SCIENTIFIC NOTEBOOK

Number 205

by

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Bruce:
Please close this scientific notebook. No further entries will be made.

Rui Chen
7/28/97

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1. INITIAL ENTRIES

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By agreement with the CNWRA QA this NoteBook is to be printed at approximate quarterly intervals. This computerized Scientific NoteBook is intended to address the criteria of CNWRA QAP-001.

1.1. Objectives

The objectives of this study is to examine changes in joint aperture from normal faulting. Subsequent changes in the average rock mass porosity will also be estimated for each fault block, for all fault blocks combined, and for the entire model. The significance of these modeling results are to be discussed in regard to effective and safe isolation of high-level nuclear waste at YM.

1.2. Technical Approaches

The problem is to be investigated by conducting fully coupled mechanical-hydraulic simulations of a normal fault model that include three fault zones analogous to the Solitario Canyon, Ghost Dance, and Bow Ridge Faults at the proposed repository site for high level nuclear waste at Yucca Mountain (YM).

1.3. Data Sources

The input information for UDEC analyses include model geometric data and material property data. Model geometry data are obtained based on an east-west vertical cross section through the proposed repository taken from the Center for Nuclear Waste Regulatory Analyses (CNWRA) three-dimensional geological framework model for YM (Stirewalt and Henderson, 1995). Mechanical and hydrologic properties are selected to represent the host rock of the proposed repository at YM, the Topopah Spring welded tuff, based on a number of sources as summarized in Ahola et al. (1996). This properties are also given in Table 1-1.

1.4. Computers, Computer Codes, and Data Files

Table 1-2 lists computer equipment and computer codes. Table 1-3 provides names, type, and content of data files for UDEC analyses. Table 1-3 gives names, content, and locations of some of the important data and result files.

Table 1.1. Material mechanical and hydraulic properties

Parameters		Units	Values
Intact Block Parameters			
Young's Modulus		GPa	32.3
Poisson's Ratio		-	0.21
Density		kg/m^3	$2.297(10^3)$
Rock Joint Parameters			
Normal Stiffness		GPa	13.46
Shear Stiffness		GPa	24.3
Cohesion		MPa	0.08
Friction Angle		°	35
Tensile Strength		MPa	0.04
Dilation Angle		°	5
Residual Aperture	Vertical Joints	m	0.0002
	Horizontal Joints	m	0.0001
Zero Stress Aperture	Vertical Joints	m	0.001
	Horizontal Joints	m	0.0005
Fluid Parameters			
Density		kg/m^3	1000
Bulk Stiffness		MPa	$3.0\ (10^3)$

Table 1-2. Computing equipment

Machine Name	Type	OS	Location	Computer Code	Language
ULTRA	Sun Workstation	Solaris 2.5	Bldg. 189	UDEC	Fortran 77
ULTRA	Sun Workstation	Solaris 2.5	Bldg. 189	MicroSoft Excel	-

Table 1-3. Name, type, and contents of some of the important files

File Names	Type	Content
ym7.dat	ASCII	Input data file for UDEC, with fault slipping sequence of 3-2-1
ym7_0.sav	Binary	Results after initial mechanical equilibrium
ym7_1.sav	Binary	Results after initial coupled mechanical & steady-state flow
ym7_br1.sav	Binary	Results after fault 3 slip of 1m over 1 s
ym7_br2.sav	Binary	Results after 15 s of fault 3 slip
ym7_gd1.sav	Binary	Results after fault 2 slip of 1 m over 1 s
ym7_gd2.sav	Binary	Results after 15 s of fault 2 slip
ym7_sc1.sav	Binary	Results after fault 1 slip of 1 m over 1 s
ym7_sc2.sav	Binary	Results after 15 s of fault 1 slip
ym12.dat	ASCII	Input data file for UDEC, with fault slipping sequence of 2-1-3
ym12_0.sav	Binary	Results after initial mechanical equilibrium
ym12_1.sav	Binary	Results after initial coupled steady-state flow and mechanical
ym12_gd1.sav	Binary	Results after fault 2 slip of 1 m over 1 s
ym12_gd2.sav	Binary	Results 15 s after fault 2 slip
ym12_sc1.sav	Binary	Results after fault 1 slip of 1 m over 1 s
ym12_sc2.sav	Binary	Results 15 s after fault 1 slip
ym12_br1.sav	Binary	Results after fault 3 slip of 1 m over 1 s
ym12_br2.sav	Binary	Results 15 s after fault 3 slip
ym13.dat	ASCII	Input data file for UDEC, with fault slipping sequence of 1-2-3
ym13_0.sav	Binary	Results after initial mechanical equilibrium
ym13_1.sav	Binary	Results after initial coupled steady-state and mechanical
ym13_sc1.sav	Binary	Results after fault 1 slip of 1 m over 1 s
ym13_sc2.sav	Binary	Results 15 s after slip of fault 1
ym13_gd1.sav	Binary	Results after fault 2 slip of 1 m over 1 s
ym13_gd2.sav	Binary	Results 15 s after slip of fault 2
ym13_br1.sav	Binary	Results after fault 3 slip of 1 m over 1 s
ym13_br2.sav	Binary	Results 15 s after slip of fault 1

grid_br_f.f grid_br_h.f	FORTRAN	Picking out grid point numbers along fault 3 for applying velocity to drive fault slip. _f:footwall, _h:hanging wall
grid_gd_f.f grid_gd_h.f	FORTRAN	Picking out grid point numbers along fault 2 for applying velocity to drive fault slip. _f:footwall, _h:hanging wall
grid_sc_f.f grid_sc_h.f	FORTRAN	Picking out grid point numbers along fault 1 for applying velocity to drive fault slip. _f:footwall, _h:hanging wall

2. IN-PROGRESS ENTRIES

2.1. Background

Fault related deformation in fault blocks and fault zones can cause significant changes in joint aperture, thereby altering porosity, permeability, and hydraulic conductivity of the rock mass. Zhang and Sanderson (1996) studied deformation in regions of jointed rock around an extensional fault using a simple model of a planar normal fault zone. They observed significant dilation and fluid flow in the hangingwall and within the fault zone itself during faulting. Although there are a number of technical problems associated with the modeling approaches and boundary conditions in Zhang and Sanderson's simulation (Chen and Lorig, 1997), their observations have practical significance. Most importantly, their attempt indicates that when applied appropriately, numerical experiments based on a discontinuum mechanics approach can be used to explore the mechanisms controlling faulting related joint dilation and fluid flow. Similar mechanisms may also control many other fluid-flow related phenomena accompanying faulting observed *in situ*, like episodic fluid flow near active faults (Sibson, 1988, 1990 and 1994; Logon, 1994), fault controlled fluid migration and mineralization (Munroe 1995), and pore pressure changes accompanying normal faulting (Rudnicki, 1991). Faulting also affects fluid flow in other porous rock masses, such as sandstones (Antoellini and Aydin, 1995). The fact that most of these phenomena have been associated with normal faulting indicates the importance of normal faulting in controlling rock mass hydraulic properties and fluid flow.

Changes in rock mass hydraulic properties and fluid flow associated with normal faulting are particularly important at Yucca Mountain (YM), the proposed site for permanent disposal of high-level radioactive nuclear waste, because the near surface tectonic setting at YM is characterized by a system of extensional faults (Scott, 1990; Young et al. 1992) and highly jointed fault blocks (Brechtel and Kessel, 1995; Brechtel, et al., 1995). Such faulting induced changes in joint aperture imply that normal faulting at YM, in the future, may increase rock mass permeability within the perturbed region, especially along the activated as well as existing fault zones. It may facilitate flow of groundwater in the saturated zone below the repository and provide a faster path for infiltration in the unsaturated zone above the repository, and thereby, affect the effective and safe isolation of high-level nuclear waste. As a defensive measure, the Department of Energy (DOE) is considering an offset distance from the faults for emplacement of waste.

In the present study, fully coupled mechanical-hydraulic analyses were conducted of a normal fault model analogous to the YM fault system. The distinct element code UDEC (Itasca Consulting Group, Inc., 1996) was used to examine changes in joint aperture from normal faulting. Subsequent changes in the average rock mass porosity were then estimated for each fault block, for all fault blocks combined, and for the entire model. The significance of these modeling results are discussed in regard to effective and safe isolation of high-level nuclear waste at YM.

2.2. Model Description

The distinct element model was constructed based on an east-west vertical cross section through the proposed repository at YM taken from the Center for Nuclear Waste Regulatory Analyses (CNWRA) three-dimensional geological framework model for YM (Stirewalt and Henderson, 1995). The model configuration for the distinct element analyses consists of three fault zones labeled as Faults 1 through 3 in Figure 2-1. These fault zones are analogous to the three major fault zones near the proposed repository, namely the Solitario Canyon, Ghost Dance, and Bow Ridge Faults. Each fault is represented

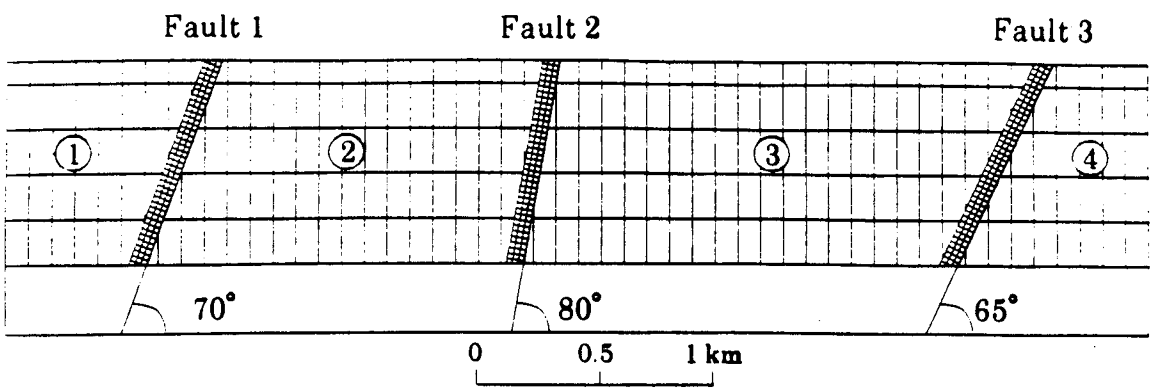


Figure 2-1: Geometry of YM fault model. Fault zones are modeled as 75 m wide zones with two orthogonal joint sets. There are two regional joint sets (vertical and horizontal) with spacings of 100 m and 200 m, respectively.

by a 75 m wide zone which is assumed to be highly fractured with two orthogonal joint sets parallel and perpendicular to the fault zone. The joint spacing for both joint sets within the fault zones is 25 m. Fault blocks are labeled as Blocks 1 through 4. Each fault block contains two hypothetical regional scale joint sets, horizontal and vertical, respectively. Joint spacing is 100 m for the vertical joint set and 200 m for the horizontal joint set, reflecting observations at YM that spacing of vertical (subvertical) joints is much smaller than that of horizontal joints (Brechtel and Kessel 1995; Brechtel et al., 1995). All of the fault zones and fault blocks were assumed to be above a basal substructure that is assumed to be unjointed for purposes of model simplification.

