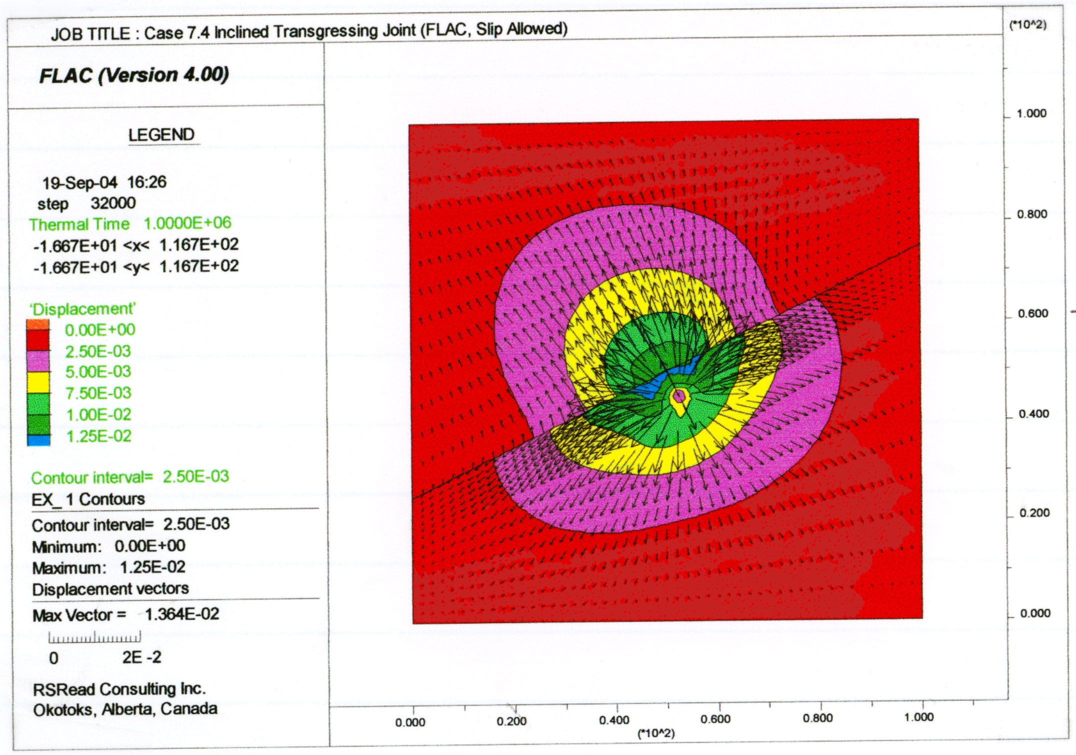
FLAC input file f74input.txt (case 7.4)



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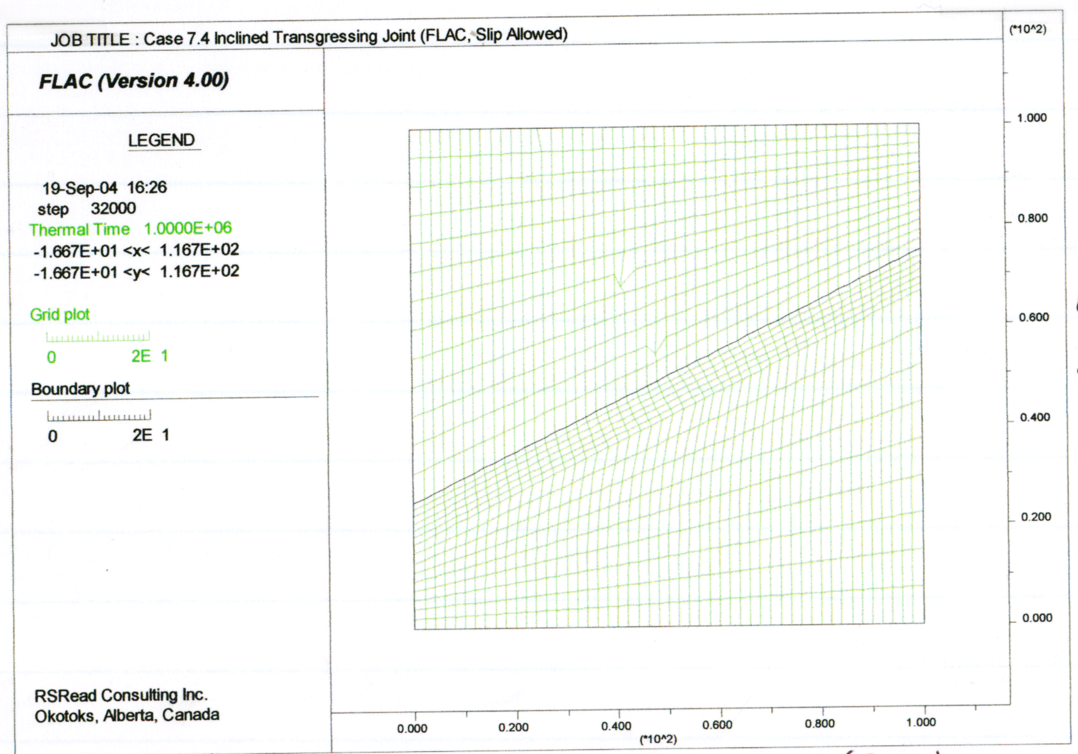
File f74disp.emf Displacement contours and vectors.



