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Structural Monitoring at a Pressurized Grout Remote Backfilling AMLR Project at Beulah, North Dakota

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ABSTRACT

In the summer of 2000, the North Dakota Public Service Commission conducted a pressurized grout remote backfilling project within a residential neighborhood in Beulah, North Dakota. Grout was pumped into shallow mine voids directly underneath homes, driveways, city streets and other structures. Specialized surveys and monitoring techniques were used to minimize the risks of property damage resulting from grout injection. These included visual inspections, pre- and post-construction ground surveys, installation of crack monitors, and other types of stress monitoring. Although some surface lifting occurred, there was no significant damage to homes or other private property.

INTRODUCTION

The Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission (PSC) is charged with the reclamation of hazardous abandoned mine sites in North Dakota. Beulah is located in west-central North Dakota, about eighty miles northwest of Bismarck. Lignite coal mining has been, and continues to be, a principal industry around Beulah. Several underground room and pillar lignite mines were operated in and near Beulah from the early 1900's until about 1955. Mined coal seams in the Beulah area are relatively thick and the overburden is unconsolidated and shallow. As the underground mines have deteriorated with time, deep collapse features, or sinkholes, have surfaced. These features usually occur suddenly and are very dangerous, especially when they occur at or near residential and commercial areas and public roads.

Pressurized grout remote backfilling is a method of filling underground mined workings before they collapse to the surface. In this technique, also known as pumped slurry backfilling, mine flushing, and pressure grouting, a cementitious grout is pumped under pressure through drilled holes into the mine cavities to fill them and reduce the likelihood of collapse. After injection, the grout hardens and stabilizes the overburden to prevent collapse of the mined workings. In the summer of 2000, the AML Division conducted a pressurized grout remote backfilling project within and near the city of Beulah. An objective of this project was to stabilize collapsing underground mined workings beneath a residential area. Drilling was conducted in yards, driveways, city streets and boulevards and grout was pumped through these holes into mine voids directly beneath houses and other structures.

Pumping grout into shallow mine voids may cause surface lifting that can damage structures. Several techniques were used during the 2000 Beulah/Zap Phase IV AML Project to document any structural movements resulting from grout injection and to reduce the probability of serious structural damage. The structural survey and monitoring techniques used during this project have been developed through conversations with representatives of other states and over the past ten years of pressurized grout remote backfilling projects in North Dakota. To my knowledge, this is the first published paper devoted to the topic of structural surveys and monitoring for pressurized grout remote backfilling projects. I hope the information provided can be useful to other reclamation professionals utilizing pressurized grout remote backfilling for underground mine stabilization in residential or commercial areas.

HAZARDS FROM UNDERGROUND MINE SUBSIDENCE

Land subsidence refers to the lowering, sinking, or collapse of the land surface. In the US, more than 17,000 square miles in 45 states have been directly affected by subsidence[1]. The principal causes are aquifer system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost[1]. In 1991, the National Research Council estimated that annual costs from flooding and structural damage caused by land subsidence exceeded $125 million[1].

Underground coal mine subsidence has caused serious damage in several states including Colorado, Illinois, North Dakota, Ohio, Pennsylvania, West Virginia, and Wyoming. Wilbert et.al.[2] listed at least seventeen dangerous subsidence events in the city of Rock Springs, Wyoming, associated with underground mining. These occurred near a hospital, several residential and commercial areas, and city streets. Colaizzi, et al.[3] discussed reclamation of subsidence events under a municipal swimming pool, near a church, and under the foundation of a house in Rock Springs. On March 4, 1995, mine subsidence caused a section of Interstate 70 to suddenly collapse in Guernsey County Ohio[4]. Four vehicles were damaged as they swerved to avoid the nine-foot deep sinkhole but fortunately no serious injuries were sustained.