The top boundary of the model was assumed to be a stress-free boundary, simulating the ground surface. Other boundaries were modeled as boundary-element boundaries. A boundary-element boundary is an artificial boundary that simulates the semi-infinite extent of isotropic, linear, elastic material (Itasca Consulting Group, Inc., 1996). Boundary element boundaries are, therefore, a realistic simulation of the subsurface conditions. The fluid pressure in the model was assumed to be hydrostatic, i.e., 9.81 MPa/km, and the model was assumed to be saturated with water. The hydraulic boundaries were pressure boundaries selected such that the fluid pressure in the entire model remains hydrostatic. The hydraulic pressure along the top and bottom boundaries was 0 and 11.772 MPa (at 1200 m depth), respectively. Hydraulic pressure along left and right boundaries increases linearly downward. The *in situ* stresses are the total stresses that include vertical stress caused by gravity, horizontal stress related to vertical stress by an assumed Poisson's ratio given in Table 1, and hydrostatic fluid pressure caused by the weight of pore water. For modeling, it was assumed that intact rock blocks were impermeable and bounded by permeable joints.

Intact rock blocks were modeled as a linear elastic material. Rock joints were modeled according to Mohr-Columbous failure criterion. Mechanical and hydrologic properties were selected to represent the host rock of the proposed repository at YM, the Topopah Spring welded tuff, based on a number of sources as summarized in Ahola et al. (1996). Those properties are also given in Table 1. Figure 2-2 shows the uniform distribution of joint aperture before fault slip.

2.3. Modeling Approach

Modeling initiated with a static analysis to achieve steady-state, *in situ* mechanical and hydraulic conditions. The initial analysis was followed by 1 m displacement of the three fault zones in pre-defined sequences. Fault slip was simulated by applying shear displacement directly to the entire fault zone, which was achieved by applying a velocity parallel to the fault zone to grid points along the fault zone and using the FISH functions available in UDEC vision 3.00 (Itasca Consulting Group, Inc., 1996) to fix velocity over a certain length of time (0.5 s in this case) that would accumulate the desired total shear displacement (1 m in this case) along the fault zone in a stable fashion. The direction of the velocity applied to grid points was upward parallel to the fault zone in the hangingwall, and downward parallel to the fault zone at grid points in the footwall. After each fault slip, the model response was monitored until a new equilibrium was reached before simulating the next fault slip to allow full recovery of stresses and deformation. Joint aperture changes due to each fault slip were then examined and corresponding changes in porosity were estimated.

In UDEC, a rock joint is represented numerically as a contact surface formed between two block edges. A contact surface between two deformable blocks is composed of individual point contacts, each with a definite contact length to form a domain. Joint hydraulic aperture, a, at a specific contact is given, in general, by:

$$a = a_0 + u_n \quad (1)$$

where a_0 is joint aperture at zero normal effective stress, and u_n is the joint normal displacement. For the current study, a residual aperture is assumed below which mechanical closure does not affect the contact permeability (see Table 1). The upper bound of the hydraulic aperture is identical to the mechanical aperture.

The average percentage porosity, ϕ, in a specific area of interest, S, was approximately estimated as:

$$\phi = \frac{\sum_{i=1}^{n} (a_i \times l_i)}{S} \times 100\% \quad (2)$$

where a_i and l_i are hydraulic aperture and domain length at contact i, n is the total number of contacts at the time ϕ is estimated within a specific area S.

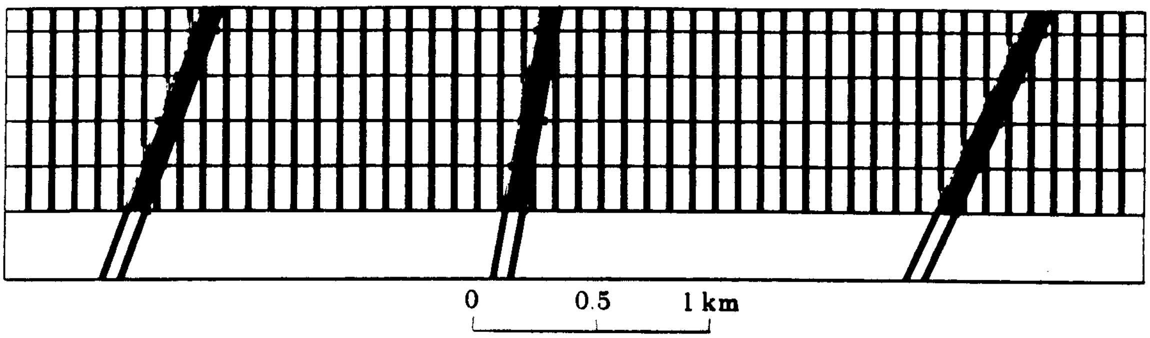


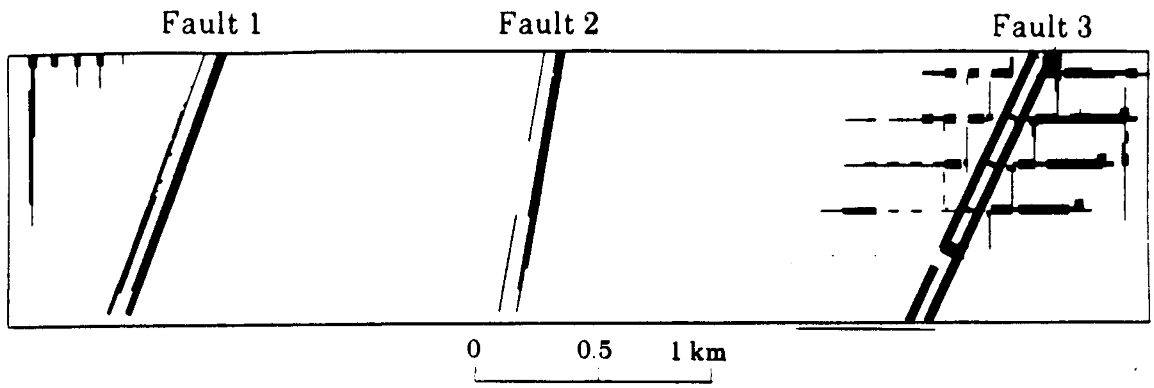
Figure 2-2: Uniform distribution of joint aperture before fault slip. The initial joint aperture is 0.001 m for vertical joints and 0.0005 m for horizontal joints.

2.4. Description of Modeling Results

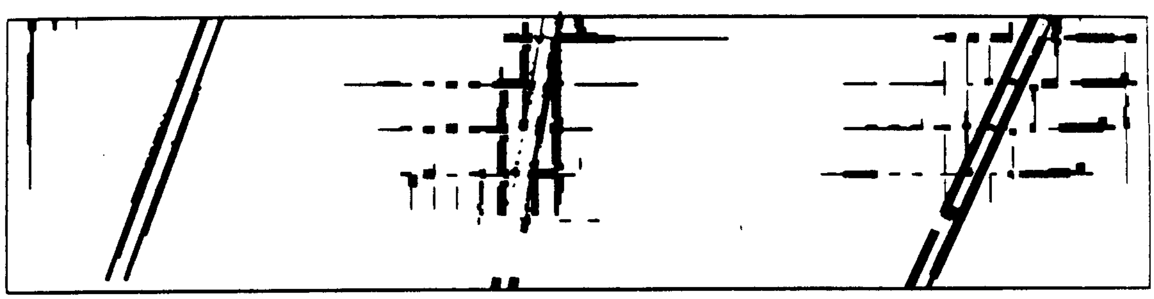
The two most significant modeling results that directly affect hydraulic conductivity of the rock mass are joint dilation and subsequent changes in joint permeability. Other factors, such as joint connectivity, joint shear displacement, and changes in stress state near the activated fault zones, may also affect rock mass hydraulic properties. However, evaluation of these effects is rather complicated and involves sophisticated estimation of a permeability tensor for a jointed rock mass (Zhang et al., 1996), which is beyond the scope of the current paper.

Joint Aperture

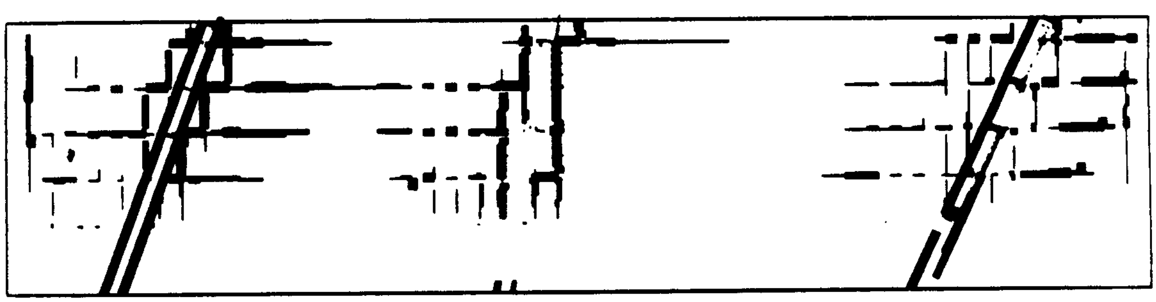
The most significant disturbance to a jointed rock mass from normal faulting is joint dilation, reflected by changes in joint aperture. Figures 2-3a through 2-3c show the distribution of joint aperture after each fault slip in the sequence of 3-2-1. In these figures, the thickness of the solid lines is proportional to the magnitude of the joint aperture. Joint apertures greater than 0.01 m or less than 0.002 m are not included for clarity. These figures show that slip on each fault zone creates a disturbed zone along the activated fault. Joint aperture increases along both horizontal and vertical joints within the disturbed zone. The width of the disturbed zone appears to be controlled by the dip angle of the activated fault. Higher angle fault (Fault 2) generates narrower disturbed zones, while lower angle fault (Fault 1) generates wider disturbed zones. The dip angle of the activated fault also appears to control the orientation of joint dilation. Greater dilation occurs along vertical joints following slip along higher angle faults, while greater dilation occurs along horizontal joints following slip along lower angle faults.



(a) After slip on Fault 3 only



(b) Slip on Fault 2 after slip on Fault 3



(c) Slip on Fault 1 after slip on Faults 2 and 3

Figure 2-3: Distribution of joint aperture after fault slip. Each line represents 0.002 m aperture. The thickest part of the line group has five lines. Apertures greater than 0.01 m and less than 0.002 m are not included for clarity. The white area, therefore, has joint aperture less than 0.002 m.

In general, dilation along vertical joints occurs in the immediate neighborhood of the activated fault, while dilation along horizontal joints extends to a considerable distance ($\approx$600 m) away from the activated fault zone. This joint structural characteristic within the disturbed zone greatly increases the potential for fluid flow along the fault zone. Particularly, dilation along horizontal-subhorizontal joints creates pathways that could lead water bodies perched in the fault blocks to flow to the opened vertical joints and the fault zone, and to drain downward along these channels. In Block 2, the disturbed zones from combined slip events along Faults 1 and 2 are almost interconnected.

