SCIENTIFIC NOTEBOOK

by

Robert Terhune

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INTEGRATED PARALLEL TECHNOLOGY
Pleasanton, California

for

CENTER FOR NUCLEAR WASTE ANALYSES
San Antonio, Texas

Note: This Scientific notebook 137E was substituted for Scientific notebook 137 in which no entries were made. Scientific notebook 137E describe a series of preliminary scoping calculations to model the development of a fault in alluvium.

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Scientific notebook number: 137E

Title of Research: Numerical modeling of faulting in alluvium

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Task objective: The initial purpose of these scoping calculations is to investigate the propagation of a fault through alluvium. Effects of varying alluvium thickness and angle of fault are to be investigated. See following page for more specific information.

Special qualification requirements: Background in finite element analysis and a knowledge of the physical properties of rocks and alluvium in southwestern Nevada.

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Fault Scarp Task
Start date May 17, 1996 Friday

Task Description

Layered geologic structure with Tuff layer at base of the structure which is divided by a 70 degree dipping fault and topped to the surface with an alluvium layer. The throw of the fault in the Tuff is 10 m. On the down side of the fault the alluvium layer is 20 m thick. On the up side of the fault the alluvium layer is 10 m thick. The region in the alluvium within 20 m of the fault in the Tuff is to be finely zoned with zone sizes of 0.5 m for one set of calculations and 0.25 m for another set. The motion to be studied is a 2 m drop of the Tuff on the down side of the fault.
Developed elastic EOS for the Tuff. Reference data in TerraTek report. "Characterization of Yucca Flat Materials." by R. G. Van Burkirk, D. S. Gardner, S. W. Butters, Nov. 1978, TR 78-67

May 21 1996 Tuesday
Developed elastic EOS for the Alluvium. Reference data in LLNL report. "Ultrasonic Velocities and Strength of Frenchman's Flat Alluvium" by M. S. Costantino, B. P. Bonner, UCID 18862, Lawrence Livermore National Laboratory, Jan. 1980
Set up calculation using elastic media, and 90 degree fault in Tuff. Course zones of 2 m. Grid is 200 m wide with the fault in the center and 100 m in depth, and 2 m thick. Purpose is to calibrate displacement to 2 meters drop. Calc 1

May 22, 1996 Wed.
Calc 1 gave a drop of 0.2 meters.
Set up Calc 2 with higher pressure on sponge material
Worked on inelastic equation of state for alluvium. Used reference from Univ. of California at Davis. "Triaxial tests of Alluvium" by H. Chu, J. Scott, H Brandt. Univ. of California at Davis, Dept. of Mechanical Engineering, July 1977.

May 23, 1996 Thurs.
Calc 2 gave a drop of 2.2 meters. Good enough.
Change of units from Psi to GPa. Worked on inelastic EOS.

May 24, 1996 Fri.
Set zoning size in fine zone region to 2 m by 2 m. Set up Calc 3 to look at tensile stresses in alluvium above the fault.

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Worked on inelastic EOS.

May 27, 1996 Mon.
Calc 3 With gravity applied, the alluvium did not fall. Mass of alluvium insufficient to drop alluvium with only 100 m of material as a lever.
Extended grid to -300 m in width and shortened the depth to 60 m. to keep the speed of the calculation up. Calc 4

May 28, 1996 Tue.
Calc 4. The alluvium dropped with the Tuff drop on the down side of the fault but bent the Tuff layer on the up side and put the up side in tension as it lifted it up.
Extended the depth back to 100 m. Calc 5

May 29, 1996 Wed.
Calc 5. did the same thing as Calc 4.
Calc 6. Changed the density of the Tuff to 5.0 to add more mass and weight.