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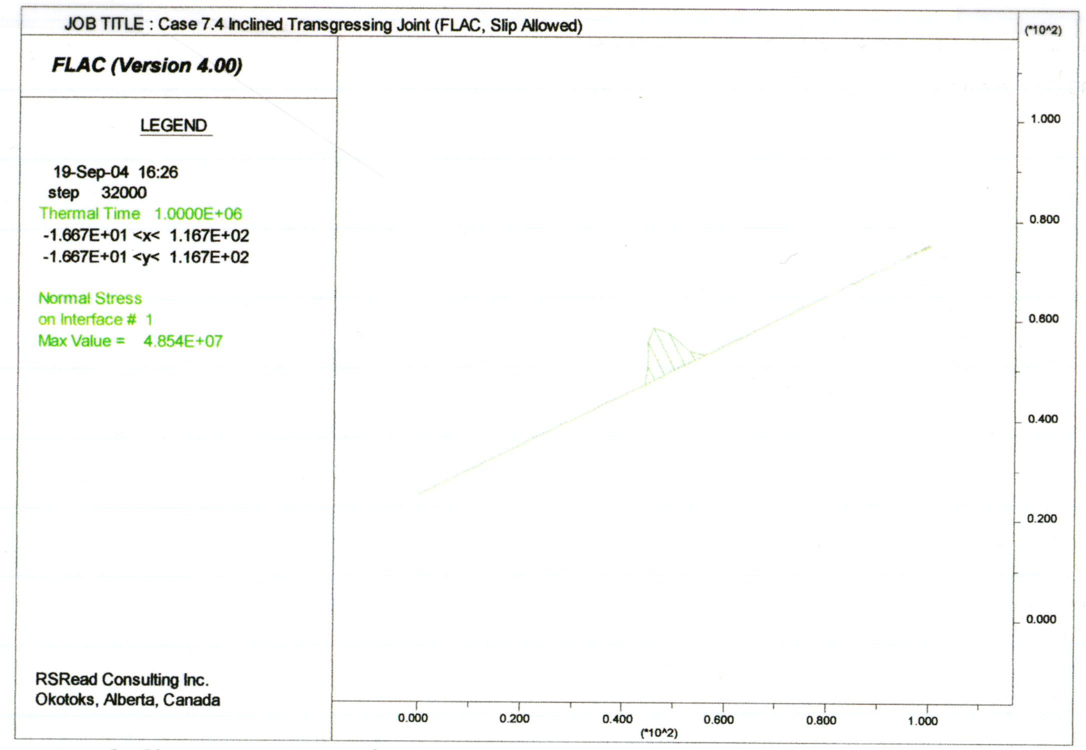
File f74grid.emf Grid for case 7.4 (FLAC)



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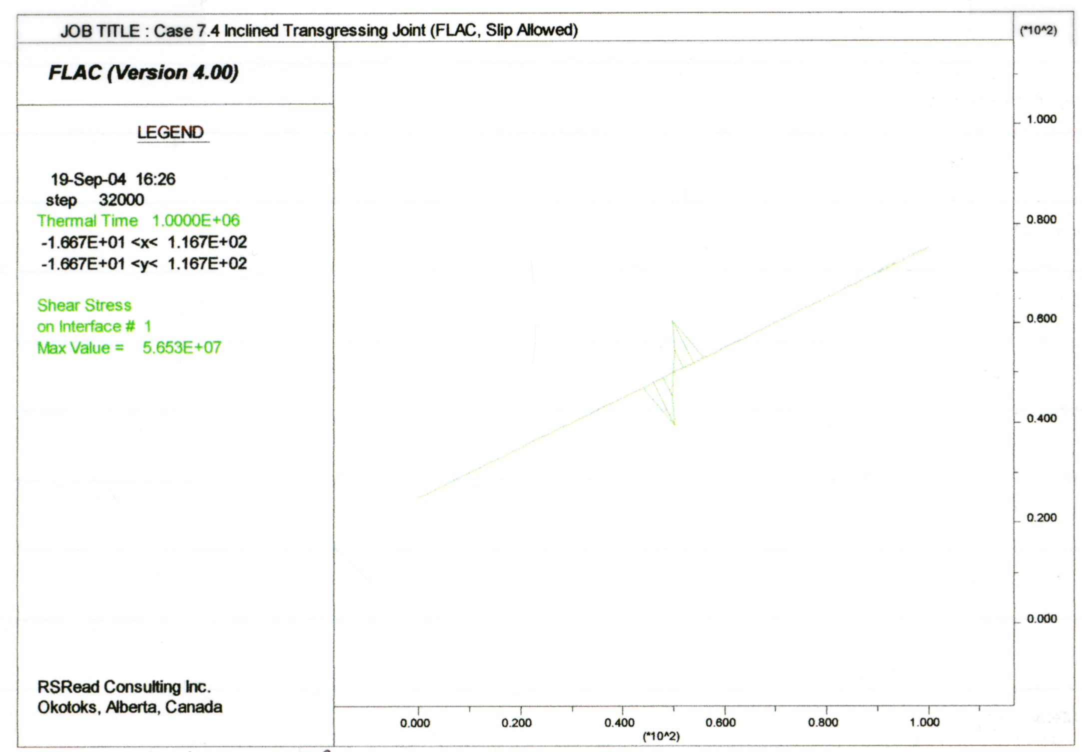
File f74jns.emf Joint normal stress