Another phenomenon that may have significance to the performance of the proposed YM repository is that slip on Fault 3 induces both normal and shear displacements along Faults 1 and 2. These secondary normal displacements are demonstrated by increased aperture along Faults 1 and 2 after slip on Fault 3 (Figure 3-3a). Similar secondary shear displacement can be observed from plots of joint shear displacement after each fault slip event. Fault 2 represents the Ghost Dance fault that extends through the proposed repository area. These results suggest that a slip event on another fault zone in YM region could trigger secondary slip on the Ghost Dance fault. Secondary rupture on faults within the repository block is an important consideration for performance analyses of the mechanical effects on waste package integrity and drift stability due to faulting and seismicity.

Rock Mass Porosity

Initial porosity and porosity after each fault slip event were calculated for each of the four fault blocks, for all fault blocks combined, and for the entire model. Porosity change within the activated fault could not be correctly simulated because displacement along the fault is prescribed. Figure 2-4 compares the initial average rock mass porosity with porosity after a single fault slip event on each of the three faults. The comparison is made for porosity in Block 2, Block 3, the average porosity of all of the fault blocks, and the average porosity of the entire model. Blocks 2 and 3 are of particular interest because they correspond to regions within the proposed repository at YM. The numbers above the columns indicate percentage changes in the average porosity with respect to the initial porosity. Slip on Fault 1 caused about 174 percent increase of porosity in Block 2, 137 percent increase in the average porosity in all blocks, and 114 percent increase in the average porosity of the entire model. Slip on Fault 1 had very little effect in Block 3. Slip on Fault 2 caused similar porosity changes (about 190 percent) in Blocks 2 and 3, 123 percent increase in the average porosity of all fault blocks, and about 70 percent increase in the entire model. Slip on Fault 3 had little effect on Block 2. It caused 272 percent porosity increase in Block 3, 150 percent increase in the average porosity of all fault blocks, and about 130 percent increase in the entire model. As Figure 2-3 shows, over 95 percent of changes in porosity associated with each fault slip event occur within the disturbed zone along the activated fault.

Table 2 compares percentage changes in rock mass average porosity due to the combined effect of slip events on all three faults in different sequences. In general, the slip sequence does not significantly affect total changes in porosity. However, porosity change in Block 3 is much less when the fault slip sequence is 3-2-1. It appears that some of the joints that opened up during slip on Fault 3 were closed after slip on Fault 2.

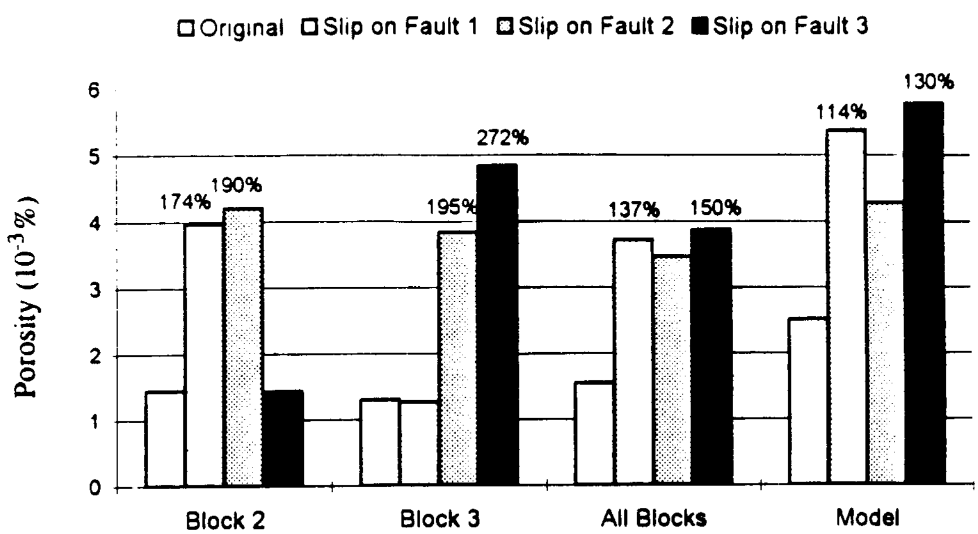


Figure 2-4: Comparison of the initial average rock mass porosity with porosity after a single fault slip

Table 2-1. Porosity changes (percentage increase) due to combined effects of fault slip along all three faults in different sequences

Slip Sequence	Block 2	Block 3	All Blocks	Entire Model
1-2-3	250	587	367	261
2-1-3	293	594	396	287
3-2-1	257	360	337	213

2.5. Summary

Current modeling results show that fault slip can increase joint aperture and rock mass porosity. Rupture along the entire fault zone creates a disturbed zone along the activated fault zone and significant joint dilation occurs in the disturbed zone. Both the distribution and direction of joint dilation are strongly influenced by the dip angle of the ruptured fault. Rupture along higher angle faults produces narrower disturbed zones and greater dilation along vertical (subvertical) joints; rupture along lower angle faults produces wider disturbed zones and greater dilation along horizontal (subhorizontal) joints.

Fault slip appears to increase the average rock mass porosity by two orders of magnitude in terms of percentage change due to a 1 meter rupture along an individual fault zone. At least 95 percent of these increases in porosity occur in the disturbed zone along the ruptured fault. Such significant increases in rock mass porosity would certainly affect permeability and, hence, flow of ground water. The disturbed zone along the activated fault could create preferential faster pathways for infiltration of surface water. In addition, slip events could trigger secondary faulting thereby affecting the mechanical integrity of waste package and drift stability.

Changes in porosity associated with each fault slip analyzed in the current study do not reflect porosity changes that may occur in geologic time between successive fault slip events. The calculations only address the potential for change immediately following an earthquake produced by normal faulting. Other processes that could reduce porosity over time, such as fracture filling and other geochemical processes or the compressive effects of *in situ* stress, are not considered.

