BRIERLEY ASSOCIATES
Creating Space Underground

IN DEPTH
September 2015

Numerical Modeling

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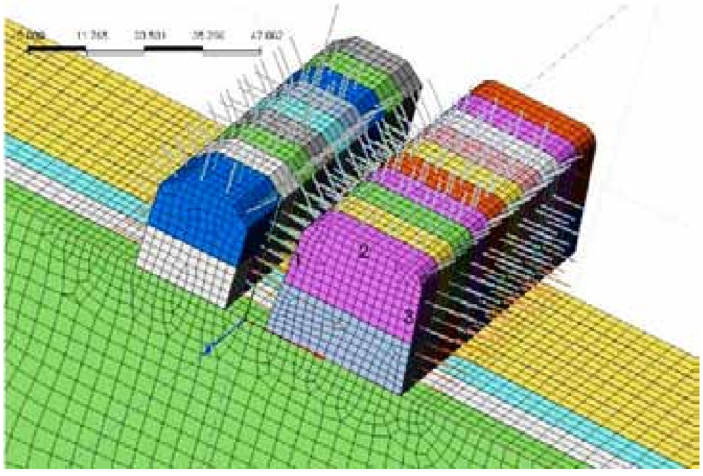
As the breadth and complexity of projects have increased so has the need to develop and evaluate solutions with the end result being an effective, efficient and constructible design. Brierley Associates' tradition of service embraces complex and challenging projects. As we move into our sixteenth year of operation, Brierley Associates increasingly takes advantage of geotechnical numerical modeling software such as Midas GTS and other platforms. Dr. Mohamed Gamal, Dr. Eric Lindquist and Phillip Burgmeier lead our modeling efforts. Recent projects include: expansion of underground facilities at Fermi National Accelerator Laboratory in Batavia, IL; evaluation of salt mine behavior in Virginia; and the design of the access shaft to retrieve "Bertha" in Seattle, WA.



Locations of survey target points in the existing MINOS Access Tunnel at Fermi Lab

Near-Detector Hall at Fermi National Accelerator Laboratory in Batavia, IL

Chamber excavation in Scales Formation

Fermilab, located in Batavia, Illinois conducts essential physics research. As part of the ongoing evolution of the laboratory, a new Near Detector Hall (NDH) was designed and constructed adjacent to the Main Injector Neutrino Oscillation Search (MINOS) Hall. This new cavern is 350-ft underground, and is 20-ft wide by 22-ft high by 75-ft long.

Some of the design challenges included: the relatively weak Scales Formation; deformation limitation to protect the existing large magnets and; the thin rock pillar to remain between the existing tunnel and the proposed hall. Dr. Gamal completed 3D finite element analyses (FEA) to determine the most effective support system and construction sequence to maintain stability of the proposed and existing facilities.

FEA led to these recommended project changes

- Construct 8-ft drifts instead of the 10-ft drifts shown in the bid documents. This alternative minimized exposure of the Scales Formation to moisture and expedited installation of rock support.
- Rather than using tie-rods to reinforce the pillars as proposed by the owner's designer; Brierley developed a procedure to install grouted, pre-stressed bolts from the existing MINOS Access Tunnel before the start of the new NDH excavation. By doing this, the effect was some confinement to the pillar, thus, reducing the potential of opening and loosening of small discontinuities under the loads induced by the excavation. This confinement helped maximize arching of the load above the new opening.
- To improve load arching above the relatively thin rock pillar that was to remain, spot pre-stressed rock bolts were also installed in the existing MINOS Access Tunnel.

During construction, survey readings of the pillar section agreed favorably with the values predicted by the model. Most importantly, both the model and the field measurements showed that the maximum deformation change did not occur at the reinforced pillar, but took place at the unreinforced vertical wall opposite to the reinforced pillar, which indicates that load arching above the opening was successfully achieved.

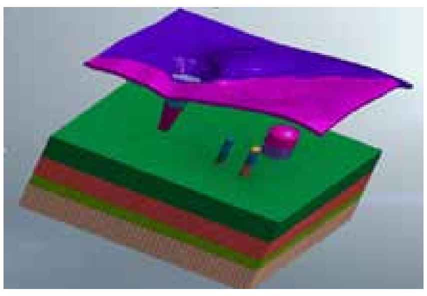
Finite Element Modeling for Deep Caverns, Saltville, VA

Brierley Associates was retained to develop a three dimensional (3D) continuum Finite Element (FE) analysis to investigate the mechanical behavior of several existing deep caverns and potential new caverns. One of the largest caverns had an excavated diameter of 300-ft. Other caverns had excavated diameters that ranged from 80-ft to 90-ft with heights up to 100-ft. Given the variable surface topography above the caverns, a digital terrain model was developed and "draped" above the existing and proposed caverns to accurately simulate different scenarios.

Actual digital terrain model used to develop the model on the right.

Initially, benchmark finite element runs were carried out by modeling only one uniform cylindrical cavern within a monolithic media and imposing a simple loading condition. This yielded less accurate results as reflected by the noise level in the contour plots for the initial in-situ stress condition. By changing the model and using hybrid elements the results were excellent for the same initial condition with almost zero noise.

The benchmark runs were compared against the results obtained from the analytical solution for simple loading conditions for verification. These runs were also used to establish the FE mesh extent in the horizontal and vertical directions and to determine the proper size of the elements. This expansive model was 4,800-ft by 5,200-ft and extended to a depth of 6,200-ft. Ultimately, our modeling efforts determined the most appropriate construction scenario, drift dimensions and the minimum salt beam thickness above the caverns to minimize creep.



3D FE model for deep strategic gas storage. Parts of the model are removed to expose the storage caverns and the deep pre-existing sinkhole.