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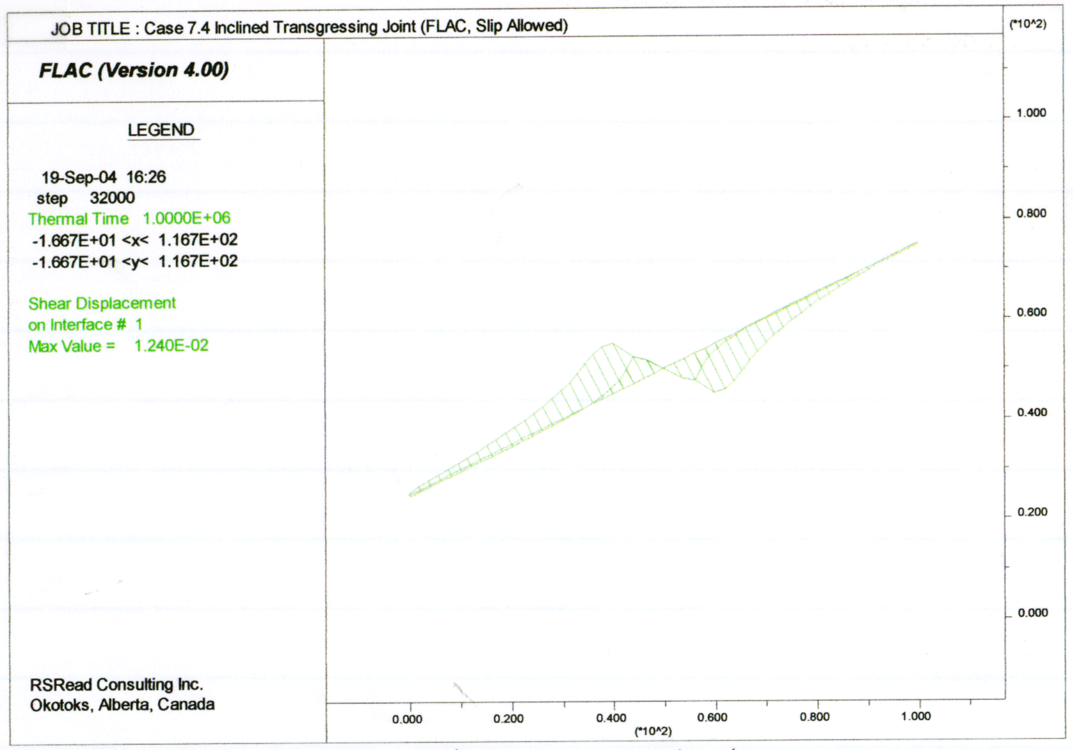
File f74jss.emf Joint shear stress



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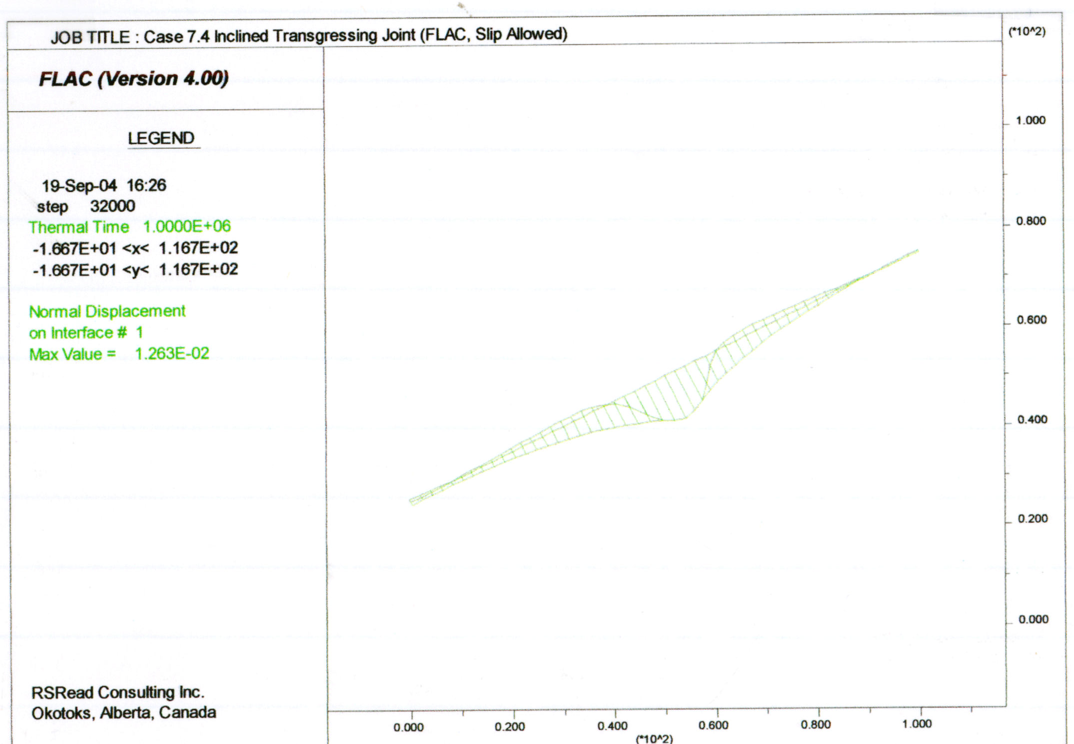
File f74jsd.emf Joint shear displacement



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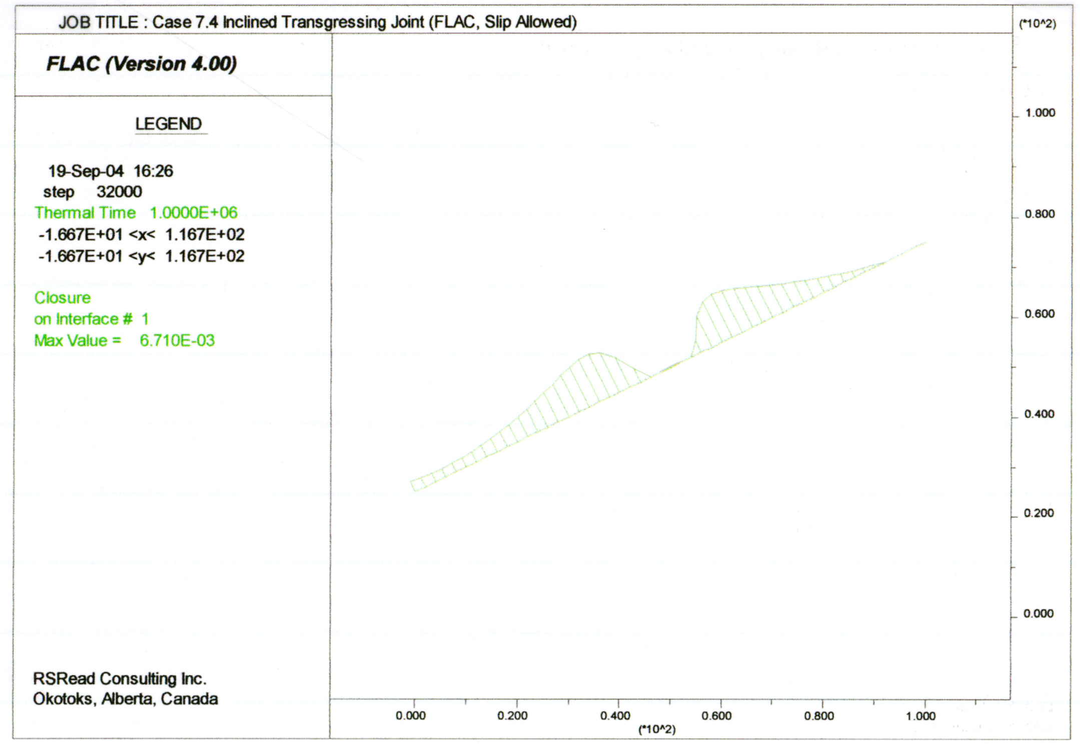
File f74jnd.emf Joint normal displacement.