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APPENDIX A

Inut Data Files for UDEC Calculation
YM7.DAT
YM12.DAT
YM13.DAT

YM7.DAT

```
*************************************************************************************
* This input file is for coupled steady-state flow and mechanical analyses to
* study the effect of various fault slip scenarios on aperture and permeability
* change of jointed rock mass near the reposity site. The model includes
* three major fault zones in the reposity area: Ghost Dance, Bow Ridge, and
* Solitario Canyon. The study was intrigued by Zhang,X and D.J. Sanderson.
* 1996. Numerical modelling of the effects of fault slip on fluid flow around
* extensional faults. J. of Structural Geology. 18:109-119.
*
* Modeling sequences include:
* - initial mechanical equilibrium under total stress (true in situ stress
*   plus the assumed water load (YM7_0.SAV)
* - coupled steady-state flow and mechanical analysis to steady-state under
*   hydrostatic load applied to vertical boundaries, fix on top and bottom
*   boundaries, and using 'in situ pp' (YM7_1.SAV)
* - Bow Ridge fault slip of 1 m over 1 second (YM7_BR1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Bow Ridge fault zone (YM7_BR2.SAV)
* - Ghost Dance fault slip of 1 m over 1 second (YM7_GD1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Ghost Dance fault zone (YM7_GD2.SAV)
* - Solitario Canyon fault slip of 1 m over 1 second (YM7_SC1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Solitario Canyon fault zone (YM7_3.SAV)
*
* July 25, 1996
*************************************************************************************
*
set log ym7.log
set plot po
start
******************************
* Title and block definition
******************************
head
YM Repository Fault Model/YM7.DAT
*
round 0.1
set ovtol 0.15                          * contact overlap tolerance
block 0.0 -1200.0 0.0 0.0 5000.0 0.0 5000.0 -1200.0
split 0.0 -900.0 5000.0 -900.0
split 936.76 0.0 500.0 -1200.0
split 856.95 0.0 529.38 -900.0
split 2416.59 0.0 2205.0 -1200.0
split 2340.43 0.0 2181.74 -900.0
split 4585.66 0.0 4026.09 -1200.0
split 4502.91 0.0 4083.23 -900.0
```

```
*
****************
* create joints
****************
* -----------------------------------------------
* hanging-wall joint of the Solitario Canyon Fault
* -----------------------------------------------
jregion 0.0 -900.0 0.0 0.0 856.95 0.0 529.38 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 0 -900.0
*
* ------------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* ------------------------------------------------------------
jregion 609.19 -900.0 936.76 0.0 2340.43 0.0 2181.74 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 659.19 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 659.19 -900.0
*
* ----------------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* ----------------------------------------------------
jregion 2257.9 -900.0 2416.59 0.0 4502.91 0.0 4083.23 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 2200.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 2200.0 -900.0
*
* ----------------------------
* footwall of Bow Ridge Fault
* ----------------------------
jregion 4165.98 -900.0 4585.66 0.0 5000.0 0.0 5000.0 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 5000.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 5000.0 -900.0
*
*-----------------------------
* Solitario Canyon Fault Zone
* ----------------------------
jregion 529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0
jset  70.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
jset 160.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
*
* ------------------------
* Ghost Dance Fault zone
* ------------------------
jregion 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0
jset  80.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
jset 170.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
*
* ---------------------
* Bow Ridge Fault zone
```

```
* --------------------
jregion 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0
jset  65.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
jset 155.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
*
* ----------------------------------------------------
* delete joints which do not completely intersect a block
* ----------------------------------------------------
jd
*

del area 2.0e-2
****************************
*
***************************
* auto generation of zones
***************************
*
* -------------------------
* fault zone discretization
* -------------------------
gen region  529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0 edge 50
gen region 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0 edge 50
gen region 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0 edge 50
*
* -------------------------------------
* hanging-wall joint of Solitario Canyon
* -------------------------------------
gen region 379.38 -900.0 706.95 0.0 856.95 0.0 529.38 -900.0 edge 75
gen region 0.0 -900.0 0.0 0.0 706.95 0.0 379.38 -900.0 quad 150
*
* ---------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* ---------------------------------------------------------
gen region 609.19 -900.0 936.76 0.0 1086.76 0.0 759.19 -900.0 edge 75
gen region 759.19 -900.0 1086.76 0.0 2190.43 0.0 2031.74 -900.0 quad 150
gen region 2031.74 -900.0 2190.43 0.0 2340.43 0.0 2181.74 -900.0 edge 75
*
* ------------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* ------------------------------------------------
gen region 2257.9 -900.0 2416.59 0.0 2566.59 0.0 2407.9 -900.0 edge 75
gen region 2407.9 -900.0 2566.59 0.0 4352.91 0.0 3933.23 -900.0 quad 150
gen region 3933.23 -900.0 4352.91 0.0 4502.91 0.0 4083.23 -900.0 edge 75
*
* --------------------
* footwall of Bow Ridge
* --------------------
```

```
gen region 4165.98 -900.0 4585.66 0.0 4735.66 0.0 4315.98 -900.0 edge 75
gen region 4315.98 -900.0 4735.66 0.0 5000.0 0.0 5000.0 -900.0 quad 150
*
* ------------------------
* base rock discretization
* ------------------------
gen region 0.0 -1200.0 0.0 -900.0 609.19 -900.0 500.0 -1200.0 quad 150
gen region 500.0 -1200.0 609.19 -900.0 2257.9 -900.0 2205.0 -1200.0 quad 150
gen region 2205.0 -1200.0 2257.9 -900.0 4165.98 -900.0 4026.09 -1200.0 quad 150
gen region 4026.09 -1200.0 4165.98 -900.0 5000.0 -900.0 5000.0 -1200.0 quad 150
*
pr max
*
*****************************************************************************
* specify in situ stress and boundary conditions:
* - in situ stresses are the total stress, i.e., true in situ stress due to
*   the dead-weight of the overburden plus water
* - vertical boundaries are stress boundaries with the horizontal equal to
*   the in situ horizontal stress conponent and the vertical stress is zero.
*****************************************************************************
grav 0.0 -9.81
insitu stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0323 szz 0.0 &
     zgrad 0.0 0.01578
bound cor 37 50 stress 0.0 0.0 0.0                        * top
bound cor 24 37 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0       * left
bound cor 50 63 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0       * right
bound cor 63 24 yvel=0.0 xfree                            * bottom
*
*
**********************************************
* joint and intact block mechanical properties
**********************************************
*
* ------------------------
* block elastic properties
* ------------------------
prop mat=1 k=18.39e3 g=13.22e3 d=0.002297
*
* ------------------------------------
* block mohr-coulomb failure properties
* ------------------------------------
prop mat=1 coh=18.0 fric=20.0 tens=5.0 dil=0.0
*
* ----------------------------------------------
* vertical-subvertical joint mechanical properties
* ----------------------------------------------
* prop jmat=1 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
```

```
prop jmat=1 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0.0 &
   kn=24.3e3 ks=13.46e3
*
* ----------------------------------------
* horizontal-subhorizontal joint mechanical
* ----------------------------------------
* prop jmat=2 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
prop jmat=2 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0 &
   jn=24.3e3 ks=13.46e3
*
* ---------------------------------------------------------------
* fault zone joint mechanical properties reduce friction angle and
* apply zero cohesion to induce more shear displacement
* ---------------------------------------------------------------
* prop jmat=3 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0 jfric=5.0 jtens=0 &
*     jn=1.0e5 ks=1.0e5
prop jmat=3 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=5.0 jtens=0 &
   jn=24.3e3 ks=13.46e3
*
* ------------------------------------------------------------------------
* mechanical properties for the interface between basement and the fractured
* block to insure the continueous downward movement of the whole hanging-wall
* during fault slip by "grouting" the interface
* ------------------------------------------------------------------------
* prop jmat=4 jks=1.0e5 jkn=1.0e5 jdil=0 jc=1e10 jfric=1e10 jtens=1e10 &
*     jn=1.0e5 ks=1.0e5
prop jmat=4 jks=13.46e3 jkn=24.3e3 jdil=5 jc=1e10 jfric=1e10 jtens=1e10 &
   jn=24.3e3 ks=13.46e3
*
* set jcondf 5
change 0.0 5000.0 -1200.0 0.0 mat 1
change angle 80 120 jmat=1
change angle -40 40 jmat=2
*
* ------------------
* grouting interface
* ------------------
change 0 5000 -90.5 -89.5 jmat=4
*
* -----------
* fault zones
* -----------
* change region 419.69 -1200.0 856.45 0.0 937.26 0.0 500.5 -1200.0  jmat=3
* change region 2128.34 -1200.0 2339.93 0.0 2417.09 0.0 2205.5 -1200.0 jmat=3
* change region 3942.84 -1200.0 4502.41 0.0 2586.16 0.0 4026.59 -1200.0 jmat=3
*
*******************************************
```

```
* history for initial mechanical analyses
*******************************************
his ncyc=10 unbal             * #1
his damp                     * #2
his ydis 500.0 -1200.0        * #3, bottom of Solitario Canyon
his ydis 2205.0 -1200.0              * #4, bottom of Ghost Dance
his ydis 4026.09 -1200.0      * #5, bottom of Bow Ridge
his ydis 0.0 -1200.0          * #6, left bottom corner
his xdis 0.0 -1200.0          * #7, left bottom corner
his ydis 5000.0 -1200.0       * #8, right bottom corner
his xdis 5000.0 -1200.0       * #9, right bottom corner
*
* ----------------------------------------
* dilation (normal displacement of fractures
* ----------------------------------------
his ndis 107567               * #10, vertical middle of Ghost Dance
his ndis 98003                * #11, vertical top of Ghost Dance
his ndis 123507               * #12, vertical bottom of Ghost Dance
his ndis 224221               * #13, hanging-wall of Ghost Dance
his ndis 231452               * #14, footwall of Ghost Dance
his ndis 77594                * #15, middle of Solitario Canyon
his ndis 187851               * #16, hanging-wall of Solitario Canyon
his ndis 202538               * #17, footwall of Solitario Canyon
his ndis 138478               * #18, Bow Ridge
his ndis 259987               * #19, hanging-wall of Bow Ridge
his ndis 266019               * #20, footwall of Bow Ridge
* ---------------------
* slip along fractures
* ---------------------
his sdis 107567               * #21, vertical middle of Ghost Dance
his sdis 98003                * #22, vertical top of Ghost Dance
his sdis 123507               * #23, vertical bottom of Ghost Dance
his sdis 224221               * #24, hanging-wall of Ghost Dance
his sdis 231452               * #25, footwall of Ghost Dance
his sdis 77594                * #26, middle of Solitario Canyon
his sdis 187851               * #27, hanging-wall of Solitario Canyon
his sdis 202538               * #28, footwall of Solitario Canyon
his sdis 138478               * #29, Bow Ridge
his sdis 259987               * #30, hanging-wall of Bow Ridge
his sdis 266019               * #31, footwall of Bow Ridge
* ---------------------
* shear stress on joints
* ---------------------
his sstr 107567               * #32, vertical middle of Ghost Dance
his sstr 98003                * #33, vertical top of Ghost Dance
his sstr 123507               * #34, vertical bottom of Ghost Dance
his sstr 224221               * #35, hanging-wall of Ghost Dance
his sstr 231452               * #36, footwall of Ghost Dance
```

```
his sstr 77594            * #37, middle of Solitario Canyon
his sstr 187851           * #38, hanging-wall of Solitario Canyon
his sstr 202538           * #39, footwall of Solitario Canyon
his sstr 138478           * #40, Bow Ridge
his sstr 259987           * #41, hanging-wall of Bow Ridge
his sstr 266019           * #42, footwall of Bow Ridge
* -----------------------
* normal stress on joints
* -----------------------
his nstr 107567           * #43, vertical middle of Ghost Dance
his nstr 98003            * #44, vertical top of Ghost Dance
his nstr 123507           * #45, vertical bottom of Ghost Dance
his nstr 224221           * #46, hanging-wall of Ghost Dance
his nstr 231452           * #47, footwall of Ghost Dance
his nstr 77594            * #48, middle of Solitario Canyon
his nstr 187851           * #49, hanging-wall of Solitario Canyon
his nstr 202538           * #50, footwall of Solitario Canyon
his nstr 138478           * #51, Bow Ridge
his nstr 259987           * #52, hanging-wall of Bow Ridge
his nstr 266019           * #53, footwall of Bow Ridge
**********************************************
* initial mechanical cycles before hydro
**********************************************
damp auto
set delc off
cycle t=5.0
save ym7_0.sav
*
**************************************************
* set parameters for steady-state flow analyses
**************************************************
set capratio 50
set flow steady
set flow on
reset dis jdis
*
* ----------------
* fluid properties
* ----------------
fluid dens=0.001 bulk=3.0e3
*
*
**********************************************
* joint flow properties and fluid properties
**********************************************
prop jmat=1 ares=0.0002 azero=0.001 jperm=2.38e8
prop jmat=2 ares=0.0001 azero=0.0005 jperm=2.38e8
prop jmat=3 ares=0.0002 azero=0.001 jperm=2.38e8
```

```
prop jmat=4 ares=0.0001 azero=0.0005 jperm=2.38e8
*
*****************************
* apply hydrostatic pressure
*****************************
insitu pp=0.0 pygrad=-0.0098
bound cor 37 50 pp=0.0                          * top
bound cor 63 24 pp=11.76                        * bottom
bound cor 24 37 pp=0.0 pygrad=-0.0098           * left
bound cor 50 63 pp=0.0 pygrad=-0.0098           * right
*
his flowtime                   * #54
*
* -----------------------
* pore pressure on joints
* -----------------------
his pp 2257.9 -900.0           * #55
his pp 2000.0 -350.0           * #56
*
*****************************************
* begin flow calculation to steady-state
*****************************************
* set dtflow 1
set maxmech 500
reset damp
cycle t=15
sav ym7_1.sav
*
***************************************
* Bow Ridge fault displacement analyses
***************************************
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 xfree yfree
bound cor 1782 24 yvel=-0.9063 xvel=-0.4226
bound his linear
reset damp
cycle t=1
save ym7_br1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 8 second
*
bound cor 1782 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 yvel=0.0 xfree
```

```
reset damp
cycle t=15
save ym7_br2.sav
*
****************************************
* Ghost Dance fault displacement analyses
****************************************
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 xfree yfree
bound cor 920 24 yvel=-0.9848 xvel=-0.1736
bound his linear
reset damp
cycle t=1
save ym7_gd1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 8 second
*
bound cor 920 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 yvel=0.0 xfree
reset damp
cycle t=15
save ym7_gd2.sav
*
***********************************************
* Solitario Canyon fault displacement analyses
***********************************************
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 xfree yfree
bound cor 532 24 yvel=-0.9397 xvel=-0.3420
bound his linear
reset damp
cycle t=1
save ym7_sc1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 1 second
*
bound cor 532 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 yvel=0.0 xfree
```