May 30, 1996 Thurs.
Calc. 6 looked good with the tensile stress developing at the surface about 8 m on the up side of the fault and extending down to the corner of the scarp.
Set up a fine zone calculation of 0.5 m by 0.5 m to run over the weekend. Calc 7

May 31, 1996 Fri.
Calc. 7 Running very slow with the fine zones. Still in equilibrium phase.
Worked on inelastic EOS. Developed parameters for best fit to triaxial data for strength curve.

June 3, 1996 Mon.
Calc. 7 came off with too small of a delta time interval. Zone in alluvium, on the fault and next to the tuff layer on the down side was squeezed too small that the delta t dropped below the cutoff point. High compression's exists along the fault between the Tuff and the Alluvium on the down side as the Alluvium loses its support when the Tuff drops down.

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June 4, 1996
Need to reconsider the fine zone problem. Set up course zone problem like Calc. 6 except added a fault in the alluvium where the tensile stress was observed in Calc. 6, with the tensile strength across the fault set at 0.01 GPa (100 bars).

June 5, 1996
Calc 7. Fault opened up some but alluvium hung up on top of scarp and did not drop onto dropped tuff layer. Difficult to identify stress state with such small blocks.
Modified layering of alluvium to give multiple horizontal layers 5 m thick. Set tensile strength between layers at 20 bars = 0.002 GPa. Tied top alluvium layer to outer boundary to keep it from moving either up or down. Calc 8.

June 6, 1996
Calc 7 never came to equilibrium. Suspect the difference is the boundary condition on top alluvium layer. Took problem off and modified.
Changed alluvium eos to be more representative of surface alluvium instead of alluvium at 400 m depth. Set density to 1.5 Mg/cu m., sound speed = 0.914 m/s, poisson's ratio = 0.3. Modified sponge eos to have slower sound speed to increase calculation time step. Changed boundary condition in top layer alluvium to restrict horizontal movement only.

June 7,1996
Displacement of scarp was 3 meters with pressure of 0.08 GPa. Changed pressure to 0.03 GPa to try again.

June 10, 1996
Displacement of sponge was only 0.2 m. The decrease in pressure to 0.03 GPa was too much. Increased pressure back to 0.08 GPa. Made zones 10 m thick to increase time step.

June 11, 1996
Calculation finished but disk 2 can not be booted up. This means that I can't used Taurus to look at Dyna3d results. Need to reformat disk 2.
Received fax from Larry McKague giving technical specifications for faulting in alluvium. Every thing is pretty much as stated in task description except for conditions for consulting with SwRI.

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SwRI is to be consulted:

1. If deformation at the initial state cannot be avoided, the nature of such deformation should be discussed before proceeding with the analysis
2. IPT is to choose a material model available in their code that best simulates the weak-rock response, and to discuss the model with SwRI so that they can recommend appropriate parameter values for applying the model to the alluvium.
3. The discretization within the study zone is expected to be important due to strain localization occurring in the alluvium. IPT will conduct two analyses using the following discretization:
    a. zone size 0.25 m by 0.25 m
    b. zone size 0.50 m by 0.50 m

The procedure for subsequent analyses will depend on the results of the first two. As a result, a meeting will be held between IPT and SwRI at the conclusion of the first two analyses to evaluate and define the scope and procedure for subsequent analyses.

June 18, 1996

Critical system files moved from disk 2 to /home directory. Lost most of calculational files. Disk 2 shut down. Home Disk reformatted and new directories established. Computer back on line.
Set up new calculation. "Aluv1d"
Changed tensile strength between layers to 0.01 GPa(100 bars)
Changed pressure to compress sponge as follows

In uniaxial strain

The principal strains eta1 ≠ 0, eta2 = eta2 = 0

The principal stresses are

sig1 = (Lamda + 2* G)* eta1

sig 2 = sig3 = Lamda*eta1

where

Lamda is Lamb's constants and

G is the modules of rigidity.

and

Lamda = 2*G*pr/(1-2*pr)

where

pr is Poisson's ratio

Using the above the pressure P can be expressed as a function of sig1 and Poisson's ratio where

P = sig1*(pr +1)/(3*(1-pr))

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The equation of state of the sponge has a threshold pressure of 0.022 GPa and a pore collapse pressure of 0.03 GPa. We can calculate the required vertical stress on the sponge block to compress the block. pr = 0.25

sig1(0.022) = 0.022*(9/5) = 0.0396 GPa

sig1(0.030) = 0.030*(9/5) = 0.0540 GPa

The vertical stress used started at 0.038 GPa at time 0 and ramped up to 0.06 GPa at time 3 seconds.