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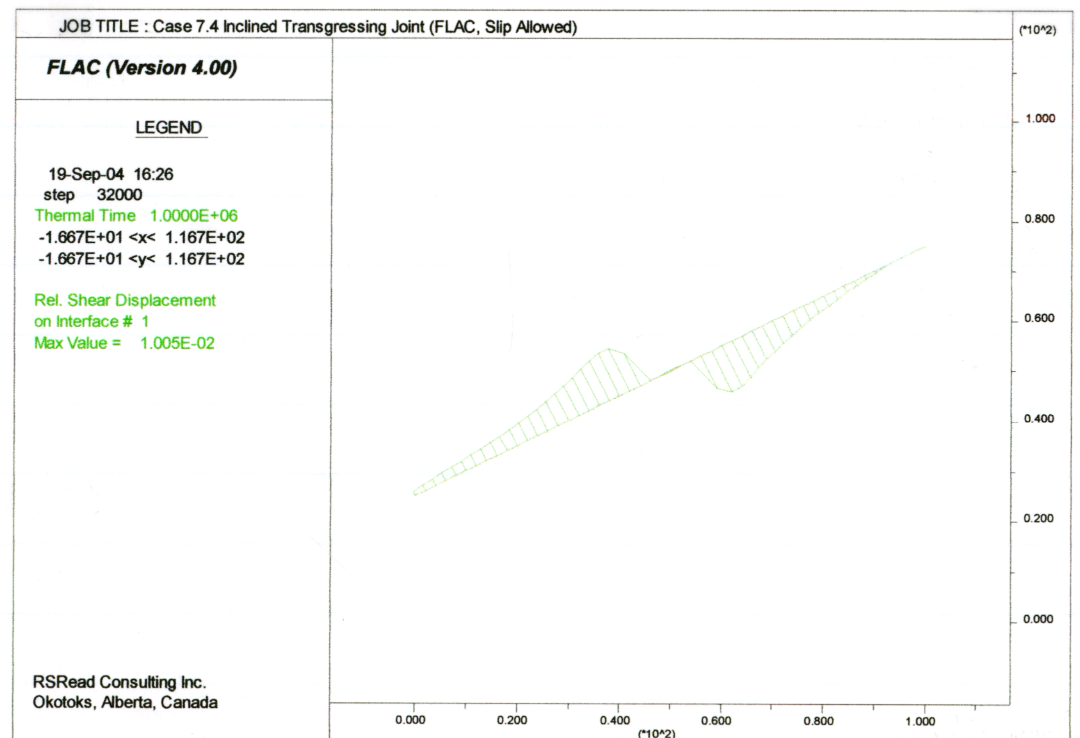
File f74jrnd.emf Joint relative normal displacement



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File f74jrsd.emf Joint relative shear displacement.

```
res f74afinal.sav
;
def xxx
  nn=561
end
xxx
def table_fill
  array f74a(11,nn)
;
; Bottom of interface
;
  thvalr=thvald*pi/180.0
  pnt=int_pnt
  xnot=x(1,16)
  ynot=y(1,16)
  loop while pnt # 0
    pa = imem(pnt+$kicapt)
    loop while pa # 0
      ival=imem(pa+$kidi)
      jval=imem(pa+$kidj)
      xval=fmem(pa+$kidx)
      yval=fmem(pa+$kidy)
      lval=sqrt(((xval-xnot)*(xval-xnot))+((yval-ynot)*(yval-ynot)))
      dxvalb=xdisp(ival,16)
      dyvalb=ydisp(ival,16)
      dtvalb=sqrt((dxvalb*dxvalb)+(dyvalb*dyvalb))
      thetav=atan2(dyvalb,dxvalb)
      dsvalb=dtvalb*cos(thetav-thvalr)
      dnvalb=dtvalb*sin(thetav-thvalr)
;
; Top of interface
;
      dxvalt=xdisp(ival,17)
      dyvalt=ydisp(ival,17)
      dtvalt=sqrt((dxvalt*dxvalt)+(dyvalt*dyvalt))
      thetav=atan2(dyvalt,dxvalt)
      dsvalt=dtvalt*cos(thetav-thvalr)
      dnvalt=dtvalt*sin(thetav-thvalr)
;
; Interface
;
      dclos=fmem(pa+$kidand)
      dride=fmem(pa+$kidasd)
      tempvalb=temp(ival,16)
      tempvalt=temp(ival,17)
;
; Create table entries
;
      table(1,ival)=yval
      table(2,ival)=xval
      table(3,ival)=lval
      table(4,ival)=dsvalb
      table(5,ival)=dnvalb
      table(6,ival)=dsvalt
      table(7,ival)=dnvalt
      table(8,ival)=dclos
      table(9,ival)=dride
      table(10,ival)=tempvalb
      table(11,ival)=tempvalt
;
; Array entries
;
      f74a(1,ival)=string(yval)
      f74a(2,ival)=string(xval)
      f74a(3,ival)=string(lval)
      f74a(4,ival)=string(dsvalb)
      f74a(5,ival)=string(dnvalb)
      f74a(6,ival)=string(dsvalt)
      f74a(7,ival)=string(dnvalt)
      f74a(8,ival)=string(dclos)
      f74a(9,ival)=string(dride)
      f74a(10,ival)=string(tempvalb)
      f74a(11,ival)=string(tempvalt)
      pa=imem(pa)
    endLoop
    pnt=imem(pnt)
  endloop
  status=open('f74adata.out',1,1)
  status=write(f74a,561)
end
;
set thvald=26.565051
cal int.fin
table_fill
;
set log f74aslip.out
pr if 1
set log f74asr.out
pr sratio j=16,17
ret
```

[signature] Sep 20/04

FLAC input file f74test.txt

Modified version of TABLE_FILL to directly output relative displacements.