reset damp
cycle t=15
save ym7_sc2.sav
return

```
YM12.DAT
***************************************************************************************
* This input file is for coupled steady-state flow and mechanical analyses to
* study the effect of various fault slip scenarios on aperture and permeability
* change of jointed rock mass near the reposity site. The model includes
* three major fault zones in the reposity area: Ghost Dance, Bow Ridge, and
* Solitario Canyon. The study was intrigued by Zhang,X and D.J. Sanderson.
* 1996. Numerical modelling of the effects of fault slip on fluid flow around
* extensional faults. J. of Structural Geology. 18:109-119.
*
* Modeling sequences include:
* - initial mechanical equilibrium under total stress (true in situ stress
*   plus the assumed water load (YM7_0.SAV)
* - coupled steady-state flow and mechanical analysis to steady-state under
*   hydrostatic load applied to vertical boundaries, fix on top and bottom
*   boundaries, and using 'in situ pp' (YM7_1.SAV)
* - Bow Ridge fault slip of 1 m over 1 second (YM7_BR1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Bow Ridge fault zone (YM7_BR2.SAV)
* - Ghost Dance fault slip of 1 m over 1 second (YM7_GD1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Ghost Dance fault zone (YM7_GD2.SAV)
* - Solitario Canyon fault slip of 1 m over 1 second (YM7_SC1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Solitario Canyon fault zone (YM7_3.SAV)
*
* July 25, 1996
***************************************************************************************
*
set log yml2.log
set plot po
start
******************************
* Title and block definition
******************************
head
YM Repository Fault Model/YM12.DAT
*
round 0.1
set ovtol 0.15                        * contact overlap tolerance
block 0.0 -1200.0 0.0 0.0 5000.0 0.0 5000.0 -1200.0
split 0.0 -900.0 5000.0 -900.0
split 936.76 0.0 500.0 -1200.0
split 856.95 0.0 529.38 -900.0
split 2416.59 0.0 2205.0 -1200.0
split 2340.43 0.0 2181.74 -900.0
split 4585.66 0.0 4026.09 -1200.0
split 4502.91 0.0 4083.23 -900.0
```

```
****************
* create joints
****************
* ---------------------------------------------
* hanging-wall joint of the Solitario Canyon Fault
* ---------------------------------------------
jregion 0.0 -900.0 0.0 0.0 856.95 0.0 529.38 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 0 -900.0
*
* ---------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* ---------------------------------------------------------
jregion 609.19 -900.0 936.76 0.0 2340.43 0.0 2181.74 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 659.19 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 659.19 -900.0
*
* -----------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* -----------------------------------------------
jregion 2257.9 -900.0 2416.59 0.0 4502.91 0.0 4083.23 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 2200.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 2200.0 -900.0
*
* -------------------------
* footwall of Bow Ridge Fault
* -------------------------
jregion 4165.98 -900.0 4585.66 0.0 5000.0 0.0 5000.0 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 5000.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 5000.0 -900.0
*
*--------------------------
* Solitario Canyon Fault Zone
* -------------------------
jregion 529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0
jset  70.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
jset 160.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
*
* ---------------------
* Ghost Dance Fault zone
* ---------------------
jregion 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0
jset  80.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
jset 170.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
*
* ------------------
* Bow Ridge Fault zone
* ------------------
```

```
jregion 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0
jset  65.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
jset 155.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
*
* ------------------------------------------------------
* delete joints which do not completely intersect a block
* ------------------------------------------------------
jd
*

del area 2.0e-2
****************************
*
***************************
* auto generation of zones
***************************
*
* -------------------------
* fault zone discretization
* -------------------------
gen region  529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0 edge 50
gen region 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0 edge 50
gen region 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0 edge 50
*
* -------------------------------------
* hanging-wall joint of Solitario Canyon
* -------------------------------------
gen region 379.38 -900.0 706.95 0.0 856.95 0.0 529.38 -900.0 edge 75
gen region 0.0 -900.0 0.0 0.0 706.95 0.0 379.38 -900.0 quad 150
*
* ------------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* ------------------------------------------------------------
gen region 609.19 -900.0 936.76 0.0 1086.76 0.0 759.19 -900.0 edge 75
gen region 759.19 -900.0 1086.76 0.0 2190.43 0.0 2031.74 -900.0 quad 150
gen region 2031.74 -900.0 2190.43 0.0 2340.43 0.0 2181.74 -900.0 edge 75
*
* ----------------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* ----------------------------------------------------
gen region 2257.9 -900.0 2416.59 0.0 2566.59 0.0 2407.9 -900.0 edge 75
gen region 2407.9 -900.0 2566.59 0.0 4352.91 0.0 3933.23 -900.0 quad 150
gen region 3933.23 -900.0 4352.91 0.0 4502.91 0.0 4083.23 -900.0 edge 75
*
* ---------------------
* footwall of Bow Ridge
* ---------------------
gen region 4165.98 -900.0 4585.66 0.0 4735.66 0.0 4315.98 -900.0 edge 75
```

```
gen region 4315.98 -900.0 4735.66 0.0 5000.0 0.0 5000.0 -900.0 quad 150
*
* ------------------------
* base rock discretization
* ------------------------
gen region 0.0 -1200.0 0.0 -900.0 609.19 -900.0 500.0 -1200.0 quad 150
gen region 500.0 -1200.0 609.19 -900.0 2257.9 -900.0 2205.0 -1200.0 quad 150
gen region 2205.0 -1200.0 2257.9 -900.0 4165.98 -900.0 4026.09 -1200.0 quad 150
gen region 4026.09 -1200.0 4165.98 -900.0 5000.0 -900.0 5000.0 -1200.0 quad 150
*
pr max
*
*****************************************************************************
* specify in situ stress and boundary conditions:
* - in situ stresses are the total stress, i.e., true in situ stress due to
*   the dead-weight of the overburden plus water
* - vertical boundaries are stress boundaries with the horizontal equal to
*   the in situ horizontal stress conponent and the vertical stress is zero.
*****************************************************************************
grav 0.0 -9.81
insitu stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0323 szz 0.0 &
      zgrad 0.0 0.01578
bound cor 37 50 stress 0.0 0.0 0.0                          * top
bound cor 24 37 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0      * left
bound cor 50 63 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0      * right
bound cor 63 24 yvel=0.0 xfree                               * bottom
*
*
**********************************************
* joint and intact block mechanical properties
**********************************************
*
* ------------------------
* block elastic properties
* ------------------------
prop mat=1 k=18.39e3 g=13.22e3 d=0.002297
*
* ------------------------------------
* block mohr-coulomb failure properties
* ------------------------------------
prop mat=1 coh=18.0 fric=20.0 tens=5.0 dil=0.0
*
* -----------------------------------------------
* vertical-subvertical joint mechanical properties
* -----------------------------------------------
* prop jmat=1 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
prop jmat=1 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0.0 &
```

```
   kn=24.3e3 ks=13.46e3
*
* ------------------------------------------
* horizontal-subhorizontal joint mechanical
* ------------------------------------------
* prop jmat=2 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
prop jmat=2 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0 &
   jn=24.3e3 ks=13.46e3
*
* ---------------------------------------------------------------
* fault zone joint mechanical properties reduce friction angle and
* apply zero cohesion to induce more shear displacement
* ---------------------------------------------------------------
* prop jmat=3 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0 jfric=5.0 jtens=0 &
*     jn=1.0e5 ks=1.0e5
prop jmat=3 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=5.0 jtens=0 &
   jn=24.3e3 ks=13.46e3
*
* ------------------------------------------------------------------------
* mechanical properties for the interface between basement and the fractured
* block to insure the continueous downward movement of the whole hanging-wall
* during fault slip by "grouting" the interface
* ------------------------------------------------------------------------
* prop jmat=4 jks=1.0e5 jkn=1.0e5 jdil=0 jc=1e10 jfric=1e10 jtens=1e10 &
*     jn=1.0e5 ks=1.0e5
prop jmat=4 jks=13.46e3 jkn=24.3e3 jdil=5 jc=1e10 jfric=1e10 jtens=1e10 &
   jn=24.3e3 ks=13.46e3
*
* set jcondf 5
change 0.0 5000.0 -1200.0 0.0 mat 1
change angle 80 120 jmat=1
change angle -40 40 jmat=2
*
* ------------------
* grouting interface
* ------------------
change 0 5000 -90.5 -89.5 jmat=4
*
* -----------
* fault zones
* -----------
* change region 419.69 -1200.0 856.45 0.0 937.26 0.0 500.5 -1200.0  jmat=3
* change region 2128.34 -1200.0 2339.93 0.0 2417.09 0.0 2205.5 -1200.0 jmat=3
* change region 3942.84 -1200.0 4502.41 0.0 2586.16 0.0 4026.59 -1200.0 jmat=3
*
******************************************
* history for initial mechanical analyses
```

```
******************************************
his ncyc=10 unbal          * #1
his damp                   * #2
his ydis 500.0 -1200.0     * #3, bottom of Solitario Canyon
his ydis 2205.0 -1200.0    * #4, bottom of Ghost Dance
his ydis 4026.09 -1200.0   * #5, bottom of Bow Ridge
his ydis 0.0 -1200.0       * #6, left bottom corner
his xdis 0.0 -1200.0       * #7, left bottom corner
his ydis 5000.0 -1200.0    * #8, right bottom corner
his xdis 5000.0 -1200.0    * #9, right bottom corner
*
* ----------------------------------------
* dilation (normal displacement of fractures
* ----------------------------------------
his ndis 107567            * #10, vertical middle of Ghost Dance
his ndis 98003             * #11, vertical top of Ghost Dance
his ndis 123507            * #12, vertical bottom of Ghost Dance
his ndis 224221            * #13, hanging-wall of Ghost Dance
his ndis 231452            * #14, footwall of Ghost Dance
his ndis 77594             * #15, middle of Solitario Canyon
his ndis 187851            * #16, hanging-wall of Solitario Canyon
his ndis 202538            * #17, footwall of Solitario Canyon
his ndis 138478            * #18, Bow Ridge
his ndis 259987            * #19, hanging-wall of Bow Ridge
