Pressurized Grout Remote Backfilling at AML Sites near Beulah and Zap, North Dakota[1]

Presented By
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ABSTRACT

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. Several underground lignite coal mines were operated near the cities of Beulah and Zap, North Dakota, from the early 1900's until about 1955. Coal seams in this area were relatively thick and the overburden generally shallow. As these mines have deteriorated with time, deep collapse features, or sinkholes, have surfaced in many areas. These features are very dangerous, especially when they occur at or near residential and commercial areas and public roads.

In the past five years, sinkholes have surfaced beneath a commercial building (boat dealership, lounge, and gas station) and beneath a nearby occupied mobile home north of Beulah. Sinkholes have also surfaced near KHOL Radio Station in Beulah and in the right of way of a public road south of Zap. The AML Division has conducted several emergency sinkhole filling projects in these areas. In 1995-97, the AML Division conducted exploratory drilling which confirmed the presence of collapsing underground mines at these sites.

In 1997, the AML Division will begin reclamation at these sites utilizing pressurized grout remote backfilling. In this technique, a cementitious grout is pumped through cased drill holes directly into the mine cavities to fill them and thereby stabilize the surface from collapse. This project is especially interesting because grout will be pumped through holes drilled inside the commercial building. Grout will also be pumped through angled holes that intercept mined workings directly beneath the structures and roads. Several specialized monitoring techniques will be used to alert contractors if any movement in the structures occurs during grouting activities. Informational meetings will be held with landowners, business owners, residents and road authorities before, during and after the project. The project is expected to be conducted from June through September 1997.

Additional Key Words: Underground Coal Mining, Subsidence, Hazard Mitigation, Exploratory Drilling, Specialty Drilling, Structural Monitoring

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INTRODUCTION

Pressurized grout remote backfilling is a proven technique for subsurface stabilization of undermined areas (Beechie 1993). In this technique, a cementitious grout is pumped through cased drillholes directly into the mined cavities in order to prevent collapse of mined workings. In 1997, the Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission (PSC) began a large scale pressurized grout remote backfilling reclamation project at three sites near the cities of Beulah and Zap, North Dakota. This project was designed to reduce the chances of dangerous subsidence events beneath high-use commercial and residential areas and public roads. The project is ongoing at the time of this publication.

This project will be the conclusion of a systematic process leading to reclamation of these hazardous abandoned underground mine workings. This process included site selection, public input, emergency remediation of dangerous subsidence features, exploratory drilling, and pressurized grout backfilling.

Lignite and Lignite Mining in North Dakota

It has been estimated that fifteen billion tons of mineable lignite coal lie beneath the surface of western North Dakota (Oihus 1983). Lignite is a dark-brown to black, low-grade coal that is softer than bituminous coal. It has been mined commercially in North Dakota since the 1870s. Underground room and pillar mining was the predominant method until about 1940. In this method, coal was removed from an underground "room" about 100-300 feet long and 10-20 feet wide. Solid coal pillars of about the same dimension were left on either side of the room to support the roof, and the mine advanced by alternating rooms and pillars.

Many small commercial mines were developed in the early 1900's and the number of coal mines in North Dakota peaked at about 320 in 1940. Steam shovels and draglines made large-scale surface (strip) mining economically attractive and by 1966, strip mining was the exclusive method in North Dakota. Presently, more than 30 million tons of lignite are strip-mined annually in North Dakota to fuel several large electrical generating plants and a coal gasification plant.

The cities of Beulah and Zap, about 85 miles northwest of Bismarck in west central North Dakota, have always been important centers of lignite coal production. At least 50 commercial lignite mines have been located within a 20 mile radius of these two cities (Kjos and Schreiner 1984). Most of these mines were small underground room and pillar mines, but a few were surface (strip) mines and some were quite large. Two of the currently operating strip mines in the state are located within 10 miles of Beulah, the Coteau Properties Company Freedom Mine and Knife River Coal Mining Company Beulah Mine. The Freedom mine fuels two electrical generating plants and the Great Plains Coal Gasification Plant. It produces about 15 million tons annually, about half the state's tonnage of lignite coal.

Subsidence Hazards From Abandoned Underground Mines

The coal seam in the Beulah and Zap area ranges in thickness from about 10-20 feet and the overburden is relatively shallow - about 40-100 feet of mostly unconsolidated material. As the underground mines have deteriorated with time and begun to collapse, deep vertical subsidence features (sinkholes) have surfaced in many areas. These features can be more than 20 feet in diameter and 20 feet deep and can occur instantly. Sinkholes can be extremely hazardous when they occur at or near developed areas or roads. To my knowledge, no deaths have occurred in North Dakota as a result of collapsing underground mines. However, sinkholes have frequently surfaced in residential and commercial areas and road rights-of-way. During the winter of 1995-6, a man was seriously injured when he ran his snowmobile into a deep sinkhole a couple miles northeast of Beulah.