The subroutine table_fill was modified so as to access internal FLAC variables for relative shear and normal displacement. Modified output from f74final.sav was stored in Excel file f74.xls to create plots for comparison with UDEC.

[signature] Sep 20/04.

Case 7.5 and 7.6 – not duplicated with FLAC given very small save used.

Case 7.7 run using FLAC to simulate an inclined joint (14° to horizontal) using typical Yucca Mtn conditions and properties. This case was developed using FLAC input file f77input.txt. Friction angle = 41° and no slip allowed.

Case 7.8 run using FLAC simulated the same case as Case 7.7 but with realistic properties for joint cohesion and tension. Friction angle = 41° f78input.txt.

Case 7.9 was identical to case 7.8 but used an friction angle of 20°.

Case 7.10 is identical to case 7.9 but with stresses rotated 90° to simulate impacts on a steeply dipping fracture 14° off vertical.

Input files f77input.txt, f78input.txt, f79input.txt and f710input.txt are attached to the following pages and are stored in directory /Case7/FLAC/.

Runs batched and completed Sep 21/04.

[signature] Sep 21/04

[signature] Sep 20/04.

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```
; Case 7.7 - FLAC 4.0 input file (Sep 20, 2004; RSR)
;
; Inclined transgressing joint in a heated infinite rock
mass.  Joint
; properties selected to disallow slippage.  Heat source 5x5
m centered
; at x=51.210, y=45.149. Joint angle 14° from horizontal.
Power is
; 1500 W/m (60 w/cu.m. x 25 sq.m).  Typical Yucca Mountain
properties used.
;
config thermal extra 10
call dispmag.fis
;
; Geometry
;
;Points
;
;A, 0.000, 37.534
;B, 100.000, 62.466
;C, 0.000, 34.957
;D, 100.000, 59.890
;E, 0.000, 29.804
;F, 100.000, 54.737
;G, 48.179, 46.969
;H, 49.389, 42.118
;I, 53.031, 48.179
;J, 54.240, 43.328
;K, 51.210, 45.149
;L, 50.605, 47.574
;M, 50.000, 50.000
;N, 48.790, 54.851
;O, 45.162, 69.406
;P, 37.534, 100.000
;Q, 0.000, 37.534
;R, 18.465, 42.138
;S, 30.594, 45.162
;T, 40.297, 47.581
;U, 47.574, 49.395
;V, 50.000, 50.000
;W, 52.426, 50.605
;X, 59.703, 52.419
;Y, 69.406, 54.838
;Z, 81.535, 57.862
;AA, 100.000, 62.466
;
grid 50 29
model elastic th_isotropic
mod null j=16
gen 0.000,34.957 0.000,37.534 100.000,62.466 100.000,59.890
i=1,51 j=14,16 ; C A B D
gen 0.000,29.804 0.000,34.957 48.179,46.969 49.389,42.118
i=1,25 j=10,14 ; E C G H
gen 54.240,43.328 53.031,48.179  100.000,59.890
100.000,54.737 i=27,51 j=10,14 ; J I D F
gen 0.0,37.534 0.0,100.0 100.0,100.0 100.0,62.466 i=1,51
j=17,30 ; Upper block
int 1 aside from 1,16 to 51,16 bside from 1,17 to 51,17
gen 49.389,42.118  48.179,46.969  53.031,48.179
54.240,43.328 i=25,27 j=10,14 ; H G I J
mark i=25,27 j=10,14
gen 0.0,0.0 0.0,29.804 100.0,54.737 100.0,0.0 i=1,51 j=1,10
gen 0.000,29.804 0.000,34.957 48.179,46.969 49.389,42.118
i=1,25 j=10,14 ; E C G H
gen 54.240,43.328 53.031,48.179  100.000,59.890
100.000,54.737 i=27,51 j=10,14 ; J I D F
gen 49.389,42.118  48.179,46.969  53.031,48.179
54.240,43.328 i=25,27 j=10,14 ; H G I J
mark j=10,14
gen adjust
unmark
mark i=25,27 j=10,14
ini x=48.790 y=54.851  i=25 j=19 ; N
ini x=45.162 y=69.406  i=24 j=22 ; O
ini x=37.534 y=100.000 i=20 j=30 ; P
;
; Material properties
;
prop de=2210.0 b=19.2e9 s=13.6e9
prop thexp=10.0e-6 cond=2.13 spec=990.0
int 1 kn=5.0e11 ks=5.0e11
int 1 c=1.0e20 f=0.0 t=1.0e20 di=0 ; no slip
;
;int 1 c=100.0e3 f=41.0 t=40.0e3 di=0 ; slip
;
; Initial conditions
;
ini temp 25.0
ini syy -8.1e6 var 0 2.2e6 i=1,51 j=1,30
ini sxx -2.1546e6 var 0 0.5852e6 i=1,51 j=1,30
ini sxy 0 i=1,51 var 0.0 0.0 j=1,30
ini szz -2.1546e6 var 0 0.5852e6 i=1,51 j=1,30
;
; Boundary conditions
;
;apply yvel 0.0 j=1
;apply yvel 0.0 j=30
;apply xvel 0.0 i=1 j=1,16
;apply xvel 0.0 i=1 j=17,30
;apply xvel 0.0 i=51 j=1,16
;apply xvel 0.0 i=51 j=17,30
;
fix y j=1
fix y j=30
fix x i=1 j=1,16
fix x i=1 j=17,30
fix x i=51 j=1,16
fix x i=51 j=17,30
;
; Apply heat source
;
interior source 60 i=25,26 j=10,13
;
set mech on therm off
step 2000
ini xd 0
ini yd 0
ini xv 0
ini yv 0
;
; Time and force history
;
hist unbalanced ;1
hist thtime ; 2
;
; Thermal histories
;
hist temp i=26 j=12 ;3
hist temp i=26 j=14 ;4
hist temp i=26 j=16 ;5
hist temp i=25 j=19 ;6
hist temp i=24 j=22 ;7
hist temp i=20 j=30 ;8
;
; Mechanical histories
;
hist ydisp i=26 j=12 ;9
hist ydisp i=26 j=14 ;10
hist ydisp i=26 j=16 ;11
hist ydisp i=25 j=19 ;12
