APPLICATION OF GEOTOMOGRAPHY AT THE
MONKS HOLLOW DAMSITE, UTAH

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Abstract
An integrated seismic investigation at the Monks hollow damsite demonstrated the
importance of concomitant field engineering studies and wide-aperture geophysical testing
to assess, define, and quantify the lateral and vertical extent of variable rock strength
present in an abutment for a proposed arch dam. Seismic common offset, refraction and
tomography surveys were conducted within the right abutment adit and on the ground
surface. The surveys defined the lateral extent of low moduli rock, associated with
jointing, faulting, and poor cementation; and also identified the presence of high moduli
material, indicative of well cemented and unfractured rock.

Introduction
During the summer of 1989, a multipurpose geophysical program was implemented at the
Monks Hollow Damsite located approximately 30 miles southeast of Provo, Utah.
Extensive geological and geophysical investigations were undertaken to better define rock
mass properties within the entire foundation. Due to an abrupt termination of the Monks
Hollow project, a comprehensive analysis of the field data was not possible. The following
is a summary of the geophysical investigations performed to assess the character of the
right abutment.

An exploration adit was excavated (unsupported) approximately 300 feet into the right
abutment. The rock exposed within the adit consists almost entirely of Jurassic-age
Nugget Formation which is a fine- to medium-grained sandstone. Near the end of the
exploration adit an inactive normal fault was encountered (F5), where Jurassic-age micritic
limestone of the Twin Creek Formation was down-faulted against the Nugget Formation.
Engineering geologic investigations indicated that the Nugget sandstone had a wide
variation in material properties. A geophysical program consisting of common offset
surveying, refraction profiling, and tomographic imaging was implemented to obtain a
quantitative assessment of moduli and rock-mass variability, primarily within the Nugget
sandstone.

Common Offset Surveys
The common offset survey utilized geophones horizontally attached to the adit rib spaced
on four-foot centers along the entire adit length. A 24-channel floating-point seismograph
recorded repeated hammer blows against the rock rib. Each geophone location also
represented a shot point. Common-receiver gathers (i.e., receiver signals recorded at a
common distance from the shot points) were processed in the field for every offset
distance. The most useful offset was the 16-foot gather (receiver/channel 3) which
displayed anomalous delayed first arrivals, frequency dispersion, and attenuated body
waves. The qualitative nature of this method allowed quick and accurate determination of the existence, characteristics, and/or extent of: 1) shear/fracture zones; 2) poorly cemented sandstone; 3) dolomite cemented sandstone; 4) fault gouge and breccia near the F5 fault; and, 5) competent/high moduli limestone. The results provided a useful tool for semi-quantitative assessment of Nugget sandstone exposed in the right abutment adit.

**Refraction Profiling**

In order to quantify the information provided from the common offset data, compressional-wave refraction profiling was implemented utilizing a slightly different approach to typical refraction data processing. With each shot record obtained from the common offset survey, which represents a 24-channel single-ended refraction spread, the seismic wave arrivals were interpreted as lateral variations in velocity rather than with depth into the adit rib. That is, assigning velocity branches to the travel time curve revealed that increasing velocity with distance along each spread was the exception rather than the rule. Examining each shot record in detail allowed the position of small, high and low velocity zones to be identified. A plot of P-wave velocity versus station was obtained for the entire length of the exploration adit. P-wave velocities ranged from 2,825 to 7,387 ft/sec in the Nugget Formation, and from 9,200 to 11,424 ft/sec in the Twin Creek Formation. This refraction program allowed direct correlation of observed P-wave velocity data with uniaxial jacking test moduli data obtained at four locations within the adit. The correlation showed a linear dependence between P-wave velocity and elastic modulus, with 89 percent confidence limits, thereby allowing interpretation of modulus variations everywhere P-wave data was obtained.

