Optical Televiewer Logging 
Foundation Grouting Evaluation 
Calaveras Dam Replacement Project 

By 

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Calaveras Dam Replacement Project
San Francisco PUD

Located Approximately 50 miles Southeast of San Francisco, CA

Aerial View of Original Calaveras Dam
Built in the 1910’s
Calaveras Dam Replacement Project

Replacement Dam to be Constructed 1200 feet Downstream (North) of Original Dam

Rendering of Earthen Replacement Dam Completion Looking South
Foundation grouting meaning creating a grout curtain within two bedrock units (Temblor and Franciscan) to control seepage below the dam.
Our Interest Left Abutment - Photo Views (2013-14)
A grout curtain was installed via percussion drilled bores on 24-ft horizontal spacing with tertiary and finer splits in two rows parallel and laterally offset 5-feet to the center-line. Drill holes were inclined 20 degrees from vertical and positioned on the center-line.

Row A drill holes bearing West
Row B drill holes bearing East
Grout Curtain Cross-section Left Abutment
Bedrock Unit Below Left Abutment

Temblor Formation

- Tertiary-Age marine fine- to medium grained sandstone
- Moderately to highly fractured
- Contains three prominent joint sets
Grout Verification Program Left Abutment

Verification Boreholes and Testing Methods

- 13 Percussion-drilled Borings (2.75-inch diameter) within the Temblor Formation located along the center-line.
  - Water testing at 10-ft double packer test intervals
  - Measurement of grout takes at 20-ft double packer interval

- 3 Representative OPTV logged boreholes situated on the center line

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**Diagram Notes:**
- VP-841, 863 depths 50-ft
- VP-920 Slant depth 135 feet
Survey Method - Optical Televiewer (OPTV)

**Downhole Probe**
Dimensions: 2-in diameter x 6.6 ft.

**OPTV Output**
Unwrapped oriented, color image of the borehole wall. Records borehole azimuth and tilt for correction to interpreted fracture orientations, implemented to compute borehole trajectory.
OPTV Log Acquisition on the Center Line

View of Abutment Grade Looking Upslope

View of Logging Truck Looking Downslope
Logging on the Left Abutment Center Line

Setup for Boreholes VP-841 & VP-863
September 2014 Survey

Setup for Borehole VP-920
October 2015 Survey
Objective: Identify Grout-filled vs Unfilled Fractures

Unwrapped OPTV Image
VP-841.0

Grout-filled

Unfilled, Open

Unwrapped OPTV Image
VP-920.0

Grout-Filled
Example of Fracture with Grout in Borehole VP-920

<table>
<thead>
<tr>
<th>Depth</th>
<th>BOREHOLE VIEW</th>
<th>3D</th>
</tr>
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<tbody>
<tr>
<td>1ft 8ft</td>
<td>0°  90°  180°  270°  0°</td>
<td>230°</td>
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- Unwrapped Image Showing “BOREHOLE VIEW”
- 3-D Representation of Borehole Viewed West to East at Center Azimuth of N230
VP-841 & VP-863 Fracture ID and Directional Summary

VP-841.0
4 of 27 identified fractures showed grout takes. 3 fractures dip to the southeast. Overall a low incidence of grout-filled fractures.

VP-863.0
3 out of 21 identified fractures showed grout takes. 2 dip to the southeast. Overall a low incidence of grout-filled fractures.
Majority of fractures (15 out of 21 identified fractures) showed indications of being completely or partially filled with grout. Overall, high incidence of grout-filled fractures.

Most grout-filled fractures have a dip direction to the southeast.

Dip angles of grout-filled fractures ranged from 30 degrees to near vertical with half the total dipping between 40 and 50 degrees from horizontal.
VP-841 water testing indicated formation had low permeability as indicated by low Lugeon values (< 2.0). This is true whether fractures were un-grouted or grouted. However, several grouted fractures in zone from 36 to 38-ft bgs corresponded to a water test zone with less than 0.1 Lugeon (nd).

VP-863 water testing indicated that the upper 20 feet of rock is highly permeable (see relatively high Lugeon values). Fractures were relatively open with no visible grout within apertures. Several grouted fractures (30 to 40-ft) did correlate to reduced Lugeon values.
VP-920 showed very low permeability through the extent of the borehole. Note the drastic reduction in Lugeon values (less than 0.5) for the entire borehole.

In so much as the majority of fractures were grout-fill, the grout curtain could be said to have effectively plugged fracture voids.

Massive sections of the borehole have near zero permeability.
CONCLUSIONS

• Optical televiewer logging can distinguish the presence of grout-filled fractures in percussion drilled verification boreholes.

• In most cases, occurrences of grout-filled fractures correlate to low Lugeon values. VP-920 is a prime example where the high incidence of grout-filled fractures and low permeability reflect efficacy of the grout curtain emplacement.

• Optical televiewer date presents a supplemental “picture” to “reviewers” as to how the grout curtain infiltrated the fracture network.

• Orientation of grout-filled fractures appears to favor a fracture population with a southeast dip direction.
Based on deviation survey, the subsurface the inclination of VP-920 ranged from 9 to 14 degrees bearing the southeast with a dog-leg kick to the south at mid depth.

- VP-920 intercepts the west dipping grout injection Row A. By design, this a favorable geometry for intercepting southeast dipping fracture planes.
- Row B intercepts the southeast dipping fracture planes obliquely in a down dip direction.
- Curiously the subsurface borehole trajectory, as the hole deeps, deflects away from the grout curtain emplacement array.

Why the High Incidence of Grout-Filled Fractures in VP-920?

But what else is there....
Why the High Incidence of Southeast dipping Grout-Filled Fractures continued…

Directional Diagrams from a Representative Exploratory Borehole (2012) in the Left Abutment Prior to Grout Injection Program
OBSERVATIONS

• The borehole trajectory of Borehole VP-920, despite deviating away from the array of grout curtain boreholes, still contained grout-filled fractures down to 134-ft bgs.

• Temblor sandstone formation in this vicinity has a prevalent southeast dip trend. It follows that the most grout-filled fractures will have the same trend.

• This southeast fracture dip direction is coincident with the natural slope direction, that is downwards towards the canyon base.

• Southeast dipping fracture planes may be under differential horizontal stress and therefore more permeable and prone to “take” grout compared to other fracture orientations.