hist ydisp i=24 j=22 ;13
hist ydisp i=20 j=30 ;14
;
hist xdisp i=26 j=12 ;15
hist xdisp i=26 j=14 ;16
hist xdisp i=26 j=16 ;17
hist xdisp i=25 j=19 ;18
hist xdisp i=24 j=22 ;19
hist xdisp i=20 j=30 ;20
;
; Thermal mechanical analysis
;
set mech off therm on
set thdt 1e4
solve age 20000000
set mech on therm off
step 2000
set mech off therm on
solve age 40000000
set mech on therm off
step 2000
set mech off therm on
solve age 60000000
set mech on therm off
step 2000
set mech off therm on
solve age 80000000
set mech on therm off
step 2000
set mech off therm on
solve age 100000000
set mech on therm off
step 2000
set mech off therm on
solve age 120000000
set mech on therm off
step 2000
set mech off therm on
solve age 150000000
set mech on therm off
step 2000
set mech off therm on
solve age 200000000
set mech on therm off
step 2000
set mech off therm on
solve age 250000000
set mech on therm off
step 2000
set mech off therm on
```

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File (FLAC)
f77input.txt
(pg 1 of 2)

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```
solve age 315400000
set mech on therm off
step 2000
save
disp_mag
save f77final.sav
;
set plot emf color
title
Case 7.7 Inclined Transgressing Joint (FLAC, No Slip Allowed)
;
set out f77grid.emf
plot gri bou iw
copy
;
; Joint condition plots
;
set out f77jnd.emf
plot if 1 ndisp
copy
;
set out f77jsd.emf
plot if 1 sdisp
copy
;
set out f77jss.emf
plot if 1 ss
copy
;
set out f77jns.emf
plot if 1 ns
copy
;
set out f77jrnd.emf
plot if 1 closure
copy
;
set out f77jrsd.emf
plot if 1 ride
copy
;
; Contour plots
;
set out f77temp.emf
plot temp fill temp iw bou iw
copy
;
set out f77disp.emf
plot ex_1 fill alias 'Displacement' ex_1 iw disp iw bou iw
copy
;
set out f77xd.emf
plot xd fill xd iw bou iw
copy
;
set out f77yd.emf
plot yd fill yd iw bou iw
copy
;
set out f77sig1.emf
plot sig1 fill sig1 iw bou iw
copy
;
set out f77sig2.emf
plot sig2 fill sig2 iw bou iw
copy
;
set out f77sdif.emf
plot sdiff fill sdiff iw bou iw
copy
;
set out f77thist.emf
plo hist 3 4 5 6 7 8 vs 2
copy
;
set out f77ydhist.emf
plo hist 9 10 11 12 13 14 vs 2
copy
;
set out f77xdhist.emf
plo hist 15 16 17 18 19 20 vs 2
copy
;
set out f77unbal.emf
plo hist 1
copy
;
set hisfile f77temp.his
his write 3 4 5 6 7 8 vs 2 begin 1 skip 10
;
set hisfile f77yd.his
his write 9 10 11 12 13 14 vs 2 begin 1 skip 10
;
set hisfile f77xd.his
his write 15 16 17 18 19 20 vs 2 begin 1 skip 10
;
def xxx
  nn=561
end
xxx
def table_fill
  array f77(11,nn)
;
; Bottom of interface
;
  thvalr=thvald*pi/180.0
  pnt=int_pnt
  xnot=x(1,16)
  ynot=y(1,16)
  loop while pnt # 0
    pa = imem(pnt+$kicapt)
    loop while pa # 0
      ival=imem(pa+$kidi)
      jval=imem(pa+$kidj)
      xval=fmem(pa+$kidx)
      yval=fmem(pa+$kidy)
      lval=sqrt(((xval-xnot)*(xval-xnot))+((yval-ynot)*(yval-
ynot)))
      dxvalb=xdisp(ival,16)
      dyvalb=ydisp(ival,16)
      dtvalb=sqrt((dxvalb*dxvalb)+(dyvalb*dyvalb))
      thetav=atan2(dyvalb,dxvalb)
      dsvalb=dtvalb*cos(thetav-thvalr)
      dnvalb=dtvalb*sin(thetav-thvalr)
;
; Top of interface
;
      dxvalt=xdisp(ival,17)
      dyvalt=ydisp(ival,17)
      dtvalt=sqrt((dxvalt*dxvalt)+(dyvalt*dyvalt))
      thetav=atan2(dyvalt,dxvalt)
      dsvalt=dtvalt*cos(thetav-thvalr)
      dnvalt=dtvalt*sin(thetav-thvalr)
;
; Interface
;
      dclos=fmem(pa+$kidand)
      dride=fmem(pa+$kidasd)
      tempvalb=temp(ival,16)
      tempvalt=temp(ival,17)
;
; Create table entries
;
      table(1,ival)=yval
      table(2,ival)=xval
      table(3,ival)=lval
      table(4,ival)=dsvalb
      table(5,ival)=dnvalb
      table(6,ival)=dsvalt
      table(7,ival)=dnvalt
      table(8,ival)=dclos
      table(9,ival)=dride
      table(10,ival)=tempvalb
      table(11,ival)=tempvalt
;
; Array entries
;
      f77(1,ival)=string(yval)
      f77(2,ival)=string(xval)
      f77(3,ival)=string(lval)
      f77(4,ival)=string(dsvalb)
      f77(5,ival)=string(dnvalb)
      f77(6,ival)=string(dsvalt)
      f77(7,ival)=string(dnvalt)
      f77(8,ival)=string(dclos)
      f77(9,ival)=string(dride)
      f77(10,ival)=string(tempvalb)
      f77(11,ival)=string(tempvalt)
      pa=imem(pa)
    endLoop
    pnt=imem(pnt)
  endloop
  status=open('f77data.out',1,1)
  status=write(f77,561)
end
;
set thvald=14.0
;
cal int.fin
table_fill
;
set log f77slip.out
pr if 1
set log f77sr.out
pr sratio j=16,17
ret
```