The compressibility curve was modified as follows

P	ln(eta)
0.0	0.0
0.022	-6.77e-4
0.03	-0.120
0.35	-0.129323

Set up calculation "aluv1d" with dip = 90 degrees and layering in alluvium in 5 meter depth layers. tensile strength between layers is 0.01 GPa

June 19, 1996

Results for Calc. Aluv1d

Calculation at 6.4 seconds. Came to equilibrium in 1400 cycles. Vertical y stress look good at zero time.

Displacement and horizontal x stress did not vary significantly from 3 sec to 6 sec. The vertical displacement on block was -2.25 m. The alluvium layer failed in tension between 1 and 2 seconds along the horizontal surface at -10 m depth, left of the scarp. Horizontal tensile stresses developed at x= 4 m, y = 0 to -5 m and at x = -16 m, y = 0 to -15 m. Compressive stresses developed at x= 2. m, y= -5 to -10 m. The vertical stresses were relieved by the horizontal tensile failure along y=-10 m and were essentially zero. Set up new calculation "Alluv2" like the one above except with dip = 70 degrees. The fault starts at x= 0, y= -10 m and runs to x= -25.2 m. y= -80 m.

June 20, 1996

Results of calculation "Alluv2" Error in boundary conditions at -300 m. Negligible impact on results. There are two tensile regions developed. One is a extension of the fault through the alluvium where the crack would start at the surface and propagate downward to the corner of the fault scarp. The other starts at x=-18 m, y=-10 m and propagates upward toward the surface at x= -22 m. The tensile strength of 0.01 GPa (100 bars) maintained the structure of the

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alluvium layers. The only tensile failure between alluvium layers was along the y= -10 m layer boundary. The crack propagated horizontally starting at the scarp tip at x = 0 m, y= 10 m and stopped at x= -20 m, y= -10 m.
Set up calculation "Alluv2a". Fixed boundary error, and changed tensile strength between alluvium layers to 0.002GPa (20 bars)

June 21, 1996
Results for calculation "Alluv2a" Layers stayed stable with 20 bars of tensile strength. Layers in region of fine zoning did separate slightly and some slippage between layers most likely occurred. Vertical displacement on Tuff block was 2.3 m max. and 2.26 below fine zone region. The main separation between layers occurred along horizontal boundary at y=-10 m from x=0 to -25 m. Alluv2a looked almost identical to Alluv2
Set up Alluv2b with the following changes

1. Moved corner of base block from x=-25.1, y=-80 to x=-24.0, y=-80.
2. Changed sponge pressure from 0.06 GPa to 0.054 GPa to give displacement on block closer to 2.0 m
3. Changed fine zone region from 2.0X1.67m to 1.0X1.0m zones.

June 24, 1996
Calculation Alluv2b complete. Looks almost identical with Aluv2a. Faxed plots of Alluv2b and Alluv2a grid to Larry McKague. Asked for a conference.
Set up calculation Alluv2c with 0.5 m x 0.5 m zones and increased fine zone region from -20 m to -30 m. Otherwise just like Alluv2b.