his ndis 266019            * #20, footwall of Bow Ridge
* ---------------------
* slip along fractures
* ---------------------
his sdis 107567            * #21, vertical middle of Ghost Dance
his sdis 98003             * #22, vertical top of Ghost Dance
his sdis 123507            * #23, vertical bottom of Ghost Dance
his sdis 224221            * #24, hanging-wall of Ghost Dance
his sdis 231452            * #25, footwall of Ghost Dance
his sdis 77594             * #26, middle of Solitario Canyon
his sdis 187851            * #27, hanging-wall of Solitario Canyon
his sdis 202538            * #28, footwall of Solitario Canyon
his sdis 138478            * #29, Bow Ridge
his sdis 259987            * #30, hanging-wall of Bow Ridge
his sdis 266019            * #31, footwall of Bow Ridge
* ---------------------
* shear stress on joints
* ---------------------
his sstr 107567            * #32, vertical middle of Ghost Dance
his sstr 98003             * #33, vertical top of Ghost Dance
his sstr 123507            * #34, vertical bottom of Ghost Dance
his sstr 224221            * #35, hanging-wall of Ghost Dance
his sstr 231452            * #36, footwall of Ghost Dance
his sstr 77594             * #37, middle of Solitario Canyon
```

```
his sstr 187851          * #38, hanging-wall of Solitario Canyon
his sstr 202538          * #39, footwall of Solitario Canyon
his sstr 138478          * #40, Bow Ridge
his sstr 259987          * #41, hanging-wall of Bow Ridge
his sstr 266019          * #42, footwall of Bow Ridge
* -----------------------
* normal stress on joints
* -----------------------
his nstr 107567          * #43, vertical middle of Ghost Dance
his nstr 98003           * #44, vertical top of Ghost Dance
his nstr 123507          * #45, vertical bottom of Ghost Dance
his nstr 224221          * #46, hanging-wall of Ghost Dance
his nstr 231452          * #47, footwall of Ghost Dance
his nstr 77594           * #48, middle of Solitario Canyon
his nstr 187851          * #49, hanging-wall of Solitario Canyon
his nstr 202538          * #50, footwall of Solitario Canyon
his nstr 138478          * #51, Bow Ridge
his nstr 259987          * #52, hanging-wall of Bow Ridge
his nstr 266019          * #53, footwall of Bow Ridge
**********************************************
* initial mechanical cycles before hydro
**********************************************
damp auto
set delc off
cycle t=5.0
save ym12_0.sav
*
************************************************
* set parameters for steady-state flow analyses
************************************************
set capratio 50
set flow steady
set flow on
reset dis jdis
*
* ----------------
* fluid properties
* ----------------
fluid dens=0.001 bulk=3.0e3
*
*
**********************************************
* joint flow properties and fluid properties
**********************************************
prop jmat=1 ares=0.0002 azero=0.001 jperm=2.38e8
prop jmat=2 ares=0.0001 azero=0.0005 jperm=2.38e8
prop jmat=3 ares=0.0002 azero=0.001 jperm=2.38e8
prop jmat=4 ares=0.0001 azero=0.0005 jperm=2.38e8
```

```
*
*****************************
* apply hydrostatic pressure
*****************************
insitu pp=0.0 pygrad=-0.0098
bound cor 37 50 pp=0.0                          * top
bound cor 63 24 pp=11.76                         * bottom
bound cor 24 37 pp=0.0 pygrad=-0.0098              * left
bound cor 50 63 pp=0.0 pygrad=-0.0098              * right
*
his flowtime                    * #54
*
* -----------------------
* pore pressure on joints
* -----------------------
his pp 2257.9 -900.0              * #55
his pp 2000.0 -350.0              * #56
*
******************************************
* begin flow calculation to steady-state
******************************************
* set dtflow 1
set maxmech 500
reset damp
cycle t=15
sav ym12_1.sav
*
***********************************************
* Solitario Canyon fault displacement analyses
***********************************************
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 xfree yfree
bound cor 532 24 yvel=-0.9397 xvel=-0.3420
bound his linear
reset damp
cycle t=1
save ym12_sc1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 1 second
*
bound cor 532 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 yvel=0.0 xfree
reset damp
```

```
cycle t=15
save ym12_sc2.sav
*
*****************************************
* Ghost Dance fault displacement analyses
*****************************************
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 xfree yfree
bound cor 920 24 yvel=-0.9848 xvel=-0.1736
bound his linear
reset damp
cycle t=1
save ym12_gd1.sav
*
* terminating the application of displacement and observing
* the model behavior for an additional 8 second
*
bound cor 920 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 yvel=0.0 xfree
reset damp
cycle t=15
save ym12_gd2.sav
*
*****************************************
* Bow Ridge fault displacement analyses
*****************************************
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 xfree yfree
bound cor 1782 24 yvel=-0.9063 xvel=-0.4226
bound his linear
reset damp
cycle t=1
save ym12_br1.sav
*
* terminating the application of displacement and observing
* the model behavior for an additional 8 second
*
bound cor 1782 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 yvel=0.0 xfree
reset damp
```

```
cycle t=15
save ym12_br2.sav
*
return
```

```
YM13.DAT
************************************************************************************
* This input file is for coupled steady-state flow and mechanical analyses to
* study the effect of various fault slip scenarios on aperture and permeability
* change of jointed rock mass near the reposity site. The model includes
* three major fault zones in the reposity area: Ghost Dance, Bow Ridge, and
* Solitario Canyon. The study was intrigued by Zhang,X and D.J. Sanderson.
* 1996. Numerical modelling of the effects of fault slip on fluid flow around
* extensional faults. J. of Structural Geology. 18:109-119.
*
* Modeling sequences include:
* - initial mechanical equilibrium under total stress (true in situ stress
*   plus the assumed water load (YM7_0.SAV)
* - coupled steady-state flow and mechanical analysis to steady-state under
*   hydrostatic load applied to vertical boundaries, fix on top and bottom
*   boundaries, and using 'in situ pp' (YM7_1.SAV)
* - Bow Ridge fault slip of 1 m over 1 second (YM7_BR1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Bow Ridge fault zone (YM7_BR2.SAV)
* - Ghost Dance fault slip of 1 m over 1 second (YM7_GD1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Ghost Dance fault zone (YM7_GD2.SAV)
* - Solitario Canyon fault slip of 1 m over 1 second (YM7_SC1.SAV)
* - Monitoring for 15 seconds for the recovery of stress, dilation etc
*   after the slip of Solitario Canyon fault zone (YM7_3.SAV)
*
* July 25, 1996
************************************************************************************
*
set log ym13.log
set plot po
start
******************************
* Title and block definition
******************************
head
YM Repository Fault Model/YM13.DAT
*
round 0.1
set ovtol 0.15                          * contact overlap tolerance
block 0.0 -1200.0 0.0 0.0 5000.0 0.0 5000.0 -1200.0
split 0.0 -900.0 5000.0 -900.0
split 936.76 0.0 500.0 -1200.0
split 856.95 0.0 529.38 -900.0
split 2416.59 0.0 2205.0 -1200.0
split 2340.43 0.0 2181.74 -900.0
split 4585.66 0.0 4026.09 -1200.0
split 4502.91 0.0 4083.23 -900.0
```

```
****************
* create joints
****************
* ---------------------------------------------
* hanging-wall joint of the Solitario Canyon Fault
* ---------------------------------------------
jregion 0.0 -900.0 0.0 0.0 856.95 0.0 529.38 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 0 -900.0
*
* ---------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* ---------------------------------------------------------
jregion 609.19 -900.0 936.76 0.0 2340.43 0.0 2181.74 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 659.19 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 659.19 -900.0
*
* -------------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* -------------------------------------------------
jregion 2257.9 -900.0 2416.59 0.0 4502.91 0.0 4083.23 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 2200.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 2200.0 -900.0
*
* --------------------------
* footwall of Bow Ridge Fault
* --------------------------
jregion 4165.98 -900.0 4585.66 0.0 5000.0 0.0 5000.0 -900.0
jset 90.0 0.0 4000.0 0.0 0.0 0.0 100.0 0.0 5000.0 -900.0
jset  0.0 0.0 4000.0 0.0 0.0 0.0 200.0 0.0 5000.0 -900.0
*
*---------------------------
* Solitario Canyon Fault Zone
* --------------------------
jregion 529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0
jset  70.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
jset 160.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 529.38 -900.0
*
* ----------------------
* Ghost Dance Fault zone
* ----------------------
jregion 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0
jset  80.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
jset 170.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 2181.74 -900.0
*
* --------------------
* Bow Ridge Fault zone
* --------------------
```

```
jregion 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0
jset  65.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
jset 155.0 0.0 2000.0 0.0 0.0 0.0 25.0 0.0 4083.23 -900.0
*
* ------------------------------------------------------
* delete joints which do not completely intersect a block
* ------------------------------------------------------
jd
*

del area 2.0e-2
****************************
*
***************************
* auto generation of zones
***************************
*
* -------------------------
* fault zone discretization
* -------------------------
gen region  529.38 -900.0 856.95 0.0 936.76 0.0 609.19 -900.0 edge 50
gen region 2181.74 -900.0 2340.43 0.0 2416.59 0.0 2257.9 -900.0 edge 50
gen region 4083.23 -900.0 4502.91 0.0 4585.66 0.0 4165.98 -900.0 edge 50
*
* -------------------------------------
* hanging-wall joint of Solitario Canyon
* -------------------------------------
gen region 379.38 -900.0 706.95 0.0 856.95 0.0 529.38 -900.0 edge 75
gen region 0.0 -900.0 0.0 0.0 706.95 0.0 379.38 -900.0 quad 150
*
* -----------------------------------------------------------
* footwall of Solitario Canyon and hanging-wall of Ghost Dance
* -----------------------------------------------------------
gen region 609.19 -900.0 936.76 0.0 1086.76 0.0 759.19 -900.0 edge 75
gen region 759.19 -900.0 1086.76 0.0 2190.43 0.0 2031.74 -900.0 quad 150
gen region 2031.74 -900.0 2190.43 0.0 2340.43 0.0 2181.74 -900.0 edge 75
*
* ----------------------------------------------------
* footwall of Ghost Dance and hanging-wall of Bow Ridge
* ----------------------------------------------------
gen region 2257.9 -900.0 2416.59 0.0 2566.59 0.0 2407.9 -900.0 edge 75