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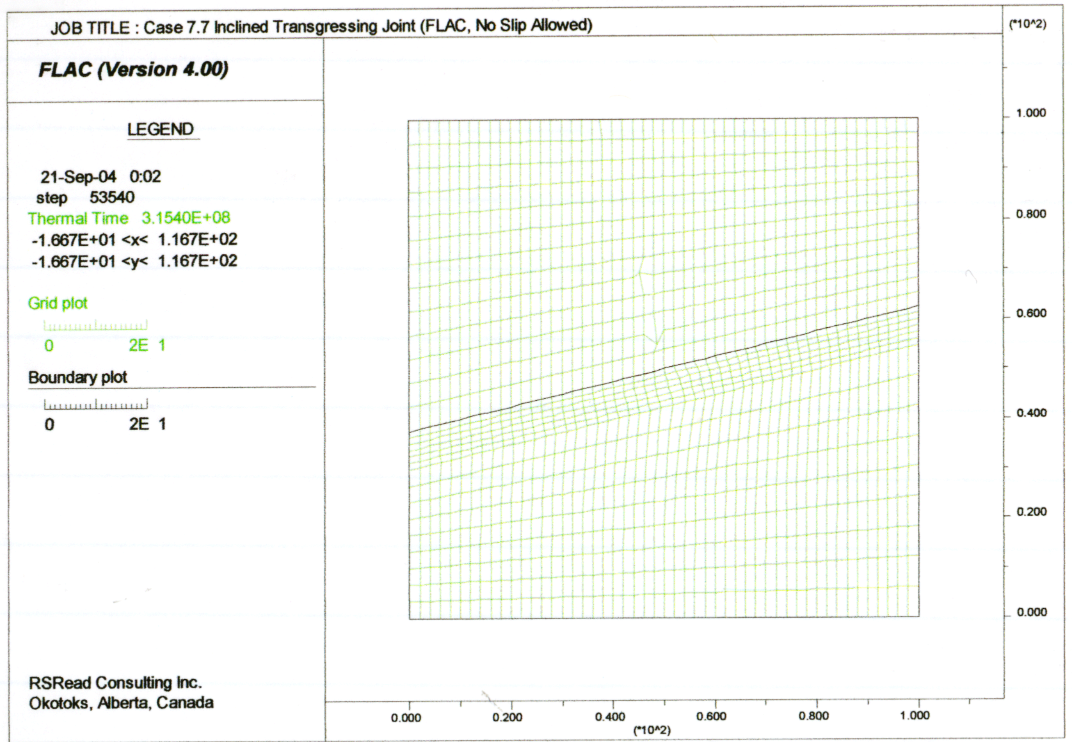
File (FLAC)
F77INPUT.TXT
(pg 2 of 2)



R
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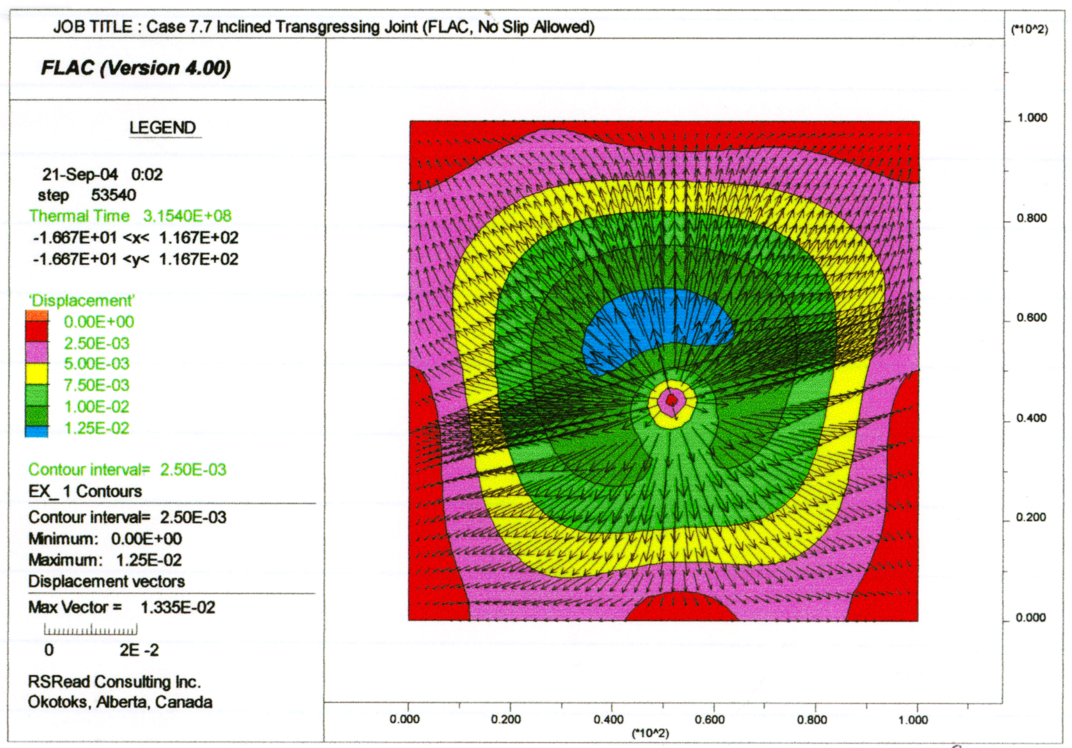
File f77grid.emf FLAC grid used for Cases 7.7, 7.8, 7.9, 7.10