June 25, 1996
Calc Alluv2c (0.5x0.5) problem running very slow. At 0.8 seconds

June 26, 1996
Calc Alluv2c (0.05x0.05) problem at 1.8 seconds.
Conference call with Larry McKague, Goodluck Ofoegbu, and Dave Farrill. Goodluck wants the tuff block to tip so that near the fault the drop is two meters and 50 m from the fault the drop is zero. Also insists on cap model for EOS for the alluvium. Sent Goodluck, fax on the EOS cap model that is in Dyna3d.
Took Calculation Aluv2c off.
Tried several ideas on how to move Tuff block and to tip it on paper.

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June 27, 1996
Call from Goodluck. Wants references from Dyna3d manual. Sent by Fax.

Goodluck's telephone no. is 210-522-6641
Goodluck's Fax number is 210-522-6081

Set up Altip1 to try to tip tuff block. First need to move block away from fault some 2.5 m. The allow gravity to tip the block.

June 28, 1996
Calculation Altip1 had the timing of the stresses to move blocks off.
Tried to move block with tangential friction on bottom.
Block 5 did not move horizontal and just dropped 2 m instead.
horizontal stresses on block gave vertical displacements up to 4 m.
Set up Altip1a with horizontal forces action on fault surface.
Reduced stresses from 0.06 GPa to 0.04 GPa.

July 1, 1996
Horizontal forces in Altip1a still too large. Displaced grid some 20 m upward and horizontal.
Set up new calculation Altip1b
Changed time vs. stress from

0. 0. 1000. 0.04 2000. 0.04 3000. 0.0 9000. 0.0

to

0. 0. 500. 0.02 1500. 0.02 2000. 0.0 9000. 0.0

changed horizontal stress to act only on block 4 to determine the stress level required to move the block.

July 2, 1996
Results for Altip1b.

Stress still too large. Displacement not uniform. Displacement at time of 0.5 sec was -2.1 m at -50 m and -1.1 m at -300 m. At time 1.0 sec it was -7.16 m at -50 m and -3.0 m at -300 m. At 1.5 sec it was -0.1 m at -50 m and -1.0 at -300 m. Moving the tuff blocks with a force applied to the boundaries will not work.
New calculation Altip1c where the Tuff blocks are given a displacement of 4.0 m to the left.

July 3, 1996
Results of calculation Altip1c. Displacement was only 0.3 m to the left. Modified displacement curve to give proportional displacement to equal 4.0 meters.
Set up Altip1d