Reclamation of Abandoned Mines in North Dakota

The Abandoned Mine Lands Division of the North Dakota Public Service Commission has been charged with reclamation of abandoned mine lands in the state since 1981. The State Reclamation Plan contains an inventory of all known abandoned coal mines in North Dakota. Of the 616 mines originally inventoried, eighty-seven were considered as Priority 1 or 2 sites: hazardous to public health, safety and general welfare. Several more sites have been added since the original inventory. The Beulah sites represent some of the highest priority AML problems in the state.

THE 1997 BEULAH/ZAP AML PROJECT

Site Characterization

The 1997 Beulah/Zap AML Project will be conducted at three undermined sites near the cities of Beulah and Zap. These include:

- Manny's Sports Center Complex, a commercial building containing a boat dealership (recently vacated), bar, and gas station/convenience store, and several nearby mobile homes, located at the intersection of U.S. Highway 200 and N. D. Highway 49, about 1 mile north of Beulah.

- KHOL Radio Station building and portions of Mercer County Highway 21, located about 1 mile northeast of Beulah.

- A segment of Mercer County Highway 13, a gravel farm to market road located about 1 mile south of Zap.

The Beulah sites are underlain by portions of the Knife River Underground Mine. This mine began as the Black Diamond Mine, a single entry underground mine, on the outskirts of Beulah, in about 1915. It increased in production steadily, went through several changes in ownership, and by 1922 was operating as the Knife River Coal Mining Company. An electric power plant was built nearby in 1925 and by 1928 annual production was over 315,000 tons, making it one of the largest mines in the state. In 1950, Knife River began a strip mine at another location near Beulah and in 1953 the underground operation closed. Knife River and its predecessors operated the underground mine for nearly 40 years and removed about ten million tons of coal. It undermined an area of well over 1000 acres immediately north and east of Beulah.

The Zap site is underlain by portions of the Lucky Strike and Dry Flint Mines. These were commercial underground, room and pillar mines that operated between about 1917 and 1937. Whereas relatively accurate data and maps are available for portions of the Knife River Mine, information on the Lucky Strike and Dry Flint Mines is sketchy at best.

Subsidence has occurred at or near Beulah and Zap for many years. Several AML reclamation projects, at a total cost of over four million dollars, have been completed near Beulah. Gravity fill remote backfilling projects have been completed near Manny's, on adjacent segments of Highway 200 and on County Road 21 near Beulah. In this technique, a slurry, usually consisting of sand, water and sometimes flyash, was "poured" from cement trucks down drilled holes into the mine workings. This works adequately when the mine is relatively open; but when the mine has begun to collapse and is rubblized, it is not very effective. Serious subsidence events subsequent to the gravity fill projects indicated that the mined areas were not completely filled and the hazard had not been abated.

Surface backfilling and grading of sinkholes has been undertaken on other areas near Beulah. This method is relatively cheap but, since it is done after subsidence has occurred, it does not provide protection to roads and structures that are undermined. A number of emergency and maintenance sinkhole filling projects have also been done near the Beulah and Zap sites. In 1993, a serious subsidence event occurred directly under the Manny's building complex (see figure 1). The resultant sinkhole was approximately 20 feet in diameter and 10 feet deep. This broke water lines, damaged air conditioning units and shut off

power to the building. The AML Division responded and had the sinkhole repaired immediately under the state's emergency program. In 1996, a sinkhole surfaced beneath and near an occupied mobile home about 300 feet north of Manny's and this was also repaired under the emergency program. Other emergency projects were conducted within 500 feet of the KHOL Radio building in 1994 and 1995. One of these included backfilling a sinkhole that was more than 100 feet long and 20 feet deep. A large sinkhole also occurred in the road right of way of County Road 13 south of Zap and it was repaired in 1995.

Two previous pressurized grout remote backfilling projects have been completed near Beulah. One was conducted in 1992 at the Beulah Eagles Club. In this project, approximately 16,000 cubic yards of grout were pumped into mine cavities beneath and near the Beulah Eagles Club Building and parking lot (Beechie 1993). The other project was done in 1993 near and beneath Roughrider Mobile Homes, Inc., a recreational vehicle dealership located directly east of Manny's. Approximately 18,000 cubic yards of grout were pumped into mine cavities during this project.

