HLWYM HEmails

From: David Ferrill
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-----Original Message-----
From: David Ferrill [mailto:David Ferrill]
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Subject:

For those of you who are interested, here is a summary of our meetings on fractures that were held last week at the CNWRA. Thanks for your participation! I am looking forward to working with many of you on various technical points identified during the meetings.

David

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Summary of meetings on fractures held at CNWRA (5-6 January 1999).

We held two days of informal meetings at CNWRA to discuss ongoing work on fractures. The purposes of the meetings were to (i) raise the level of understanding of fracturing at Yucca Mountain and ongoing efforts by CNWRA staff and consultants to evaluate fractures at Yucca Mountain and effects of fractures on unsaturated zone hydrology, saturated zone hydrology, and drift stability and rockfall. The major goal of the meetings was to establish the present data of knowledge on fracturing at Yucca Mountain, and to identify key gaps in understanding and fracture-related factors that are likely to effect repository performance with the intent of focusing future SDS fracture studies, and to identify key points for integration between SDS staff and consultants and process modelers. Prior to the meetings, I talked individually with process modelers to convey the above purposes and goal, and to solicit "talking points" related to key factors or performance effecting parameters related factors. Those talking points are provided below in unedited form after the meeting summary.

5 January 1999

The meetings started with brief self introductions by all attending, and introductory remarks by Phil Justus and myself. Bill Dunne (CNWRA Consultant, Professor of Geology and Department Head at the University of Tennessee Knoxville) gave a presentation on field studies conducted by SDS staff (D. Ferrill, P. LaFemina, J.P. Hogan, and Dunne) at Yucca Mountain that have focused on clustering of cooling joints, and fracture distribution in the north branch of Split Wash, the location of a watershed modeling effort being conducted by

USFIC staff led by Randy Fedors. A primary point of this presentation was that cooling joints in the upper lithophysal zone (Tcpul) of the crystal-poor member of the Tiva Canyon Tuff are not uniformly distributed, but instead tend to be clustered in zones that are laterally very continuous (at least several 10's of meters) and that may have a spacing on the order of 75 meters. Preliminary field observations suggest that at least some of these swarms probably cross the entire thickness of the Tcpul.

David Ferrill briefly described and showed photographic examples of tubular structures along cooling joints. These tubular features are localized along cooling joint surfaces, tending to match from side to side across the fractures, and range in diameter from sub-mm diameters to >1cm diameters. Tubular structures commonly form anastomosing networks of subhorizontal tubes, and cause considerable local variation in fracture aperture.

Darrell Sims summarized ongoing efforts by CNWRA staff (D. Waiting, D. Ferrill, D. Sims, and A. Morris) to analyze fracture data collected by detailed line surveys in the ESF at Yucca Mountain. The primary point of this presentation was that the scan line method introduces a strong directionally-dependent sampling bias, and that fracture sets that are not perpendicular to the sampling scan line are undersampled. SDS staff are systematically working through the ESF fracture data performing corrections for the directional sampling bias, and have found that the corrected fracture pattern is considerably different in many parts of the ESF from the pattern determined from the raw data alone. Fracture properties from the raw (uncorrected) data have been used in the site-scale unsaturated zone model of Yucca Mountain developed by Lawrence Berkeley National Lab.

The next presentation was by Randall Marrett (CNWRA consultant, Assistant Professor at the University of Texas at Austin), who summarized scaling properties of faults and extension fractures and common sampling biases. He also discussed work conducted by SDS staff (Marrett, Ferrill, Stamatakos) to evaluate scaling of faults and fractures at Yucca Mountain. The CNWRA effort to date has largely focused on faults and their possible role in accommodating strain, as part of the debate of recent GPS strain measurements published by Brian Wernicke and coauthors in Science. Although the work has emphasized fault scaling, Marrett presented a preliminary analysis of scaling of fracture apertures in the ESF fracture data set.

During presentations and in round-table discussions afterwards, several noteworthy points were discussed:

- The sampling bias in the ESF produced by not measuring fractures shorter than 1m has important implications for unsaturated zone flow (including seepage and dripping), and drift-stability/rockfall concerns.