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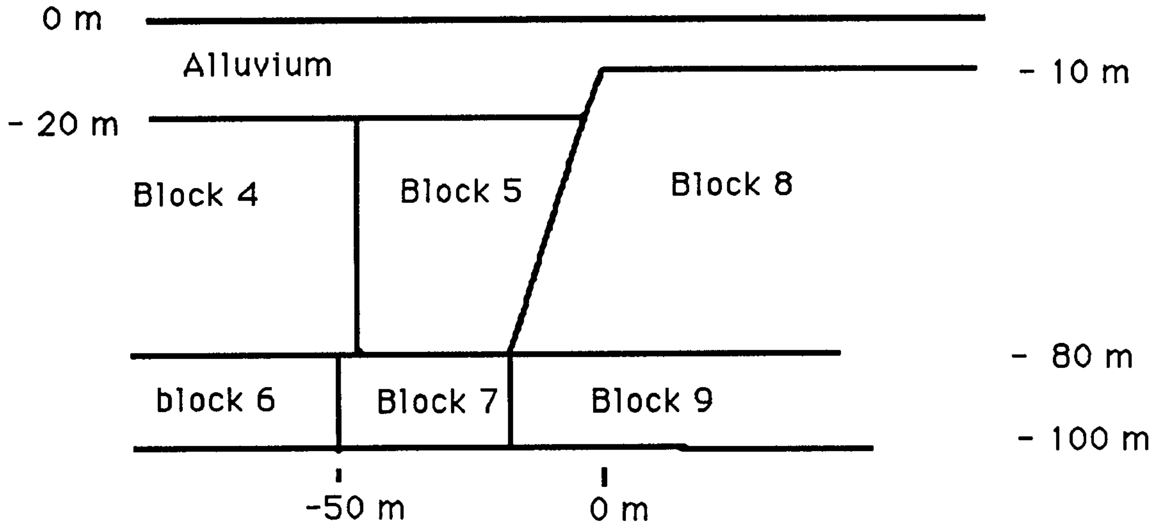
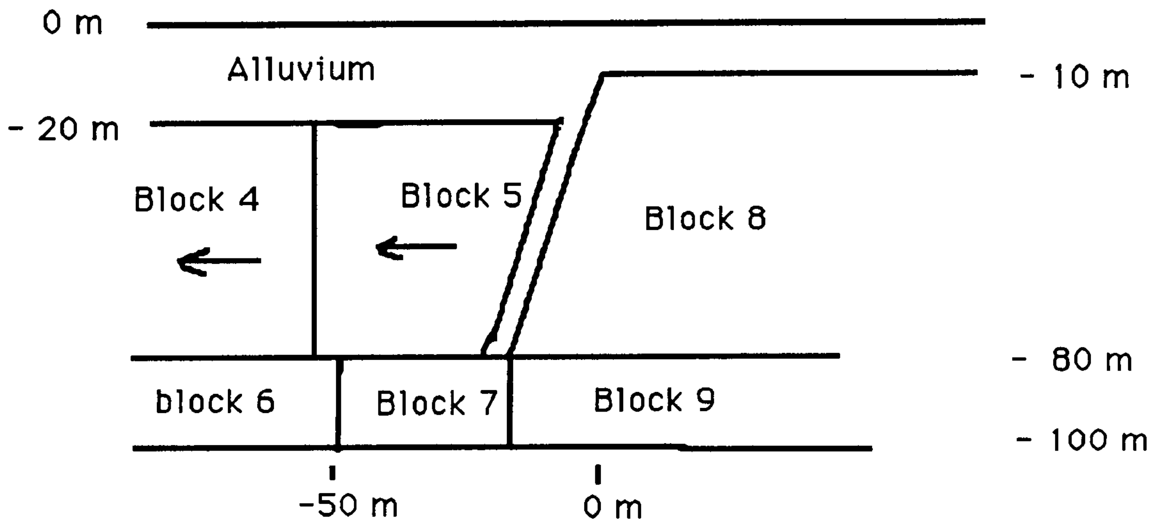
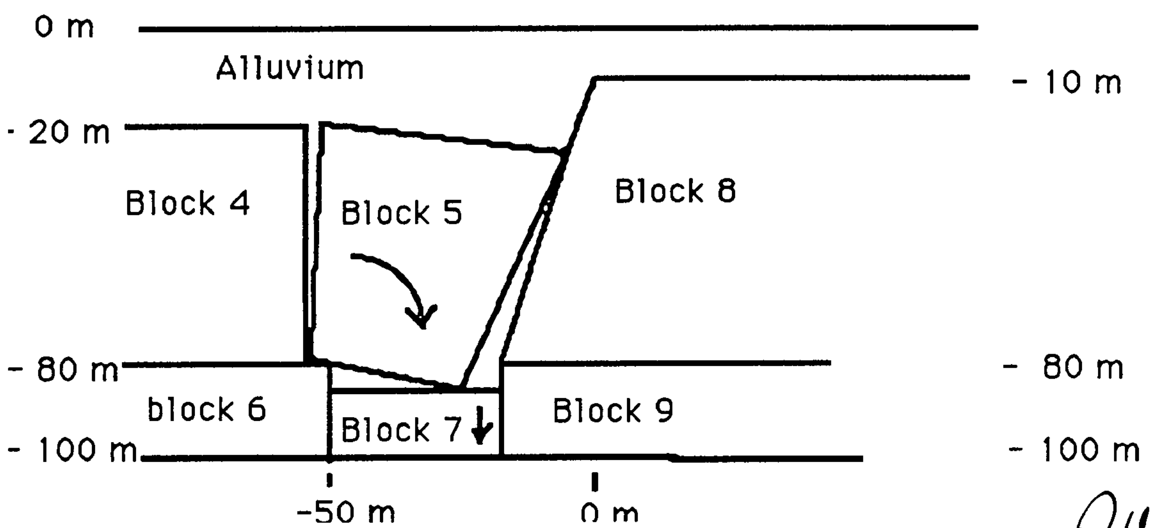
INITIAL