**Tomoagraphic Imaging**

After the results of seismic common offset and refraction profiling proved useful for determining rock properties along the adit rib, there was a desire to determine the rock properties from the adit up to the ground surface. Seismic tomoagraphic imaging was utilized for this purpose. Using a fabricated scheme for mounting geophones along the crown of the adit on 4-foot centers, signals could be recorded from explosive charges detonated on the ground surface directly above the adit. This set-up provided a 2-dimensional slice of the right abutment where P-wave velocities were computed using a standard algebraic reconstruction technique for straight ray-paths between shot points and receivers. The panel imaged by tomography was approximately 200-feet long (adit length) by 80-feet high (depth to adit). More than 860 ray paths traversed the panel providing a resolution pixel of 4 square feet.

The range of velocities obtained by tomography is very comparable to that obtained during refraction testing. A very good correlation exists between the tomography velocity data obtained along the adit crown (base of the tomograph) and the refraction velocity profile obtained on the adit rib. Only at localized high and low velocity zones detected by the refraction survey did the two independent data sets differ significantly. The tomography results are suggestive of a rock abutment with highly variable rock strength, both laterally and vertically.

The tomography investigation revealed: 1) a distinct area of low velocity associated with
the existence of the F5 fault near the end of the adit; 2) the presence of moderate velocity zones localized around existing shear zones mapped in the adit; and, 3) the presence of a relatively high velocity zone, indicative of well-cemented material, which cuts diagonally across bedding. The 2-dimensional slice of the abutment could now be imaged with respect to elastic moduli utilizing the correlation equation between P-wave velocity and modulus derived from the refraction study and in situ jacking tests. The areas of low and high velocity, that is, low and high moduli, defined by tomography enhanced foundation design for the concrete abutment buttress such that the low strength materials defined could be dealt with by increasing the size of the foundation pad, thus reducing stresses and equalizing strain over the entire foundation.

A 3-dimensional picture of the abutment was obtained by similarly acquiring tomographic data above a short drift (55-feet long) which was excavated perpendicular to the adit along the proposed centerline of the dam. Results above this drift also revealed the presence of the high velocity material identified above the adit, as well as low velocity material around known shear zones. Combining the drift and adit tomographs defined the strike of the high velocity zone to be northwest-southeast with a steep dip to the southwest. There is a remarkable correlation along the intersection of the two tomographs (adit and drift panels) which were acquired, processed, and displayed separately.

Summary of Conclusions

1) Common offset survey results were particularly useful for:
   - Geophysically delineating the known shear zones encountered in the adit.
   - Defining areas of fractured rock (some not previously geologically mapped).
   - Identification of weak, poorly-cemented rock; and, hard, well-cemented rock.
   - A very quick, efficient, and inexpensive qualitative assessment of lateral variations in material properties.

2) Refraction profiling permitted:
   - Definition of very low velocity rock, associated with poor cementation and fracturing.
   - Definition of high velocity zones, associated with dolomite cemented sandstone.
   - The resulting adit velocity profile revealed the variability of rock properties within the Nugget Formation, not recognized in the limited surface exposures.
   - Correlation between P-wave velocity and jacking test modulus values obtained at several locations within the adit.
   - A rapid, inexpensive method for mapping variability of rock strength along the adit.

3) Tomographic imaging provided:
   - A 2-dimensional slice of P-wave velocity variability in the Nugget sandstone between the ground surface and the exploration adit.
   - Identification of a large low-velocity zone adjacent to the F5 fault.
- Identification of a steeply dipping high-velocity zone, possibly associated with dolomite cementation.
- A 3-dimensional picture of the right abutment by combining the results of the adit tomograph with the tomograph acquired above the drift.
- An ability to 3-dimensionally map the variability of rock modulus based on relationships derived from refraction surveying and in situ jacking tests.
- A new method for determining variability in rock-mass properties with a non-destructive geophysical technique on a large, 3-dimensional, scale.
- Alternative designs for foundation preparation and construction.

As hindsight would have it, these geophysical investigations were all performed after the variability in rock strength was identified by expensive large scale uniaxial jacking tests. Selection of location and orientation for jacking tests were based on preliminary engineering geology assessment and principal stress direction calculations. Everyone involved with this project agreed that had the geophysical investigations preceded the these jacking tests, quite possibly, more definitive testing could have been conducted in areas of high or low strength materials delineated by the geophysical testing. And that, may be the biggest conclusion to be derived from this study.