25 Years of Dam Foundation Investigations in California, or What I Have Tried to Learn Along the Way

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California’s geology is complicated and extremely variable
All significant dam projects in California are under jurisdiction of DSOD and many are also under FERC jurisdiction

- Work plan review
- Site visits and sample/data review during investigations
- Review of summary data reports and geologic interpretations
- Engineering and design review
Challenging geology + complex project + regulatory oversight = Need for informed, comprehensive, and documented investigation

- **Informed**: based upon proven, defensible, and accepted techniques
- **Comprehensive**: thorough so that all questions are answered
- **Documented**: all aspects of investigations are recorded and presented for peer review
Many professional disciplines are required to design large complex civil projects like dams, tunnels, bridges, buildings.

- Engineering
  - Civil
  - Geotechnical
  - Hydraulic and Hydrologic
  - Structural
  - Electrical
- Environmental Sciences
- Archeology
- Economics
  … and
- Geology and Engineering Geology
Engineering Geologist’s role in dam design projects is primarily related to site selection and foundation characterization.
Site Selection will be affected by many unrelated project influences

- Geology
- Seismicity
- Property ownership/access
- Environmental conditions
- Archeological resources
- Fish passage
- Hydrology
- Reservoir storage
- Cost/client financial resources
- Availability of construction materials
- Political issues
- Site geometry and space constraints
- …and others

Lake Isabella Dam
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**Foundation Characterization**: qualitative and quantitative description of earth materials upon which the dam and appurtenant structures will be constructed

- Lithology or soil classification
- Structure
  - Bedding
  - Jointing
  - Faults and shears
- Depth of weathering/overburden thickness
- Rock strength or soil density
- Groundwater depth/elevation
- Hydraulic conductivity
- Excavatability
- Corrosive properties

- This is the most **exciting** part of the job for a geologist
Strength and stability: must support all loads imposed (structural, hydraulic, seismic)

- Low permeability: often requires pressurized grouting to achieve
- Seismically stable/non-liquefiable
- Acceptable geometry on both large scale and small scale
Rock foundation vs. Alluvial foundation: Challenges

- **Rock foundation**
  - Unfavorable joints, bedding, or shears
  - Open joints or other voids
  - Difficult excavation (hard strong rock, massive vs. jointed)
  - Variable weathering depth

- **Alluvial foundation**
  - Erodible
  - Permeable
  - Insufficient density or compaction (liquefiable, settlement)
  - Shallow groundwater
  - Variable thickness
Rock foundation vs. Alluvial foundation: Investigations

- **Rock foundation**
  - Continuous core borings
  - Hydraulic conductivity testing
  - Borehole televiwer
  - Borehole geophysical surveys
  - Pressuremeter/dilatometer borehole testing
  - Groundwater level measurements
  - Surface geophysical surveys
  - Geotechnical rock lab tests

![Seismic Refraction Survey](image1)

![Pressuremeter Probe](image2)

![Pressuremeter Installation](image3)

![Borehole TV Image](image4)
Rock foundation vs. Alluvial foundation: Investigations

- **Alluvial foundation**
  - Rotary wash borings
  - Drive samples with calibrated energy hammer
  - Sonic borings
  - Becker penetration test borings
  - Borehole geophysical surveys
  - Groundwater level measurements
  - Geotechnical soil lab tests
1. Dam Construction on Rock Foundation: Los Vaqueros Dam (built 1997 and 2012)

- Challenge: Translational bedding plane slide in proposed dam foundation area

Access paths to investigate bedding plane slide mass

Original right abutment topography

Upper part of slide mass with slot excavation
1. Dam Construction on Rock Foundation: Los Vaqueros Dam

- **Solution:** Rockfill replacement of earthfill for part of downstream embankment

Midway through rockfill solution. Note mass concrete backfill at top provided cutoff and core foundation.

Scarified bedding plane surface

Upper part of slide mass with slot excavation

Completed dam raise project

– Challenge: Part of dam foundation on NOA-bearing rocks

Serpentinite/shale mélange and clay dam core material

Serpentinite/shale mélange foundation on right abutment

Final cleaning of non-NOA-bearing Tertiary sandstone foundation on left abutment

NOA = Naturally Occurring Asbestos
2. Dam Construction on Rock Foundation: Calaveras Dam Replacement Project

– Solution: Rigorous dust control and use of PPE
3. Existing Dam on Alluvial Foundation: Uvas Dam (built 1957)

- Challenge: Alluvium of uncertain density present within foundation of existing dam
3. Existing Dam on Alluvial Foundation: Uvas Dam

- Solution: Combination of geophysical surveys, sonic, SPT and BPT borings, and geotechnical lab testing

Sonic drill rig on downstream midslope bench

Rotary wash drill rig used for SPT sampling from dam crest

BPT drill rig at toe of dam

IBPT ready for driving
4. Proposed Dam on Volcanic Rock Foundation:

- Challenges: Steep difficult-access abutments in hard volcanic rocks with potential for open vertical joints and high permeability flow-top layers, possible shear zone under river
4. Proposed Dam on Volcanic Rock Foundation:

- **Solution:** use of helicopter-access drills, vertical and inclined core borings, TV log all borings, packer test all borings, and detailed mapping.
5. Dam Constructed on Limestone Foundation: Amistad Dam (built 1969)

- Challenges: Long dam, spans international border, jointed karstic limestone with abundant seepage

- Concrete gravity spillway section of Amistad Dam

  - 6+ mile long embankment dam
  - Built on US/Mexico border
  - Central concrete gravity section with gated spillway

- Small whirlpool in reservoir over sinkhole

- Seepage weir downstream of dam

- Collected seepage downstream of dam
5. Dam Constructed on Limestone Foundation: Amistad Dam

- Solutions: drill 78 borings*, packer tests, borehole and surface geophysical surveys, dye trace seepage flow study

Tracked sonic drill performing angled hole on dam crest

Truck sonic drill performing vertical hole on dam crest

Results indicated that:
- Seepage is concentrated in discreet areas along pre-existing fractures mantled on the ground surface by younger alluvium.
- All dye injection points connect with almost all downstream receptors (i.e., there is good connectivity between fracture systems.
- High conductivity portions of boreholes correlated very well with voids observed in TV logs but not always with zones of lost core.
- Difficult to discern bedrock fractures with surface geophysical surveys.

* Borings on embankment (rocky earth fill) were started with sonic technique and then switched to rotary wash wireline core technique once rock was encountered. All other borings were started with rotary wash technique.
Lessons Learned

1. Review all available published and unpublished geologic data
2. Consider foundation type and related concerns/challenges
3. Develop initial investigation plan to address concerns/challenges
   • Borings: type, orientation, location, depth, spacing, number
   • Samples: type, spacing, contingency if difficult to collect
   • In situ testing: piezometers, hydraulic conductivity, seismic velocity, strength/modulus
   • Other: trenches/test pits, seismic refraction/reflection,
4. Revise plan based upon client and regulatory agency feedback
5. Perform initial investigation
6. Go back to 2, above.
Questions?