R
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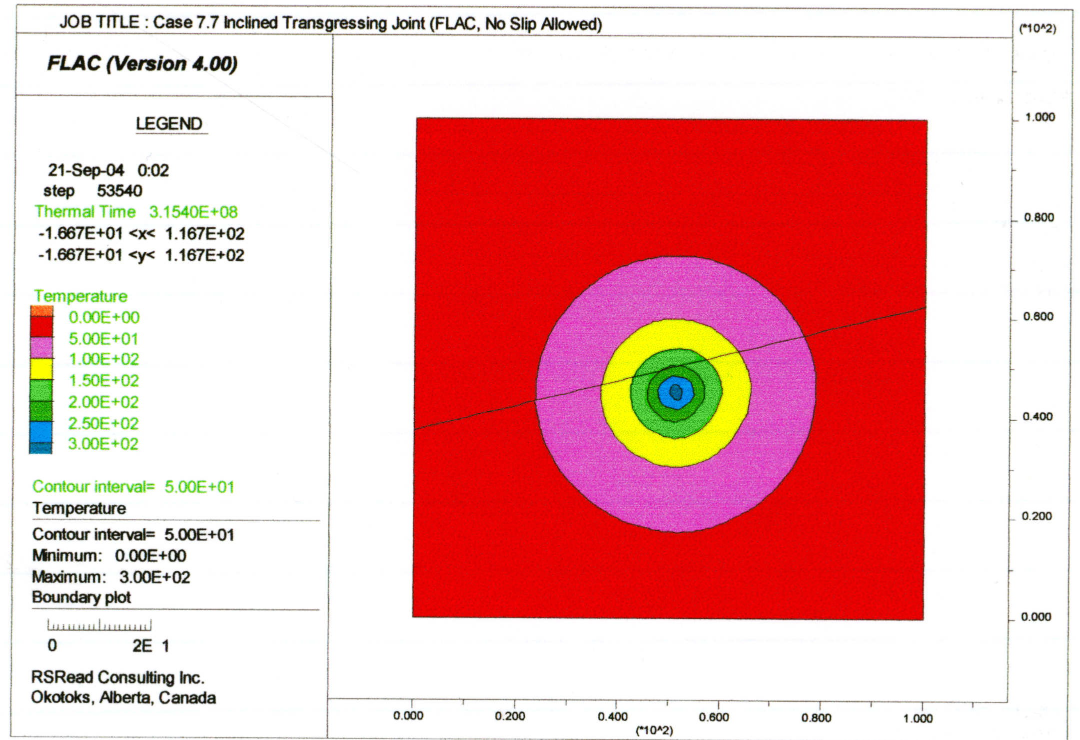
File f77disp.emf Displacement contours and vectors for Case 7.7



R
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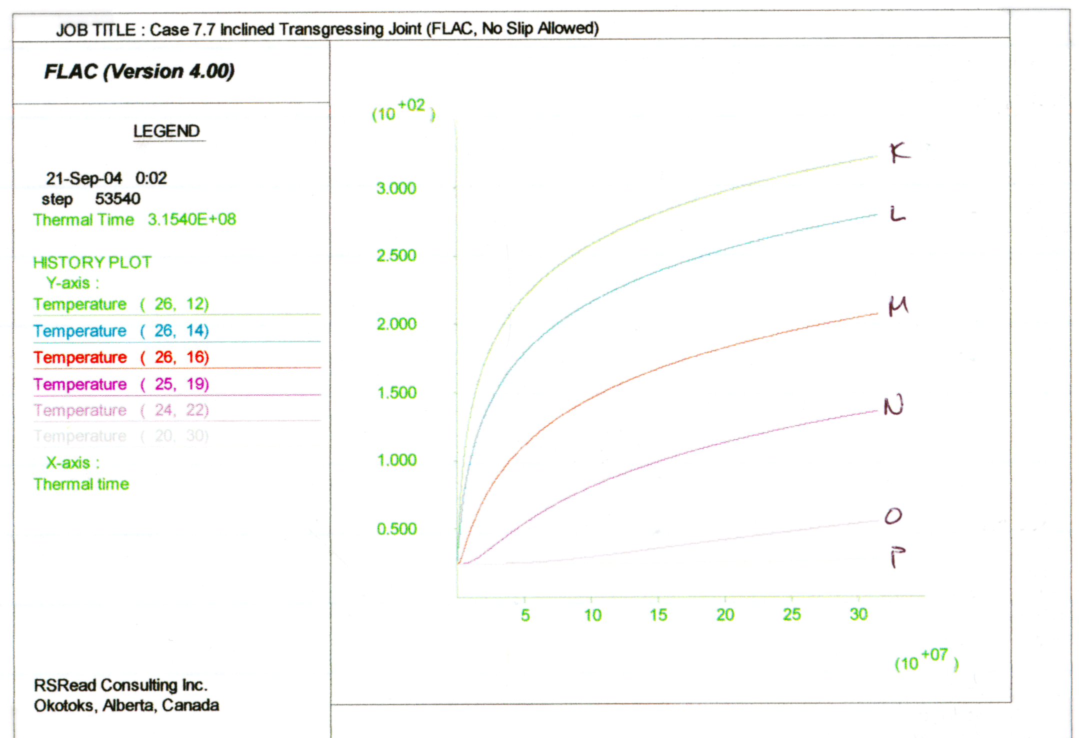
File f77temp.emf Temperature contours for case 7.7



R
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File f77hist.emf Temperature histories