- Although very small fractures are probably extremely abundant (compared with measured fractures) very small fractures may be isolated and perhaps behave as pores and could reasonably treated as part of the matrix properties. (R. Marrett)

- The downward terminations of fractures may be important collection points for water, essentially producing micro-perching of groundwater in the unsaturated zone. (J. Bradbury)

- Randy Fedors said he does not think tube structures have any important effect on infiltration and percolation.

• A question was raised regarding whether there is evidence of clustering of cooling joints in the ESF fracture data. (Discussion by P. Justus and B. Dunne)

• There was some concern expressed that we could never collect all of the data that we need to address flow questions at Yucca Mountain, and that, in the absence of complete data, it is important that end-member models be conceptualized and implemented to assess resulting performance.

6 January 1999

Meetings on Wednesday were conducted in smaller working groups in order to address talking points and concerns of SDS staff and process modelers in greater detail. These discussions yielded numerous points for potential further investigation listed below as bullets.

Unsaturated Zone Hydrology

• Investigate fracturing in the Calico Hills and Lower Topopah Springs units at Prow Pass, the Busted Butte study facility and a wash at Busted Butte that Fedors and McKague recently visited. Also, we should acquire and evaluate data previously collected from Busted Butte facility and areal survey and scan line data from Prow Pass.

• We have not seen any pavement maps from the PTn unit, although pavement studies in the PTn have been referred to in USGS reports. We need to check into those studies.

• Consider separating so-called cooling joints out of the ESF fracture data set, and assess whether there is evidence for clustering of cooling joints in the ESF data.

• Consider collecting fracture data along another scan line near to the Split Wash scan line survey conducted by Ferrill and Dunne (June 1998) to assess lateral variability in fracture development in the Tiva Canyon Tuff.

• Provide input to R. Fedors and J. Winterle regarding Chapter 7 of Lawrence Berkeley National Laboratory site-scale unsaturated zone model for Yucca Mountain.

• We discussed van Genuchten alpha, the concern that this key parameter is very poorly constrained, and that the value calculated by LBNL is erroneous due to the use of the raw ESF fracture data without correction for directional sampling bias and sampling censorship (fractures <1m not sampled).

• We may be able to independently determine aperture and frequency as the basis for calculation of a more realistic van Genuchten alpha value. As a start, we can reanalyse fracture aperture data from ESF data set, separating the aperture data by unit and structural position. We may need to collect additional higher-resolution data to augment the existing data set.

Drift Stability and Rockfall

Based on the current repository design, 75-80% of waste packages will be placed in the lower lithophysal zone (Ttpll) of the crystal-poor member of the Topopah

Springs Formation, a unit for which we have very little fracture information. For drift stability, the presence of subhorizontal fractures is particularly detrimental. In scan line studies in the lower lithophysal zone of the crystal-poor member of the Tiva Canyon Tuff (Tcpll), Dunne and Ferrill have found subhorizontal fractures that have spacings as small as 1m. We need to investigate available data on fracturing in the repository units, and determine similarity of lower lithophysal units of Topopah Springs and Tiva Canyon formations to determine whether Tiva Canyon Tuff can be used as analog for fracturing in equivalent unit of Topopah Springs Formation.

In general, fracture dip is very important in models of drift stability and rockfall. We discussed alternative ways for developing fracture patterns for input into UDEC to model drift stability. These include; (i) taking general end-member fracture patterns and generating synthetic patterns using the generator in UDEC, (ii) taking fracture population statistics from fractures studies as inputs for generating synthetic populations in Fracman, and (iii) identifying representative segments of the ESF main drift, and using full periphery maps of the ESF as the basis for constructing input fracture patterns for UDEC. End-member fracture network styles (as seen in the ESF) were verbally described to G. Ofoegbu and R.Chen, to be considered as the basis for future UDEC modeling.

There was discussion of the general concern that modeling of drift stability has been conducted in two dimensions only, in tunnel-perpendicular profiles, yet in reality the process is three dimensional. This question was left open with no obvious solution identified.