The City of Beulah, North Dakota, also has a history of dangerous sinkholes resulting from underground mine subsidence. In the early 1980s, sinkholes near the Sun Valley Trailer Park and Mercer County Highway 21 in Beulah prompted an OSM Emergency backfilling project to stabilize the surface from further collapse. Dangerous sinkholes near the Beulah Eagles Club led to exploratory drilling and a subsequent reclamation project in 1992 in which grout was pumped through holes drilled through the floor of the building[5]. In 1993, collapse of underground mined working caused a 20’ diameter and 10’ deep sinkhole directly underneath the Black Diamond Lounge in Beulah[6]. This sinkhole damaged the foundation, severed water lines and damaged air conditioning units in the building. In a 1997 reclamation project, grout was pumped through holes drilled inside and outside this building to stabilize the collapsing mined workings. Several dangerous sinkholes surfaced in the late 1990s near KHOL Radio Station in Beulah. One of these was 75’ long, 30’ wide and 30’ deep. A pressurized grout remote backfilling project to stabilize the mine under the radio station was conducted in 1999. On November 25, 1998, a sinkhole surfaced in the front yard of a residence in Beulah causing a sewer line break and damage to the yard and sidewalk. This sinkhole was repaired immediately and the grouting project that was conducted in this neighborhood in the summer of 2000 is the subject of most of the remainder of this paper. As recently as February 2001 two serious sinkholes surfaced in a machine shed about two miles north of Beulah. Figure 1 depicts one of these, about 20' diameter and 12' deep, that "swallowed" a tractor[7].

Figure 1: Underground mine subsidence "swallowed" this tractor in a machine shed north of Beulah, ND.

THE 2000 BEULAH/ZAP PHASE IV AML PROJECT

Since 1983, fifteen major reclamation projects and several smaller ones have been conducted at or near Beulah at a cost of over $5.3 million[8]. These projects have entailed either surface grading of sinkholes or remote backfilling of underground mined workings. The 2000 Beulah/Zap Phase IV AML Project was the fourth of a multi-year series of projects intended to address all remaining high priority AML problems near Beulah and Zap. The project series is anticipated to continue at least until 2004 (Phase VIII).

The 2000 Beulah/Zap Phase IV Project focused on stabilization of undermined homes, residential lots and streets in the Schmidt & Collieries Additions in Beulah. A small local underground lignite mine was operated in this area in 1916 (possibly earlier) and 1917. No mine maps are available and details about the mine are sketchy. After hearing reports of past subsidence in the area, the AML Division conducted limited exploratory drilling along city streets in this neighborhood in 1993. Exploratory drilling was scheduled to continue in 1995 but property owners would not consent to allow drilling in their yards and driveways. In 1998 a dangerous sinkhole, approximately eight feet in diameter and ten feet deep, surfaced in the front yard of Mrs. Della Bauer, 408 1st Avenue, Beulah. This prompted residents to reconsider and additional exploratory drilling was conducted in 1999. Approximately 430 holes (about 27,000 lineal feet) were drilled at this site between 1993 and 2000. One hundred fifteen of these holes intercepted mined workings and these holes (4869 lineal feet) were cased with three inch inside diameter Schedule 40 Polyvinyl Chloride (PVC) Pipe.

Work on the Beulah/Zap, Phase IV Project began May 23, 2000. The contractor, Earth, Energy and Water Systems, of New Salem, ND, began by constructing a concrete batching plant and mobilizing equipment to the site. Grout injection began June 12 and was completed August 7, 2000. Grout was hauled to the residential area in mobile mixer trucks and was pumped into the mined workings, through cased drill holes, with a Morgan Mustang 9-65 Grout Pump (see Figure 2). Grout injection continued until all void areas were filled to refusal, until ground lifting

Figure 2: Pressurized grout remote backfilling near the Jack Thielman residence in Beulah.

occurred or until injection pressures indicated that surface lifting was likely. A total of 1716 cubic yards, or about 215 truckloads, of grout were injected into mined workings at the City Site. An additional 3160 cubic yards were injected beneath a segment of Mercer County Highway 21 about 1½ mile north of the residential area. The total contract costs (construction and material testing) for this project were $371,430.

STRUCTURAL SURVEYS AND MONITORING

Because pressurized grout remote backfilling poses risks of surface lifting and resultant damage to buildings and structures, specialized surveys and monitoring techniques are prudent. Barnard[9] recommended the owner and engineer implement a survey of all structures to be affected by the project. He suggested a survey similar to those conducted by mining companies for structures in close proximity of blasting operations. The survey should document existing damage and potential problems with photos and diagrams. Any existing damages to walls, framing, foundations, concrete slabs or sidewalks should be recorded and all existing cracks should be measured with a ruler. This lets the contractor know he is responsible for damage caused by his activities and provides a reference for comparison if the homeowner has complaints or concerns after the project.