STAGE 1 Translation to left 2.5 m



STAGE 2 Compress support and tip block



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July 5, 1996
Results for Calculation Altip1d

Displacement method to move block to the left is not working. Ingrid does not generate the displacement cards for Dyna3d input deck, although it does accept the data for displacement method.

Set up Altip1e to move blocks with velocity method. Velocity increased from 0 at 0 seconds to 2.0 m/s at 2.0 seconds then back to 0 at 4.0 seconds.

July 8, 1996.
Results for Calculation Altip1e. Error in units!! Blocks thrown out of grid. Velocity set at 2.0 m/ms instead of 2.0m/s. Changed velocity to 2.0e-3 m/ms and put back on

July 9, 1996
Results for Calculation Altip1e. Blocks moved back 4.0 meters and gave room for block rotate and drop.
Set up Altip1f where block is moved back to catch left hand bottom corner. Expect that when bottom cell drops down, the block will tip and fall 2 m under gravity.

July 10, 1996
Results for Calculation Altip1f. Block dropped only 0.5 m under gravity. Corner on caught only 1/2 a zone and thus deformed the zone causing the block to drop vertically down without rotating.
Set up Altip1g. Try to rotate block with rotation velocity added to three corners of block.

July 11, 1996
Results for Calculation Altip1g. Applying velocity profile at corners only distorted the grid at the corners.
Set up Altip1h. Try gravity with a pressure acting on the upper right hand corner of block. Set pressure to vary from 0 at 4.0 seconds to 1.9e-3 GPa (20 bars) at 5.5 seconds and back to zero at 7.0 seconds, remaining 0 for the rest of the calculation

July 12, 1996
Results for Calculation Altip1h. 20 bars not enough to tip the block. The block dropped 0.6 m by gravity.
Set up Altip1j. Changed pressure to vary from 0 at 4.0 seconds to 2.0e-2 GPa (200 bars) at 5.5 seconds, remaining constant to 7.0 seconds, and then dropping to 0 at 9.0 seconds.

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July 15,1996
Block pushed down so hard that it bounced back up. Set up Altip1k and changed velocity to 0.6 m/sec to move block back and allowed block to drop.

July 16, 1996
blocked dropped but bounced back up and damaged alluvium layer causing some collapse. Total displacements were on the order of 1 m Set up Altip1m. Changed to a velocity profile to move the block down and tip it. Removed velocity that moved block back. Just moved block next to fault down parallel to fault.

July 17, 1996
Altip1m results. Block moved back because didn't lock block down at far left boundary. Block didn't drop enough.
Set up Altip1n. Changed velocity from 0.5 to 0.75 and locked down block at far left boundary. Allowed blocks to separate.

July 18,1996
Altip1n results. Results look very good. block tip as desired, but slightly more than 2 m. Max. displacement down was 2.7 m.
Set up Altip4. Like Altip1n except changed velocity multiplier from 0.75 to 0.55. Also tied blocks together.

July 19.1996
Altip4 looks the best of them all. Displacement 1.94 meters along the fault and zero at 60 m from fault. Alluvium layer showed no indication of sagging downward. Voids opened up near the fault between the alluvium layers and the tuff block that dropped. Also a void opened up where the tuff block tip downward into the slot formed by the compressed PZ layer.
Call from Goodluck. Changed his mind on tipping fault. Now wants the tuff layer to drop vertically downward as was done in first series of calculations. Wants examples of dyna3d calculations of tri-axial tests done for the equation of state cap model that was sent by fax.
Set up 4 triaxial tests with cap model equation of state. Confining pressures of 0.005, 0.010, 0.020, and 0.050 GPa.