Saturated zone hydrology

We discussed the scale dependency of permeability and the fact that in many fractured reservoirs and aquifers, one or few fractures or faults may conduct the bulk of the fluid. We briefly discussed that Stripa (Sweden) example where 80% of water inflow into a 50-m-long drift entered along a single fracture. With respect to sub-regional flow in saturated zone, the most conductive features are likely to be faults. Fault-related deformation virtually always alters the permeability from that of the undeformed host rock. Commonly, faults develop a fault process zone with a relatively impermeable fault core that reduces permeability perpendicular to the fault, and a surrounding damage zone that enhances permeability in directions parallel to the fault. We may be able to address the development of these permeability affects at Yucca Mountain through detailed mesostructural analysis of faults at the surface, in the ESF, and in boreholes or cores. These investigations should be coupled with detailed microstructural analyses of fault-zone deformation currently being conducted by M.B. Gray (CNWRA consultant). We may also be able to assess the role of this process through analog studies and literature review, and tying the investigations into various hydrologic and pneumatic test results from Yucca Mountain.

7 January 1999

On Thursday, I met individually with English Pearcy and D. Hughson to follow up on points not discussed during the previous day.

E.Pearcy and I discussed fracture data collected at Pena Blanca and their potential utility as analogs for fracturing at Yucca Mountain. The fracture data set at Pena Blanca includes a map of 11,374 fractures in welded tuff, mapped on cleared pavements. The fracture length cutoff used was smaller (20 cm?) than that used in most of the ESF (1 m). Maximum fracture apertures were measured from 222 fractures before field studies were terminated. This data set may be very useful to assess scaling properties of fractures in welded tuff, although additional data may be needed.

D. Hughson and I discussed the role of fracture apertures in the unsaturated zone. Because of the controls on fluid movement in the unsaturated zone of gravity and capillarity, the along-fracture variation of aperture turns out to be an extremely important parameter, yet one that it is completely unconstrained. We discussed various approaches to collection of data to constrain along-fracture aperture variation including: (i) serial measurements of aperture along fracture traces in the ESF or outcrop, (ii) epoxy impregnation of fractured rock samples, serial slicing of samples, and measurements of aperture along serial slices, (iii) impregnation of fracture samples with material of contrasting density, and analysis using x-ray tomography (CT scanning), and (iv) prying apart samples and mapping topography of matching sides and recombining mapped surfaces in three-dimension modeling and calculating aperture variations within fractures.

Summary Comments:

Thanks to the active participation of all participants, the meetings were quite successful in reaching the objectives and goals. I would appreciate any feedback that you wish to provide regarding the above summary or other issues related to fracturing and effects on related processes. We will be using the detailed comments above as the basis for focusing fracture studies that we are planning for the next six months, and I anticipate ongoing dialog regarding key issues described above.

Participants

Amit Armstrong
Rui Chen
John Bradbury
Neil Coleman
Bill Dunne
David Farrell
Randy Fedors
David Ferrill
Amit Ghosh
Ron Green
Latif Hamden
Melissa Hill
Debra Hughson
Phil Justus
Peter LaFemina
Randy Marrett
Larry McKague
Mike Miklas
Alan Morris
Goodluck Ofoegbu
Scott Painter
Wes Patrick

English Pearcy
Darrell Sims
Jim Winterle

Talking points provided prior to meetings:

Unsaturated Zone Hydrology

Randy Fedors

1. Estimation of van Genuchten alpha (Site-scale unsaturated flow and drift-scale seepage modeling).

The alpha is one of the parameters that define the unsaturated constitutive relationship between capillary pressure and water content. Seepage into a drift is highly sensitive to this parameter, and, there is no direct way to estimate this parameter for fractures (assuming the fractures act as a continuum for the flow of water in the unsaturated zone). The current method to estimate this parameter is based on estimates of fracture frequency and on permeability from air injection tests. The Terzagi corrections and the inclusion of fractures less than 1 m in length (extrapolation and comparison with North Portal area) will shift the alpha to a smaller values, resulting in higher seepage rates (specifically, the onset of seepage into a drift occurring at lower percolation rates).
At minimum, we need to recalculate the alpha value using the current methodology. However, new methodologies are needed.

