3D Geophysics
For Infrastructure
Phil Sirles - Olson Engineering
Geo-Modeling - Interpretation

How to Make Sense of the Model?
Visualization – Out of Lego-Space
Modeling and Analysis Package (MAP) For Near-Surface Imaging (i.e., Subsurface Characterization)

- Modeling Definitions / Approach
  VERY BASIC

3D Case Histories

- Geotechnical Foundation Investigation – Vail, CO
- Roadway Subsidence Investigation – Blue Ridge Pkwy., NC
- Dam Stability / Sinkhole Analysis – Knoxville, TN
- Evaporite Karst Investigations – sorry confidential site(s) – active projects
3D Modeling Capabilities

- **Loading**
  - Small Strains - *Seismic waves*
  - Large Strains - static & dynamic load analysis, subsidence, slope failure

- **Discontinuities (NDE)**
  - Cracks, crack propagation, distinct layers, blocks of arbitrary shape

- **Linear supports (NDE)**
  - soil nails, roof bolts, rebar
3D Model Future Abilities

- Optimized for **seismic wave propagation**, for both forward and inverse modeling
- Supports tomographic and holographic inversion: **Tolography™**
- **Soon** - full-waveform seismic inversion (FWI)
- Built-in signal processing capabilities via AI
Value of MAP Approach

The MAP approach combines & optimizes the discrete element method of numerical modeling with particle flow code, material point method, and finite differencing to produce **2D & 3D MODELS** of the subsurface … **NOT IMAGES** of the subsurface.

These **calibrated models** can then be used for further engineering evaluations (e.g., large-strain cracking, subsidence, or slope-stability; or, small-strain static or dynamic loading).
Earthen Dam Investigation
Chilhowee Dam, TN
Chilhowee Dam was built in 1957 on the Little Tennessee River ~72km (45 miles) south of Knoxville.

The dam is owned and operated by Alcoa Power Generating, Inc.
Chilhowee Dam – Plan and Elevation Drawings

405m / 1330 ft

20m / 65 ft

Embankment

Concrete Mid-section & Powerhouse

Embankment
Chilhowee Dam – Typical Section

Crest Elev. 269.1m (883 ft)

Upstream-sloping impermeable clay core

Filter System

Shell

Shell
START WITH BASE / CONCEPTUAL MODEL DEVELOPMENT – USE AS-BUILTS
BUILD CARTESIAN GRID
CROSS-SECTION MODEL DEVELOPMENT WITH AS-BUILT DAM SECTIONS
FIELD WORK – 3D ACTIVE GRID OF GEOPHONES (120 ch’s)

(5) 24-Ch DAQ’s
(120) 14-Hz Phones
(156) 10-blow SP’s
19,344 Ray Paths
LEGEND:

- **Geophone**
- **Shot Point**
- **B-2B** Boring Location and Number
- **Surface Feature**
- **Ground Surface**

3D Model – Ground Limits

3D Model – Limits

Velocity (ft/s *1000)
3D Perspective View – Full MAP Model Space

12,300 sq ft & 48 ft DOI = 590,400 cubic feet.

→ 12 hour run-time for the Desired 2-foot resolution

→ A total of 246,310 elements were used with a total of 2,864,508 velocity links.
Prospective View
(Angle 100°)

Axis of Low-velocity “trough”
Base of Low-velocity “trough”
Elevation Slice at 875 feet, ~middle of low-velocity ‘trough’ (8’ below crest elevation)
Elevation Slice at 875 feet, ~middle of low-velocity ‘trough’ (8’ below crest elevation)
Elevation Slice at 867 feet, ~base of low-velocity ‘trough’ (16’ below crest elevation)
Elevation Slice at 867 feet, ~base of low-velocity ‘trough’ (16’ below crest elevation)
Chilhowee *Won* the “Construction Project of the Year” award (for PB) at the USSD 2018 Annual Convention! Michael McCaffrey was PB’s Principal Engineer (EOR)

McCaffery, M., Sirles, P., et.al., 2009, Using Geophysics to Evaluate an Embankment Dam Sinkhole – Chilhowee Dam, TN, in Proceedings for the 29th Annual USSD Conference
Tight 3D Seismic Investigations for 3D ‘Foundation’ Investigations (1-2 ac sites) → Karst Problems
Tic-Tac-Toe Pattern: 96 Channels & 37 Shot points
Ray Coverage Tic-Tac-Toe Pattern: 96 Channels & 32 Shot points
Star Pattern: 96 Channels & 32 Shot points
Ray Coverage Star Pattern: 96 Channels & 32 Shot points
How to look “inside” a 3D volume of data:
Lots of plots?
Or … *Slice and Dice*
Visual & Useful Results To Give To The Client → 3D Output

Oasis GeoSoft Montaj Geophysics Package

- Data Analysis & Processing
- Visualization of Results
- *FREE* Viewer of (3D) Results
Visual & Useful Results To Give To The Client \(\rightarrow\) 3D Output

Oasis GeoSoft Montaj

Example Project Video Output
Geotechnical Site Characterization (China Lake Naval Weapons Facility)
MAP at a 22-ac Site to 250 feet below ground – 3D Imaging

SITE 3

Blue=Soil
Orange=Weathered Rock
Red=Hard Rock
WRAP UP
Decades of Growth to get to 3D MAP!

1988
1998
2008
2018
GRM Results → Layered Solution: Images (Cross-Sections)!
Tomography Results \(\rightarrow\) Pixel Solution: Images are Cross-Sections
MAP Results → 3D Model Output
Prospective View
(Angle 100°)

Axis of Low-velocity “trough”

Base of Low-velocity “trough”
GeoSoft Results → 3D Digital Output!
CONCLUSIONS

- Numerical Modeling is a powerful tool that can / should be used (when appropriate)
- Calibration and validation are available w/ geology and geotech info
- Models deliver more than an image
- MAP is an evolving software (*not done yet!*)
- Full waveform evaluation will be valuable
Thank You!

Any Questions?