gen region 2407.9 -900.0 2566.59 0.0 4352.91 0.0 3933.23 -900.0 quad 150
gen region 3933.23 -900.0 4352.91 0.0 4502.91 0.0 4083.23 -900.0 edge 75
*
* ---------------------
* footwall of Bow Ridge
* ---------------------
gen region 4165.98 -900.0 4585.66 0.0 4735.66 0.0 4315.98 -900.0 edge 75
```

```
gen region 4315.98 -900.0 4735.66 0.0 5000.0 0.0 5000.0 -900.0 quad 150
*
* ------------------------
* base rock discretization
* ------------------------
gen region 0.0 -1200.0 0.0 -900.0 609.19 -900.0 500.0 -1200.0 quad 150
gen region 500.0 -1200.0 609.19 -900.0 2257.9 -900.0 2205.0 -1200.0 quad 150
gen region 2205.0 -1200.0 2257.9 -900.0 4165.98 -900.0 4026.09 -1200.0 quad 150
gen region 4026.09 -1200.0 4165.98 -900.0 5000.0 -900.0 5000.0 -1200.0 quad 150
*
pr max
*
****************************************************************************
* specify in situ stress and boundary conditions:
* - in situ stresses are the total stress, i.e., true in situ stress due to
*   the dead-weight of the overburden plus water
* - vertical boundaries are stress boundaries with the horizontal equal to
*   the in situ horizontal stress conponent and the vertical stress is zero.
****************************************************************************
grav 0.0 -9.81
insitu stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0323 szz 0.0 &
      zgrad 0.0 0.01578
bound cor 37 50 stress 0.0 0.0 0.0                          * top
bound cor 24 37 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0        * left
bound cor 50 63 stress 0.0 0.0 0.0 ygrad 0.01578 0.0 0.0        * right
bound cor 63 24 yvel=0.0 xfree                              * bottom
*
*
**********************************************
* joint and intact block mechanical properties
**********************************************
*
* ------------------------
* block elastic properties
* ------------------------
prop mat=1 k=18.39e3 g=13.22e3 d=0.002297
*
* ------------------------------------
* block mohr-coulomb failure properties
* ------------------------------------
prop mat=1 coh=18.0 fric=20.0 tens=5.0 dil=0.0
*
* ----------------------------------------------
* vertical-subvertical joint mechanical properties
* ----------------------------------------------
* prop jmat=1 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
prop jmat=1 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0.0 &
```

```
    kn=24.3e3 ks=13.46e3
*
* ------------------------------------------
* horizontal-subhorizontal joint mechanical
* ------------------------------------------
* prop jmat=2 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0.08 jfric=28.0 jtens=0.04 &
*     kn=1.0e5 ks=1.0e5
prop jmat=2 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=35.0 jtens=0 &
    jn=24.3e3 ks=13.46e3
*
* ------------------------------------------------------------------
* fault zone joint mechanical properties reduce friction angle and
* apply zero cohesion to induce more shear displacement
* ------------------------------------------------------------------
* prop jmat=3 jks=1.0e5 jkn=1.0e5 jdil=0 jc=0 jfric=5.0 jtens=0 &
*     jn=1.0e5 ks=1.0e5
prop jmat=3 jks=13.46e3 jkn=24.3e3 jdil=5 jc=0 jfric=5.0 jtens=0 &
    jn=24.3e3 ks=13.46e3
*
* ----------------------------------------------------------------------------
* mechanical properties for the interface between basement and the fractured
* block to insure the continueous downward movement of the whole hanging-wall
* during fault slip by "grouting" the interface
* ----------------------------------------------------------------------------
* prop jmat=4 jks=1.0e5 jkn=1.0e5 jdil=0 jc=1e10 jfric=1e10 jtens=1e10 &
*     jn=1.0e5 ks=1.0e5
prop jmat=4 jks=13.46e3 jkn=24.3e3 jdil=5 jc=1e10 jfric=1e10 jtens=1e10 &
    jn=24.3e3 ks=13.46e3
*
* set jcondf 5
change 0.0 5000.0 -1200.0 0.0 mat 1
change angle 80 120 jmat=1
change angle -40 40 jmat=2
*
* -------------------
* grouting interface
* -------------------
change 0 5000 -90.5 -89.5 jmat=4
*
* ------------
* fault zones
* ------------
* change region 419.69 -1200.0 856.45 0.0 937.26 0.0 500.5 -1200.0  jmat=3
* change region 2128.34 -1200.0 2339.93 0.0 2417.09 0.0 2205.5 -1200.0 jmat=3
* change region 3942.84 -1200.0 4502.41 0.0 2586.16 0.0 4026.59 -1200.0 jmat=3
*
******************************************
* history for initial mechanical analyses
```

```
*****************************************
his ncyc=10 unbal        * #1
his damp                 * #2
his ydis 500.0 -1200.0        * #3, bottom of Solitario Canyon
his ydis 2205.0 -1200.0            * #4, bottom of Ghost Dance
his ydis 4026.09 -1200.0      * #5, bottom of Bow Ridge
his ydis 0.0 -1200.0          * #6, left bottom corner
his xdis 0.0 -1200.0          * #7, left bottom corner
his ydis 5000.0 -1200.0       * #8, right bottom corner
his xdis 5000.0 -1200.0       * #9, right bottom corner
*
* ----------------------------------------
* dilation (normal displacement of fractures
* ----------------------------------------
his ndis 107567          * #10, vertical middle of Ghost Dance
his ndis 98003           * #11, vertical top of Ghost Dance
his ndis 123507          * #12, vertical bottom of Ghost Dance
his ndis 224221          * #13, hanging-wall of Ghost Dance
his ndis 231452          * #14, footwall of Ghost Dance
his ndis 77594           * #15, middle of Solitario Canyon
his ndis 187851          * #16, hanging-wall of Solitario Canyon
his ndis 202538          * #17, footwall of Solitario Canyon
his ndis 138478          * #18, Bow Ridge
his ndis 259987          * #19, hanging-wall of Bow Ridge
his ndis 266019          * #20, footwall of Bow Ridge
* ---------------------
* slip along fractures
* ---------------------
his sdis 107567          * #21, vertical middle of Ghost Dance
his sdis 98003           * #22, vertical top of Ghost Dance
his sdis 123507          * #23, vertical bottom of Ghost Dance
his sdis 224221          * #24, hanging-wall of Ghost Dance
his sdis 231452          * #25, footwall of Ghost Dance
his sdis 77594           * #26, middle of Solitario Canyon
his sdis 187851          * #27, hanging-wall of Solitario Canyon
his sdis 202538          * #28, footwall of Solitario Canyon
his sdis 138478          * #29, Bow Ridge
his sdis 259987          * #30, hanging-wall of Bow Ridge
his sdis 266019          * #31, footwall of Bow Ridge
* ---------------------
* shear stress on joints
* ---------------------
his sstr 107567          * #32, vertical middle of Ghost Dance
his sstr 98003           * #33, vertical top of Ghost Dance
his sstr 123507          * #34, vertical bottom of Ghost Dance
his sstr 224221          * #35, hanging-wall of Ghost Dance
his sstr 231452          * #36, footwall of Ghost Dance
his sstr 77594           * #37, middle of Solitario Canyon
```

```
his sstr 187851            * #38, hanging-wall of Solitario Canyon
his sstr 202538            * #39, footwall of Solitario Canyon
his sstr 138478            * #40, Bow Ridge
his sstr 259987            * #41, hanging-wall of Bow Ridge
his sstr 266019            * #42, footwall of Bow Ridge
* ------------------------
* normal stress on joints
* ------------------------
his nstr 107567            * #43, vertical middle of Ghost Dance
his nstr 98003             * #44, vertical top of Ghost Dance
his nstr 123507            * #45, vertical bottom of Ghost Dance
his nstr 224221            * #46, hanging-wall of Ghost Dance
his nstr 231452            * #47, footwall of Ghost Dance
his nstr 77594             * #48, middle of Solitario Canyon
his nstr 187851            * #49, hanging-wall of Solitario Canyon
his nstr 202538            * #50, footwall of Solitario Canyon
his nstr 138478            * #51, Bow Ridge
his nstr 259987            * #52, hanging-wall of Bow Ridge
his nstr 266019            * #53, footwall of Bow Ridge
**********************************************
* initial mechanical cycles before hydro
**********************************************
damp auto
set delc off
cycle t=5.0
save ym13_0.sav
*
*************************************************
* set parameters for steady-state flow analyses
*************************************************
set capratio 50
set flow steady
set flow on
reset dis jdis
*
* -----------------
* fluid properties
* -----------------
fluid dens=0.001 bulk=3.0e3
*
*
**********************************************
* joint flow properties and fluid properties
**********************************************
prop jmat=1 ares=0.0002 azero=0.001 jperm=2.38e8
prop jmat=2 ares=0.0001 azero=0.0005 jperm=2.38e8
prop jmat=3 ares=0.0002 azero=0.001 jperm=2.38e8
prop jmat=4 ares=0.0001 azero=0.0005 jperm=2.38e8
```

```
*
*****************************
* apply hydrostatic pressure
*****************************
insitu pp=0.0 pygrad=-0.0098
bound cor 37 50 pp=0.0                          * top
bound cor 63 24 pp=11.76                         * bottom
bound cor 24 37 pp=0.0 pygrad=-0.0098              * left
bound cor 50 63 pp=0.0 pygrad=-0.0098              * right
*
his flowtime                  * #54
*
* ------------------------
* pore pressure on joints
* ------------------------
his pp 2257.9 -900.0            * #55
his pp 2000.0 -350.0            * #56
*
******************************************
* begin flow calculation to steady-state
******************************************
* set dtflow 1
set maxmech 500
reset damp
cycle t=15
sav ym13_1.sav
*
****************************************
* Ghost Dance fault displacement analyses
****************************************
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 xfree yfree
bound cor 920 24 yvel=-0.9848 xvel=-0.1736
bound his linear
reset damp
cycle t=1
save ym13_gd1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 8 second
*
bound cor 920 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 907 yvel=0.0 xfree
bound cor 920 24 yvel=0.0 xfree
reset damp
```

```
cycle t=15
save ym13_gd2.sav
*
*************************************************
* Solitario Canyon fault displacement analyses
*************************************************
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 xfree yfree
bound cor 532 24 yvel=-0.9397 xvel=-0.3420
bound his linear
reset damp
cycle t=1
save ym13_sc1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 1 second
*
bound cor 532 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 519 yvel=0.0 xfree
bound cor 532 24 yvel=0.0 xfree
reset damp
cycle t=15
save ym13_sc2.sav
*
******************************************
* Bow Ridge fault displacement analyses
******************************************
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 xfree yfree
bound cor 1782 24 yvel=-0.9063 xvel=-0.4226
bound his linear
reset damp
cycle t=1
save ym13_br1.sav
*
* terminating the application of  displacement and observing
* the model behavior for an additional 8 second
*
bound cor 1782 24 yvel=0.0 xvel=0.0
reset damp
cycle 10
*
bound cor 63 1769 yvel=0.0 xfree
bound cor 1782 24 yvel=0.0 xfree
reset damp
```

```
cycle t=15
save ym13_br2.sav
*
return
```