July 22, 1996
None of the triaxial test calculations showed any sign of yielding. all seemed to behave elastically. Its a puzzle. Sent results to Goodluck by fax.

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July 23, 1996
Begin to look if other models would give a yielding for a similar equation of state parameters.

July 26, 1996
Equation of State model no 14 behaves well.

July 29,1996
Set up calculation with failure envelope approximately half of what Goodluck sent.
Calculation yielded only slightly at a shear stress of 0.035 GPa. This is approximately 0.02 GPa above yield curve.

July 30, 1996
Set up calculation of cap model using parameters from U.C. Davis report on alluvium.
Calculation showed large deformation of the grid and the shear stresses moved above the failure envelope the dropped down to it. This is the behavior I was looking for.

July 31, 1996.
Begin investigation on how variation in the cap model parameters effect the results of the calculations.
Set up calculations eos25a(w=0.25) , eos25b,(w=0.1), eos25c(w=0).
Using model sent by Goodluck.

August 5, 1996
All three calculations were elastic at all stresses
Set up triaxial calculations for eos25d. where U. C. Davis eos was used. (rho = 1.5, k = 17 GPa, G = 10. GPa, t = -.002,
alpha = 0.01104, theta = 0.0, gamma = 0.01021, beta = 29, r= 1.22.
d = 2.5, w = 0.1)

August 6, 1996
Result: Grid was deformed as expected. shear stresses followed the yield curve as expected.
Set up triaxial calculation eos25e same as eos25d except set w = 0, d = 0.

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August 7, 1996
Result: Grid was not distorted and shear stresses followed path of triaxial test well past the yield curve.
Set up triaxial calculation eos25f same as eos25e except increased the maximum shear stress from 0.025 GPa to 0.065 GPa

August 8, 1996
Result: Calculation came off with a error when the stresses got to far above the yield curve.
Set up triaxial calculation eos25g same as eos25e except changed d = 5.0 w = 0.2
Set up aluv2d calculation using U. C. Davis cap model with density 1.5, bulk modules 7.75, shear modules 4.41 and sound speed 3.0 m/ms. Fine grid region have zones 1.0 by 1.0 m. Time step is 0.2 msec. Problem set to run to 9 sec.

August 9, 1996
Result: Grid deformed but not as much as the deformation in eos25d, The shears stresses were above the failure curve but definitely showed plastic yielding.
Set up triaxial calculation eos25h same as eos25e except set d = 0.0 w = 0.5
Set up triaxial calculation eos 25k same as eos25c with Goodluck Eos. except maximum shear stress to 0.00079 GPa
Set up triaxial calculation eos25m same as eos25e except changed bulk modules and shear modules to reflect the modules measured in Davis study. k = 7.75 GPa, G= 4.41 GPa
August 12, 1996
Results eos25h: This calculation behaved the same as eos25e.
Results eos25k: This calculations behaved the same as eos25c.
Results eos25m: This calculation behaved the same as eos25d. The change in bulk of shear modules, keeping poisson's ratio the same did not change the results.
Set up triaxial calculation eos25n same as eos25c except changed the bulk modules in Goodlucks model to give a sound velocity of 1/4 km/s. The modulii Goodluck sent gave a sound velocity of 014 km/s which is half the sound speed of air.

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August 13, 1996
Results of eos25n: The results where the same as eos25k. The shear stress went to over twice the shear stress of the failure envelope with out any sign of yielding.
Set up eos25p same as eos25d except with the average sound velocity and density of the NTS test site alluvium.