2. Characterizing fracture properties of Calico Hills Formation (Unsaturated flow and transport below the repository)

We need to define the unsaturated flow patterns through the nonwelded units below the repository. Locally, significant lateral flow occurs as evidenced by presence of perched water zones and as indicated by low matrix permeabilities of the zeolitically altered nonwelded unit. However, vertical flow does occur through the unaltered nonwelded (vitric and devitrified units), probably as both matrix and fracture flow. There is limited data on fractures (borehole data only) in the nonwelded units below the repository. Fracture data for these units is tabulated in the Berkeley site-scale flow model documentation. There are a number of questions. How can we characterize the fracture system using vertical borehole data when the fractures of highest concern are mostly vertical? Are Terzagi corrections useless here? Can the PTn be used as analog to the nonwelded units below the repository? The PTn has the advantage of comparing ESF tunnel and niche/alcove data, and borehole data.

3. Defining fracture characteristics in small watershed area (Linkage of surface water flow and shallow infiltration).

A small watershed at the upper portion of Split Wash is being studied for the distribution of shallow infiltration tied directly to precipitation and runoff.
The characteristics of surface features such as talus piles, bare bedrock, slope aspect, and soil thickness are being analyzed in terms of potential for infiltration versus lateral hillslope flow (either as overland flow or as subsurface lateral flow). We would like to tie the fracture characteristics of the bedrock to infiltration both in areas of bare bedrock and for soil covered

areas. The distribution of the fracture characteristics across the watershed can be incorporated into the flow models either in a deterministic way or a statistical/stochastic way depending on the tree climbing abilities of the structural geologists (how far out on a limb to go). The characteristics that would be used are fracture frequency/spacing, size distribution in both length and aperture, fracture aspect in relation to hillslope aspect, and variation between hydrostratigraphic units.

4. The topology of the drift boundary - roughness & Rockfall (Drift-scale seepage modeling, unsaturated flow).

Percolation reaching the drift horizon may divert around the drift due to capillary diversion, may seep into the drift but flow along the drift wall, or may drip into the drift and onto the waste packages. For the latter two possibilities, the topology of the crown of the drift will have a major impact. Our current modeling approach is to assume a smooth, circular surface. Clearly this needs to be modified for both pre- and post-Rockfall situations. Defining likely topologies for the post-Rockfall period could possibly be extrapolated from Goodluck's modeling. Defining pre-Rockfall topologies could be approximated from fracture characteristics from the ESF, and supported by observations in the ESF. The hydrologists approach for incorporating the topology into the flow modeling has not been clearly defined yet; so the question remains on how to proceed after characterizing the topologies.

Debra Hughson

Some things I would like to know about fractures:

1. At what scale can we treat a network of fractures as a porous media continuum?

2. What is the aperture distribution of fractures in the repository formation?

3. Is the spatial variability of air permeabilities due more to variation in aperture or fracture density or is there another cause such as fracture connectivity?

4. How reliable is the number given for fracture frequency in the repository formation DOE parameter set? Is this frequency highly variable or more uniform?

5. Do fractures with less than 1m trace form an interconnected network?

6. If you count fractures with less than 1m trace how does this change the fracture frequency number?

7. How frequent are prominent discrete fractures in the repository formation? At natural analog sites are seeps usually associated with these prominent discrete fractures?

8. How much additional fracturing or fracture widening is caused by the tunnel boring machine or niche excavation and can this be observed in niche 3650?

I'll stop here for now but there will probably be more questions.

Saturated Zone Hydrology

Jim Winterle

1. J. Winterle is presently investigating the potential for anisotropic transmissivity and "compartmentalized" flow in the saturated zone at YM. Important questions include:

• Can the major N-S trending fault systems cause compartmentalization that limits groundwater flow from one fault block to another?

• What is distribution of fracture orientations, lengths, apertures in the SZ?

• Can fracture data from the ESF be applied to other geologic units or the same units at greater depths in the saturated zone?

2. J. Winterle is also investigating flow features that affect saturated zone contaminant transport. A key parameter in this regard is the effective spacing

Text item: Part 2

between major transmissive zones. Can available fracture data be used to constrain this important parameter?