APPENDIX B

Utility FORTRAN Files
YM_APE.F
GRID_BR_F.F
GRID_BR_H.F
GRID_GD_F.F
GRID_GD_H.F
GRID_SC_F.F
GRID_SC_H.F

GRID_BR_F.F

```
      PROGRAM POROCITY
C *********************************************
C This program calculates porocity from UDEC
C extracted aperture data for YM fault model.
C
C The aperture data is extracted for each subarea
C using PRINT FLOW command in UDEC as follows:
C
C  pr file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 flow
C
C A batch file was writen to automatically a
C complish these tasks, ym7s1_ape.bat
C
C Variables are defined as follows:
C
C      s(i): area of blocks 1-4, and fault 1-3
C      L(i): length of contact i
C      A(i): area of open contact i
C      AT(i): total area of open contact (pores)
C      P(i): accumulative porosity
C
C Rui Chen
C Jan. 23, 1997
C *********************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180,OFNAME*80
      CHARACTER*80 FNAME(7)
      REAL*8 VAR(1000,10)
      REAL*8 L(1000),A(1000),AT(7),P(7),S(7),P1(7),P0(7)
      INTEGER N(7)
C
C Open files
C
      PRINT*,'ENTER OUTPUT FILENAME'
      READ(*,'(A80)') OFNAME
      OPEN(UNIT=3,FILE=OFNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C
C Calculate areas in different regions
C
C     -- area for hangingwall, SC & GD, GD & BR, footwall, SC, GD, and BR
C     -- area for Blocks 1, 2, 3, and 4, and faults 1,2, and 3
C
      S(1)=(529.38+856.95)*900/2
      S(2)=((2181.74-609.19)+(2340.43-936.76))*900/2
      S(3)=((4083.23-2257.9)+(4502.91-2416.59))*900/2
```

```
      S(4)=((5000-4585.66)+(5000-4165.98))*900/2
      S(5)=(609.19-529.38)*900
      S(6)=(2257.9-2181.74)*900
      S(7)=(4165.98-4083.23)*900
C
C m=1, initial stage before fault slip
C m=2, after first fault slip
C m=3, after second fault slip
C m=4, after third fault slip
C
      DO 77 m=1,4
       IF (m .EQ. 1) THEN
        FNAME(1)='ym7_A1_1.out'
        FNAME(2)='ym7_A2_1.out'
        FNAME(3)='ym7_A3_1.out'
        FNAME(4)='ym7_A4_1.out'
        FNAME(5)='ym7_A5_1.out'
        FNAME(6)='ym7_A6_1.out'
        FNAME(7)='ym7_A7_1.out'
       ELSE IF (m .EQ. 2) THEN
        FNAME(1)='ym7_A1_2.out'
        FNAME(2)='ym7_A2_2.out'
        FNAME(3)='ym7_A3_2.out'
        FNAME(4)='ym7_A4_2.out'
        FNAME(5)='ym7_A5_2.out'
        FNAME(6)='ym7_A6_2.out'
        FNAME(7)='ym7_A7_2.out'
       ELSE IF (m .EQ. 3) THEN
        FNAME(1)='ym7_A1_3.out'
        FNAME(2)='ym7_A2_3.out'
        FNAME(3)='ym7_A3_3.out'
        FNAME(4)='ym7_A4_3.out'
        FNAME(5)='ym7_A5_3.out'
        FNAME(6)='ym7_A6_3.out'
        FNAME(7)='ym7_A7_3.out'
       ELSE
        FNAME(1)='ym7_A1_4.out'
        FNAME(2)='ym7_A2_4.out'
        FNAME(3)='ym7_A3_4.out'
        FNAME(4)='ym7_A4_4.out'
        FNAME(5)='ym7_A5_4.out'
        FNAME(6)='ym7_A6_4.out'
        FNAME(7)='ym7_A7_4.out'
       ENDIF
C
C Read the database file and calculate the total aperture
C
C Before fault slip
```

```
C
      DO 55 k=1,7
       OPEN(UNIT=1,FILE=FNAME(k),STATUS='OLD',FORM='FORMATTED')
       AT(k)=0
       N(k)=0
        DO 88 J=1,10000
         READ(1,'(A)',END=99) LINE
          N(k)=N(k)+1
          READ(LINE,*) (VAR(J,I),I=1,8)
          L(J)=VAR(J,5)
          A(J)=VAR(J,6)
          AT(k)=AT(k)+L(J)*A(J)
         READ(1,'(A)',END=99) LINE
   88    CONTINUE
   99   CONTINUE
       P(k)=AT(k)/S(k)*100
C
C Calculate percentage changes in porosity
C
       IF (m .EQ. 1) THEN
        P0(k)=P(k)
       ENDIF
       P1(k)=(P(k)-P0(k))/P0(k)*100
   55  CONTINUE
C
C Printing Results
C
      If (m .EQ. 1) THEN
       WRITE(3,*) 'Before Fault Slip'
      ELSE IF (m .EQ. 2) THEN
       WRITE(3,*) "After Slip of Bow Ridge Fault"
      ELSE IF (m .EQ. 3) THEN
       WRITE(3,*) "After Slip of Ghost Dance Fault"
      ELSE
       WRITE(3,*) "After Slip of Solitorial Canyon Fault"
      ENDIF
      WRITE(3,2000) (P(i),P1(i), i=1,7)
      WRITE(3,*)
   77 CONTINUE
C
 2000 FORMAT('Block 1        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Block 2        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Block 3        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Block 4        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Fault 1        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Fault 2        ', E10.5 '; Change (%)  ', E10.5, /
     .       'Fault 3        ', E10.5 '; Change (%)  ', E10.5)
      END
```

GRID_BR_H.F

```
      PROGRAM GRID
C
C ---------------------------------------------------------------------
c  This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c  fault displcement.  The input file for this program is obtained
c  in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c ---------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_f.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_fadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_frem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
      n=0
      DO 88 J=1,10000
        READ(1,'(A)',END=99) LINE
        if (line .EQ. 'Hangingwall') then
          id=1
        else if (line .EQ. 'Footwall') then
          id=2
        endif
        if (line(1:3).EQ.'   ') then
             READ(LINE,*) (VAR(j,i),I=1,5)
             grid(j)=var(j,1)
             n=n+1
             if(id.EQ.2) then
               write(3,2000), grid(j),grid(j)
               write(4,3000), grid(j),grid(j)
```

```
C           else if (id.EQ.2) then
C             write(3,4000), grid(j),grid(j)
C             write(4,5000), grid(j),grid(j)
            endif
         endif
   88  CONTINUE
   99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', '  0.4226 ', i7, ' 5',/
     .       7x,'rset', '  0.9063 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
     .       7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.4226 ', i7, ' 5',/
     .       7x,'rset', '  0.9063 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
     .       7x,'rset', ' 0 ', i7, ' 6')
      END
```

GRID_BR_H.F

```
      PROGRAM GRID
C
C ----------------------------------------------------------------------
c This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c fault displcement.  The input file for this program is obtained
c in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c ----------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_h.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_hadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_br_hrem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
      n=0
      DO 88 J=1,10000
        READ(1,'(A)',END=99) LINE
        if (line .EQ. 'Hangingwall') then
          id=1
        else if (line .EQ. 'Footwall') then
          id=2
        endif
        if (line(1:3).EQ.'   ') then
             READ(LINE,*) (VAR(j,i),I=1,5)
             grid(j)=var(j,1)
             n=n+1
             if(id.EQ.1) then
               write(3,2000), grid(j),grid(j)
               write(4,3000), grid(j),grid(j)
```

```
C           else if (id.EQ.2) then
C             write(3,4000), grid(j),grid(j)
C             write(4,5000), grid(j),grid(j)
          endif
        endif
  88  CONTINUE
  99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', ' -0.4226 ', i7, ' 5',/
    .      7x,'rset', ' -0.9063 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
    .      7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.4226 ', i7, ' 5',/
    .      7x,'rset', '  0.9063 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
    .      7x,'rset', ' 0 ', i7, ' 6')
      END
```

GRID_GD_F.F

```
      PROGRAM GRID
C
C ----------------------------------------------------------------------
c  This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c  fault displcement.  The input file for this program is obtained
c  in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c ----------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_f.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_fadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_frem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
      n=0
      DO 88 J=1,10000
        READ(1,'(A)',END=99) LINE
        if (line .EQ. 'Hangingwall') then
          id=1
        else if (line .EQ. 'Footwall') then
          id=2
        endif
        if (line(1:3).EQ.'   ') then
             READ(LINE,*) (VAR(j,i),I=1,5)
             grid(j)=var(j,1)
             n=n+1
             if(id.EQ.2) then
               write(3,2000), grid(j),grid(j)
               write(4,3000), grid(j),grid(j)
```

```
C          else if (id.EQ.2) then
C            write(3,4000), grid(j),grid(j)
C            write(4,5000), grid(j),grid(j)
           endif
         endif
  88  CONTINUE
  99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', '  0.1736 ', i7, ' 5',/
    .       7x,'rset', '  0.9848 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
    .       7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.1736 ', i7, ' 5',/
    .       7x,'rset', '  0.9848 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
    .       7x,'rset', ' 0 ', i7, ' 6')
      END
```

GRID_GD_H.F

```
      PROGRAM GRID
C
C -----------------------------------------------------------------------
c  This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c  fault displcement.  The input file for this program is obtained
c  in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c -----------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_h.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_hadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_gd_hrem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
      n=0
      DO 88 J=1,10000
        READ(1,'(A)',END=99) LINE
        if (line .EQ. 'Hangingwall') then
          id=1
        else if (line .EQ. 'Footwall') then
          id=2
        endif
        if (line(1:3).EQ.'   ') then
             READ(LINE,*) (VAR(j,i),I=1,5)
             grid(j)=var(j,1)
             n=n+1
             if(id.EQ.1) then
               write(3,2000), grid(j),grid(j)
               write(4,3000), grid(j),grid(j)
```

```
C           else if (id.EQ.2) then
C             write(3,4000), grid(j),grid(j)
C             write(4,5000), grid(j),grid(j)
          endif
        endif
   88  CONTINUE
   99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', ' -0.1736 ', i7, ' 5',/
     .      7x,'rset', ' -0.9848 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
     .      7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.4226 ', i7, ' 5',/
     .      7x,'rset', '  0.9063 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
     .      7x,'rset', ' 0 ', i7, ' 6')
      END
```

GRID_SC_F.F

```
      PROGRAM GRID
C
C -------------------------------------------------------------------
c This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c fault displcement.  The input file for this program is obtained
c in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c -------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_f.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_fadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_frem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
       n=0
       DO 88 J=1,10000
         READ(1,'(A)',END=99) LINE
         if (line .EQ. 'Hangingwall') then
           id=1
         else if (line .EQ. 'Footwall') then
           id=2
         endif
         if (line(1:3).EQ.'   ') then
              READ(LINE,*) (VAR(j,i),I=1,5)
              grid(j)=var(j,1)
              n=n+1
              if(id.EQ.2) then
                write(3,2000), grid(j),grid(j)
                write(4,3000), grid(j),grid(j)
```

```
C            else if (id.EQ.2) then
C              write(3,4000), grid(j),grid(j)
C              write(4,5000), grid(j),grid(j)
           endif
        endif
  88  CONTINUE
  99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', '  0.3420 ', i7, ' 5',/
     .       7x,'rset', '  0.9397 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
     .       7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.3420 ', i7, ' 5',/
     .       7x,'rset', '  0.9397 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
     .       7x,'rset', ' 0 ', i7, ' 6')
      END
```

GRID_SC_H.F

```
      PROGRAM GRID
C
C --------------------------------------------------------------------
c  This program pick out grid point numbers for on the hangingwall of the
C  hangingwall boundary of the fault zone and write them into
C  'rset' format for UDEC input file to rset the velocity to app.
c  fault displcement.  The input file for this program is obtained
c  in UDEC using "print file=filename reg x1 y1 x2 y2 x3 y3 x4 y4 grid disp"
C  Note: before run this program, one should make sure that blocks in the
C  input file are grouped to hangingwall and footwall and so labled.
c --------------------------------------------------------------------
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      INTEGER GRID(80),VAR(80,80)
      INTEGER N,id
C
C Open files
C       PRINT*,'Enter name of the input file:'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_h.inp'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR ADD GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_hadd.def'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C       PRINT*,'ENTER OUTPUT FILENAME FOR REMOVE GRID POINT VEL'
C       READ(*,'(A80)') FNAME
      FNAME='grid_sc_hrem.def'
      open(unit=4,file=FNAME,status='unknown',form='formatted')
C
C Read the database file
      n=0
      DO 88 J=1,10000
        READ(1,'(A)',END=99) LINE
        if (line .EQ. 'Hangingwall') then
          id=1
        else if (line .EQ. 'Footwall') then
          id=2
        endif
        if (line(1:3).EQ.'   ') then
            READ(LINE,*) (VAR(j,i),I=1,5)
            grid(j)=var(j,1)
            n=n+1
            if(id.EQ.1) then
              write(3,2000), grid(j),grid(j)
              write(4,3000), grid(j),grid(j)
```

```
C           else if (id.EQ.2) then
C             write(3,4000), grid(j),grid(j)
C             write(4,5000), grid(j),grid(j)
          endif
        endif
  88  CONTINUE
  99 CONTINUE
C
C
 2000 FORMAT(7x,'rset', ' -0.3420 ', i7, ' 5',/
    .        7x,'rset', ' -0.9397 ', i7, ' 6')
 3000 FORMAT(7x,'rset', ' 0 ', i7, ' 5',/
    .        7x,'rset', ' 0 ', i7, ' 6')
 4000 format(7x,'rset', '  0.3420 ', i7, ' 5',/
    .        7x,'rset', '  0.9397 ', i7, ' 6')
 5000 format(7x,'rset', ' 0 ', i7, ' 5',/
    .        7x,'rset', ' 0 ', i7, ' 6')
      END
```