Barnard[9] recommended including the homeowner's input into the pre-construction survey. The homeowner can provide information not easily obtained by the engineer such as the location of gas lines, drainage problems around the house, and sensitive items (i.e. hedges, flower gardens) that must not be damaged by the project. Barnard suggested "block meetings" to introduce the pre-construction survey and to keep homeowners informed about the construction process. In conjunction with these, a quick response method for dealing with complaints should be established. Also, the contractor's plans for ensuring the safety of citizens near the work area should be clearly communicated.

Beechie[5] conducted a pre-construction survey of the Beulah Eagles Club building prior to grout injection beneath it. The AML Project Manger, the contractor's superintendent, and an engineer contracted by AML conducted the survey. This survey included a map showing all structural flaws of the foundation, floor, walls and ceiling. Video and still photography were also used to document the pre-construction condition. This survey was considered a necessity in order to relieve the contractor from unwarranted disputes with property owners and as evidence if a dispute arose between the owner and contractor about liability for damages.

During the 2000 Beulah/Zap Phase IV Project, grout was pumped into mine voids that were generally less than fifty feet below surface. In most cases, the underground mine had already begun to collapse and the void areas were interspersed between the original mine level and the surface. These mine voids were located directly beneath homes, driveways, sidewalks, city streets and other structures. Overburden at the City Site generally consisted of unconsolidated glacial till, sand and clay. In order to stabilize the surface and prevent subsequent collapse, the mined voids had to be filled as completely as possible. Since the mine was already in an intermediate state of collapse, the grout needed to be pumped with sufficient pressure to penetrate rubble between void pockets. However, the pressure required to completely fill the mine voids also had the potential to cause surface lifting. This surface lifting could potentially cause serious damage to houses, driveways and other structures.

In order to conduct this project as efficiently and safely as possible, an adequate system of structural monitoring was absolutely essential. This system of structural monitoring was incorporated into design and execution of the project from start to finish. Some of the important components of this system are listed below.

A. Public Participation

It is difficult to overestimate the importance of public participation in a system of structural monitoring for pressurized grout remote backfilling in residential and commercial areas. At the Beulah City Site, a serious subsidence event in the front yard of one of the residents had consolidated public support for this project. On December 6, 1999, the AML Division conducted a public meeting at the Beulah Community Center. The meeting was advertised in the local newspaper and invitations were sent to each property owner in the project area. The risks of surface lifting and the structural surveys and monitoring techniques to be used during the project were discussed at this meeting. All property owners were told that they would be expected to cooperate with the contractors chosen to conduct the project; to allow them access into homes for surveying and monitoring, and to immediately notify the contractor or the AML Project Manager if they believed grouting operations were causing or had caused damage.

The grouting contractor, Earth, Energy, and Water Systems, of New Salem, ND, was required, as a part of project mobilization[10], to conduct a minimum of two informational workshops near the project site. These workshops were intended to provide information and establish agreement and collaboration among interested parties on a framework for successful project completion. The contractor was required to invite all land and property owners or residents, the project foreman, subcontractors, material testers, and any other appropriate state or local authorities. The initial workshop, held prior to any construction, was required to address: 1) a general discussion the project and project timetables; 2) identify goals, objectives, and concerns of all parties; 3) establish roles and communication framework; and 4) define a procedure for rapid resolution of disputes to minimize conflict. Based on information received in the initial meeting, the contractor was required to develop and distribute to all participants an outline that identified goals and objectives, timetables, and a communication and issue resolution framework. This initial workshop gave the contractors an opportunity to introduce the structural surveys and monitoring techniques. Additional workshops were to be held as directed by the AML Project Manager. After project completion, the contractor was required to conduct a post-construction workshop to evaluate the success of the project in meeting goals and concerns.

A post-construction landowner release form was mailed to each affected property owner and resident. This form recorded whether the affected party had complaints, property damage or unfinished clean-up items remaining as a result of the project. If there were any complaints, the contractor was required to attempt to resolve them. In addition, I spoke with each property owner and generated a clean-up and repair checklist that the contractor needed to address before demobilizing.

