Engineering
UPDATE©
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# MINE SUBSIDENCE DAMAGE DURING CONSTRUCTION OF MEDICAL CENTER AND REMEDIAL MEASURES

A ground subsidence event occurred during construction of a medical center after a shallow foundation system, and utilities for a surgery center extension were installed. MEA was contacted to perform an emergency engineering evaluation and subsidence remediation for the building site of the medical center located in Fort Smith, Arkansas.

FIGURE 1: PICTURE SHOWING SAG SUBSIDENCE WHICH FORMED DURING CONSTRUCTION AND ENCOMPASSED AN ELEVATOR PIT

The subsidence that occurred at the building site resulted form an underground room-and-pillar coal mine from the early 1900s. No mine map was available and, consequently, any stabilization considered would have to be done in the “blind”. The drilling data indicated that mine was 20 to 37 feet deep with rooms that averaged 10 feet wide to over 25 feet in some places and were flooded with groundwater 7 to 13 feet deep. From site drilling, it was determined that the support pillars were narrow and less than 20 feet wide. The estimated extraction ratio of coal was about 50% (based on all the drilling done on the site). The subsidence during construction from underground coal mining occurred when the elevator pit tilted and settled up to 20 inches and the neighboring footings tilted toward the sag center about 1 inch from the surface subsidence (see Fig. 1). In order to determine how the subsidence problem could be remediated, an engineering evaluation was conducted focusing on mine roof stability. Subsurface investigation, soil and rock mechanics laboratory testing, and mining and subsidence conditions investigations in and around the site were performed to determine a possible foundation solution.

It was determined that mine grouting was required in order to provide support to the existing roof rock and stabilize already subsided, rubblized areas. Also, to mitigate future settlement of the footings from previously disturbed collapsed areas, a deep foundation system was essential. The shallow foundation system installed prior to the subsidence event consisted of conventional perimeter and interior footings.

After the drilling and testing were complete, a design plan was developed. The mine grouting began and continued for about two and a half months. Due to stringent EPA requirements for the use of fly ash in grout mixes, no such component was considered in the mix design. However, to bring considerable cost savings to the mine grouting, bentonite was used in the mix design. The use of bentonite is an innovative and unconventional material to use in this type of application but proved to be not only economical but reliable. The project required 3,441 cy of grout to complete. Also, a total of 796 boreholes were drilled to inject the grout; 377 holes were void and 419 were found to contain coal. A total of 23,946 lineal feet of drilling was executed at the site.

MEA determined that there were two viable solutions for the deep foundation system: (a) installation of driller piers, or (b) installation of micropiles. The installation of micropiles was found to be the most cost-effective alternative. The presence of unstable hole sidewalls from poor ground conditions proved a challenge, as the micropiles could not be installed using standard procedures. After several unsuccessful pile installation attempts, the procedure had to be modified.

The procedure consisted of drilling the hole, driving the pile casing in, grouting the hole and, lastly, inserting the reinforcing bar with centralizers. To verify this pile construction procedure and the adequacy of the design of the pile system, pile verification tests were performed prior to the installation of production piles (see Fig. 2). The verification tests met the design criteria (i.e., the deformation at Design Load (DL) should not exceed 0.5 inches and the slope of the load-deformation curve should be within 0.15 mm/kN). Proof tests were also performed to verify the adequacy of the installation of production piles. As in the verification tests, the proof tests also met the requirements.

FIGURE 2: PILE VERIFICATION TEST SETUP

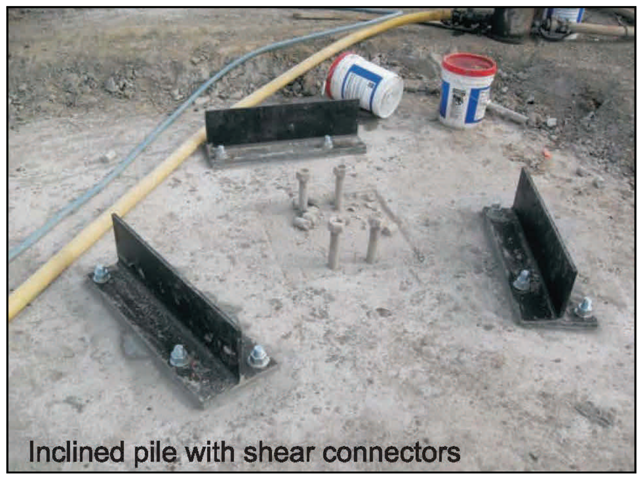


FIGURE 3: FOOTING SUPPORTED ON THREE PILES

The design of the micropile was based on the structural load being transferred by friction into mine floor rock in order to support these loads safely. Because excessive mine subsidence occurred over the building footprint, it was assumed that the overburden to the bottom of the coal layer was not reliable and could not be used to provide significant structural support by friction for the micropile proposed system. Therefore, frictional load transfer from the micropiles was considered to take place 2 feet below the mine coal layer. Also, due to disturbed overburden from adjacent mining, no load transfer from the pile to the surrounding soil was assumed. Coring of the 30 foot rock beneath the coal mine bottom showed that the floor material had a 4,500 psi to 10,000 psi uniaxial compressive strength. A nominal grout-to-ground bond strength of 8.50 tsf was verified during the field verification test. A factor of safety of 2.5 was used to estimate the bond length. Based on structural load application for each footing, three different pile types were used (Type I, Type II, and Type III) which have different capacities. Also, two different types of pile installation (vertical and inclined) were used based on the lateral design load condition. The number of vertical piles was estimated based on the pile capacity when the lateral load was less than 7 kips. When the lateral load exceeded this value, a set of three batter piles was used to provide the lateral resistance through the horizontal component of the pile axial load.

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**Other Engineering UPDATES of Interest:**

UPDATE 1: Successful Deep Mine Backfilling to Mitigate Mine Subsidence

UPDATE 6: Subsidence Mitigation by Combining Foundation Treatment with Deep Mine Grouting

UPDATE 24: Anatomy of Grouting Mine Voids

**ABOUT MEA:** Marino Engineering Associates, Inc. focuses on engineering research, practice and expert evaluations and is licensed in 24 states in the U.S. Our projects primarily have an emphasis on Geotechnical Engineering, however, we also have significant experience in projects involving transportation, subsidence engineering, laboratory testing, training, and geophysical exploration. Gennaro G. Marino, Ph.D., P.E., D.GE is president and principal engineer of Marino Engineering Associates, Inc., and has been a licensed professional engineer since 1984. To obtain additional information on MEA, one can also visit our website at www.meacorporation.com.

**FOR MORE INFORMATION:** There is a significant amount of additional information that is available on the above subject. For more information, please contact Dr. Marino at the address listed below.

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