David Farrell

I am primarily interest in the fracture data as soft information for constraining hydraulic conductivities in the welded Tuff aquifers particularly in areas where no hydraulic conductivity data exists. As a result I am interested in learning more about (i) fracture connectivity and its impact on hydraulic conductivity; (ii) fracture aperture and its impact on hydraulic conductivity; and (iii) any other innovative ways for incorporating fracture data in the estimation of hydraulic conductivity values. The scale I am interested in modeling is approximately 5 km x 5 km. The modeling will be a combination of stochastic simulations and Monte Carlo simulations. The parameter field (e.g., K or fracture parameter) will be treated as a stochastic variable with Monte Carlo simulations of flow and transport in the simulated field producing the concentration distribution at a point in the field.

Amit Armstrong

There are two things I want to discuss during the workshop:

1) Is the assumption of porous media flow in the SZ is valid?

2) If not, how it is affecting the flow field?

Scott Painter

1) Stochastic modeling and simulation of fracture networks. Need mathematical models that
capture the spatial clustering in addition to "non-classical" length/aperture distributions.
Also need computer algorithms for simulation. Many existing algorithms/models lack empirical
justification. Need for stronger links between data analysis and model/algorithm development.

2) Implications of power-law distribution for transport predictions. Connectivity of networks.
Degree of flow/transport channelization in networks. Scale-dependence in effective properties. Relationship between Eulerian and Lagrangian statistics.

Drift Stability/Rockfall

Rui Chen

I am currently working on the issue of Rockfall due to thermal load and earthquake ground motion. The analysis approach we are currently taken is thermal and dynamic simulation of an emplacement drift (drift scale) using UDEC to explicitly model rock blocks falling into the drift. Later studies may also include Key Block analyses.

For our analyses, it is important to be able to generate fracture patterns that are representative of the in situ fracture pattern in a region approximately one drift diameter into the rock mass (i.e., a region 15x15 m^2 for 5 m diameter drift) on a cross section perpendicular to the drift. The actual model, however, includes one-unit cell width (28 m) and extends vertically from ground surface to approximately groundwater level (see attached figure 1). Fracture pattern in other regions is usually scaled up to reduce the size of the problem.

From the analyses conducted so far, I see two needs for fracture analyses for Rockfall simulation:

1. Generate fracture patterns based on fracture analyses of ESF data for UDEC analyses. UDEC can take the coordinates of two end points to define a fracture. In fracture generation, it should be flexible to vary certain parameters that define the fracture network.

2. Determine block-size distribution for each generated fracture pattern as well as for overall block size distribution at the repository level. Ideally, the effect of block-size and fracture pattern should be isolated (i.e., being able to generate two fracture networks that have similar fracture pattern but different block size or vice versa).

Based on dynamic analyses conducted to date, fracture pattern appears to control the amount of simulated Rockfall. With increasing complexity of fracture patterns, especially significantly varying orientations, and decreasing block sizes (or fracture spacing), it appears the number of rock blocks falling and the extent of a Rockfall region increase. Also, the irregularity of fracture pattern appears to be an essential condition for explicitly Rockfall, since earlier attempts to explicitly simulate Rockfall failed when a regular fracture pattern was used.

The fracture generator in UDEC has various limitations that make it impossible to generate a fracture pattern that is representative of the in situ fracture pattern. These include:

1. UDEC generates fracture patterns for each predefined preliminary fracture set using parameters such as orientation, trace length, gap length, and fracture spacing; and each of these parameters is allow a uniform probability distribution. Other distribution types are not allowed. According to DOE analyses of fracture data at YM, most fracture parameters show a log-normal distribution.

2. UDEC fracture generation is conducted in 2D. Therefore, assumptions with regard to the extension of fractures in the 3rd dimension need to be forced. Ideally, a 3D fracture generator that can account for a variety of distribution types should be used to generate fracture in 3D and obtain the required 2D cross section from the 3D model for mechanical analyses.

3. Since block size is mainly determined by the number of fracture sets and spacing of each fracture set in UDEC, it is impossible to isolate the effect of fracture pattern and block size on Rockfall.

Amit Ghosh

1. Characterization of lithophysae-rich strata where truncation below 1 m have eliminated significant amount of fractures resulting in fracture spacing to meters to tens of meters.

2. Rock block analysis

3. Stability of drifts in both lithophysal and non-lithophysal strata

The scale is mainly in the drift scale, i.e., several meters around the emplacement drifts.

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