B. Pre- and Post-construction Structural Surveys

The material testing contractor, Midwest Testing Laboratory, Inc., of Bismarck, ND, conducted the pre- and post-construction structural surveys for this project. In North Dakota AML grouting projects, material testing is bid and contracted separately from the grouting construction project. The duties of the material testing contractor usually include collection and testing compressive strength of grout samples, testing the slump of grout, conducting batch plant inspections and certifying delivery slips and bills of lading. For this project, the material testing contractor was also required to conduct pre- and post-construction structural surveys of buildings and structures at or near the project site and structural stress monitoring of buildings and foundations during grout pumping[11].

The structural surveys conducted at this project site included visual inspections to check for cracking, settlement, heaving, or any other evidence of structural stress or deformities. These surveys were conducted in basements, along walls and floors, foundation walls, garages, driveways, outbuildings, slabs, sidewalks, curbs and any other structures. Cracks or other features were measured with calipers or a crack comparator card sensitive to 0.01 inch. All of these features were numbered and recorded on a chart[12]. Videotapes were also made to record the locations of these features. Each of these cracks or other features was re-inspected and re-measured after completion of the project.

Crack monitors were installed on representative cracks chosen during the visual inspections. Crack monitors are simple gauges used to measure movement of cracks in brick, concrete, and masonry structures. The crack monitors used during this project were purchased from Avongard Products, Ltd., Irvine, CA. Twenty-one crack monitors were installed. Most were installed on the exterior face of foundation walls; one was placed on an exterior slab; three on an interior wall; and one was placed on a retaining wall (see Figure 3). Crack monitors were inspected daily during grout pumping and each inspection was recorded on a crack monitor progress sheet[12].

Figure 3: Crack Monitor installed on a crack in a retaining wall at the Beulah City Site.

Elevation surveys were conducted before and after the project on or near all structures proximal to grout pumping operations. Elevation shots were taken at points on a pre-established grid throughout the project area. Elevations surveyed were required to be accurate to within 0.01 foot. The elevation shots were taken with a rod and level along city streets, curbs and gutters, sidewalks, driveways, inside houses, basements, garages, slabs, and on each manhole cover. Approximately 400 elevation shots were taken at this site of about three acres.

Floor drains were checked and found to be free draining before and after grouting activities. Electrical facilities were also checked and noted to be functioning.

Midwest also assisted the grouting contractor to conduct an ongoing relative elevation survey of structures during grouting operations. Any time that ground movement was indicated, all nearby crack monitors were immediately checked.

C. Continuous Structural Stress Monitoring

The grouting contractor, Earth, Energy, and Water Systems, injected grout through PVC-cased drill holes directly into the underground mine voids and rubblized areas. The contractor was responsible for determining safe grout injection pressures and was required to install a liquid-filled diaphragm in-line gauge to continuously measure grout pressure at the wellhead. The contractor was liable for any damages (surface or sub-surface) arising from, or during grout injection processes. The contractor was required to maintain commercial general liability insurance with minimum aggregate limits of at least $2 million and to indemnify the State of North Dakota. Earth, Energy and Water was also required to submit to the PSC Project Manager, a detailed quick response "Plan-of-Action" in the event sudden surface jacking occurred during pressure-grouting operations [10]. These requirements put the onus and responsibility for safety directly onto the shoulders of the contractor.

Earth, Energy and Water planned to continue pumping grout in each hole until refusal, until grouting pressures reached 50 pounds per square inch (PSI), or until surface lifting or cracking was noted. Grout injection began at the city site on June 12, 2000. On the third day of grout pumping, a "blowout" occurred in which grout was forced out the surface through cracks. This occurred within fifteen feet of an occupied residence. The contractor subsequently reduced the maximum pumping pressure to 30 PSI.