August 14, 1996
Results for eos25p: Error, set up with Goodluck eos instead of Davis eos.
Set up eos25q same as eos25m except with average sound velocity and density of the NTS test site alluvium. Confining pressure set to 5.0e-4 GPa.
Calculation aluv2d completed. Tuff block not restricted in horizontal direction which resulted in a 3 m gap at the fault. Stresses in the alluvium vary between -0.002 GPa and 0.0005 GPa. Layers separated at y = -20 m and y = -10 m. Need to rerun such that gap at fault does not appear.

August 15, 1996
Results for eos25q. Grid deformation as expected and shear stresses followed the failure envelope for Davis cap model. We now have two triaxial calculations at confining pressures of 5.0e-04 GPa and 5.0e-03 GPa that behaved as expected using the Davis cap model.
Set up fault-scarp calculation using the davis cap model same as eos25q with average sound velocity and density for the alluvium consistent with the Nevada Test Site alluvium. Fixed to remove the possibility of gap developing. Changed density to 1.80 gm/cc, bulk modules 2.25 GPa, shear modules 1.35 GPa, and sound velocity 1.5 m/ms.

August 16, 1996
Calculations running as expected.

August 19, 1996
Calculation aluv2e at 3.0 msec. vertical displacement = -0.06 m

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August 20, 1996
Calculation aluv2e at 4.5 msec. Vertical displacement = -0.44 m Discovered error: Shear modules was not changed from aluv2d. it is 4.41 GPa and should be 1.35 GPa. Problem stopped, fixed and restarted. Changed ramp start time from 2 sec to 0 sec. Changed stop time from 8 sec to 6 sec. Changed grid spacing next to fine zone to be smoother transition. Change shear modules to 1.35 GPa.

August 21, 1996
Calculation aluv2e came to equilibrium at 2000 cycles. Stress state at t=0 seconds looks stable with some curvature of isobars near fault. Calculation now at time of 0.3 sec.

August 22, 1996
Calculation aluv2e at time of 2.4 seconds.

August 26, 1996
Calculation aluv2e complete. Although the displacement was designed to ramp up from 0 to 2 m in the first three seconds, most of the displacement occurred between the time 2 sec. and 3 sec. This is because the threshold pressure for pore collapse was not exceeded until the time of 2 sec. The displacement at 3 seconds was -1.8 meters. At 4 seconds the displacement was 2.0 m and remained constant to the end of the calculation.

August 27, 1996
Analysis of calculation aluv2e.
The horizontal stress plots showed a compressive stress region developing in the alluvium just above the fault. The lower layers begin to separate from the upper layers at the tip of the fault causing the entire region left of the fault to be in tension. The lower two layers at 15 m and 20 m follow the tuff block as it drops. Compressive stresses form in the surface layer near the transition point between the section that is dropping and the section over the scarp. All compressive are less than .001 GPa (10 bars) and the effective plastic strain indicates that the upper layers remained elastic. A tensile stress developed in the surface layer above the scarp and with time propagates to the scarp at a point 5 to 7 meters from the tip of the fault.
Set up calculation Aluv2f same as Aluv2e except that two vertical fractures were put in the alluvium layers at x = -10 m, and x = + 4 m. Tensile strength of the bonds across the fractures are 0.001 GPa.

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August 28, 1996
Calculation Aluv2f came to equilibrium at cycle 2000.

Sept. 3, 1996
Calculation Aluv2f done. Analysis: Horizontal stress contours look identical to Aluv2e calculation at time of 2 sec. By time of 2.4 seconds the bonds at + 4 m begin to break at the top of the layer. At -10 m, the bonds at the bottom of the second layer from the surface also begin to break. At -10 m the break widens to about 1 m at 10 m depth but remains closed from the surface to 6 m depth. The fracture at +4 m widens at the top of each layer and narrows at the bottom of the layer. There is a offset along the fracture of approximately 0.5 m at 3.5 seconds which then remains constant to the end of the calculation.

Sept. 17,1996 IPT report completed.

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