The contractor was required to install laser levels and targets and provide skilled personnel to monitor ground movement continuously during pumping operations near or beneath structures[10]. This is an excellent method to monitor structural movement during grout injection. A rotating laser is used to send a continuous infrared beam in a 360-degree horizontal plane. Optical sensors, or receivers, are placed on structures where ground movement could be expected to occur. Several receivers can be used with one level to monitor movement over a wide area. If any change in the relative level between the instrument and receivers occurs, the receiver has a display that indicates which vertical direction movement has occurred. Many of the laser receivers are equipped with an audio speaker that can sound if a change in level occurs. If movement occurs beneath the laser instrument itself, it stops rotating. Rotating laser levels and receivers are manufactured by a number of companies including, Spectra Precision, Inc., Laser Alignment, Inc., and Apache Technologies, Inc.

Two levels with several receivers were used on this project. When pumping near a house, one of the lasers could be operating outdoors with targets attached to window or door frames, railings, garage walls, or any other external features. Another laser and receivers could be set in the basement to monitor any movement in the floor or foundation walls. If the levels or receivers indicated movement, grout pumping was immediately discontinued and the receivers were reset to measure the movement and all nearby crack monitors would also be rechecked. Earth Energy and Water used Laser Alignment, Model LB-10, Levels and Rod-Eye Receivers. Figure 4 shows this instrument operating in the basement of a home. The accuracy of this instrument is about 12 arc seconds, or 1/16 of an inch at 100 feet. This seemed adequate to detect surface lifting before serious structural damage occurred. The levels detected movement in the basements of two of the homes when grout was being pumped into mine voids beneath them. The contractor was able to stop grout pumping before any noticeable damage occurred in each instance.

Earth Energy and Water also provided skilled personnel to operate and monitor the levels and receivers continuously during the project. A couple times, these personnel could hear creaking in the floor joists of the homes before the level detected movement. The property owners also helped to monitor their own homes. They were asked to watch and listen for any signs of structural stress and to fill and drain a bathtub-full of water each day while grout was being pumped near their houses to make sure water and sewer facilities were working properly. In one instance when damage to sewer lines was suspected, bathtubs of three homes were filled and drained, one at a time, with water colored with food coloring. A nearby manhole cover was removed so personnel could watch for the colored water draining through.

Figure 4: Laser level and target used to monitor structural movement in Thielman's basement.

CONCLUSION

The pre-and post-construction surveys at this site were effective in documenting that there was no substantial movement to structures or concrete flatwork. More than 80 structural cracks were measured before and after construction and no changes were observed. Many other hairline cracks, too small to measure, were also inspected and these had not changed significantly. Twenty-one crack monitors were inspected daily during grout injection and no significant movements were observed. Some very minor changes in alignment of the crack monitors installed on exterior walls and slabs occurred but these were almost certainly due to thermal expansion and contraction. Approximately 400 survey shots taken before and after construction did not indicate any significant structural movement to houses, driveways or any other private structures.

The ongoing structural stress monitoring with rotating laser levels and targets was effective in alerting the contractors to slight structural movement before serious damage occurred to homes or other private property. However, noticeable surface lifting did occur in at least three instances. In each of these instances, levels and targets were not being used at the point where surface lifting occurred.

The first instance was in the back yard of a residence and resulted in the "blowout" mentioned earlier. The second was in the back yard of another residence and resulted in a surface bulge about fifteen feet in diameter and one foot high. This caused some damage to a fence and clothesline and required repair. The third instance, which occurred on July 7, 2000, was the most dangerous. It occurred on a city street and caused a bulge in the asphalt surface about twenty feet long, fifteen feet wide and one foot high (see Figure 5). Grout seeped out of cracks in the street. This required extensive cleanup and repairs. Water and sewer mains running under the street had to be checked but fortunately were not damaged. Earlier on June 30, 2000, a loaded mobile mixer truck had dropped a wheel into a sinkhole that caved through the asphalt just a few feet from where the lifting feature occurred (see Figure 6). Each of these lifting features occurred with less than 50 PSI pumping pressure and the last occurred with only 10 PSI.

The property owners and city officials in Beulah seemed generally satisfied with the structural monitoring and no serious complaints were lodged against the contractor. During the post-construction workshop, held August 21, 2000, several residents complimented the contractor and State on the attention paid to detail in the stress surveys and monitoring.

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Figure 5: Surface lifting caused by pressurized grout remote backfilling on 1st Ave. in Beulah.

Figure 6: Loaded grout truck dropped its front wheel into a sinkhole on 1st Avenue, Beulah

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