Exploratory Drilling and Project Design

Exploratory drilling was conducted at the Beulah and Zap sites under separate contracts during the winters of 1995-6 and 1996-7. This was accomplished with rotary drilling equipment utilizing forced air and injected water to bring drill cuttings to the surface. The intent of exploratory drilling was to determine the depth to mined voids and rubble zones, coal extraction methodology, size and extent of the mined workings, integrity of mined workings (intact, collapsing, etc.), the presence or absence of groundwater, and site specific lithology.

Exploratory drillholes were approximately 5 inches in diameter, were usually spaced at ten foot intervals and were drilled to the bottom of the coal seam or the mined cavity or rubble zone. These intervals and depths were designed so that drilling intercepts any mine cavities or rubble zones in the area. The relatively close spacing of drillholes is required because haul tunnels are typically 10 feet wide and a spacing of more than 10 feet may miss the targeted mined workings. Drillholes that intercepted mined workings were cased from the surface to the top of the mined void or rubble zone with three-inch inside diameter Schedule 40 PVC Pipe. Casing allows mine inspection with a borehole camera, where conditions allow, and cased drillholes can be used as injection holes into the abandoned underground mine.

Approximately 150 exploratory holes, at an average depth of 95 feet, were drilled near the Manny's building complex and nearby mobile homes. About 60 of them intercepted mined workings and were cased. Approximately 160 exploratory holes were drilled near KHOL Radio and adjacent segments of Mercer County Highway 21, at an average depth of about 80 feet. About 50 of these intercepted mined workings and were cased. Approximately 230 holes, at an average depth of 55 feet, were drilled along Mercer County Highway 13, south of Zap. Five of these holes intercepted mined workings and were cased.

Exploratory drilling was not conducted inside the buildings or underneath the mobile homes. However, systematic drilling around the perimeter of the structures and available mine maps provided information needed to extrapolate information about the mine and mining sequence under the structures.

The objective of this pressurized grout remote backfilling project was to fill the mine cavities underneath the structures and roads with as much grout as possible and thereby reduce the chances of collapse and subsidence. The key to project design was to provide for a method of delivery of grout into the mine cavities underneath the structures and roads in a manner that is safe and minimizes disturbance to the users. There is probably as much art as science in estimating the quantity of grout required to fill the mine cavities. It depends on knowledge of the mine and mining methods, the overburden, capabilities of equipment utilized, and other site specific factors. The grout quantities estimated for reclamation of the three Beulah/Zap sites were as follows: Manny's Site - 5500 cubic yards, KHOL Site - 3000 cubic yards, Zap Site - 750 cubic yards.

Making accurate estimates of required grout quantities for this project was especially difficult. Previous gravity flow backfilling projects had been done at two of three sites. Also, the mines in the project

area were in a state of intermediate collapse and mine cavities had subsided upward and were rubblized as indicated by sinkholes and many of the drillholes. Several assumptions were made to accommodate these factors. The initial grout quantity estimate was made based on the volume of each mining room and haul tunnel in the project area. These figures were then modified by factors such as previous backfilling and swell from the rubble that had collapsed into the mine workings.

Contractor Selection

In order to bid on this project, contractors were required to be pre-qualified. To be pre-qualified, a contractor (or his project superintendent) must have successfully completed at least two projects within the previous five years that demonstrate capability to provide the drilling, grout injection, and coring applicable to this method of reclamation. The same information was required for anticipated subcontractors. The contractors also had to list and describe all equipment intended to be utilized.

A pre-bid, on-site conference was held at the project sites approximately one week before the bid opening. This was to afford an opportunity to prospective bidders to receive clarification related to the project. Contractor attendance at this conference was mandatory. The grouting contractor for this project, The Concrete Doctor, Incorporated, (TCDI) of Lincolnshire, Illinois, was selected by competitive sealed bidding on June 13, 1997. Material testing was contracted separately and the successful bidder was Maxim Technologies, Inc., of Bismarck.

Public Participation

Public input and participation was an important factor because of the “high-use” nature of the project sites. Several public meetings have been held in Beulah in the past fifteen years to discuss AML problems and plans for reclamation. A public meeting was held November 25, 1996 to discuss this particular project. The AML Division has been in contact with landowners and property occupants within the project area for the past several years and has tried to accommodate their needs as much as possible. Right of Entry forms were signed by each property owner, the Mercer County Highway Department and the North Dakota Department of Transportation.

The contractor is required, as a provision of the contract, to plan and conduct a minimum of two informational workshops near the project area. These provide information and establish agreement and collaboration between the contractor and all other interested parties. Interested parties included land and property owners or residents, the project foreman, subcontractors, material testers, the AML project manager, and any other appropriate state or local authorities. The initial workshop addressed: 1) a general discussion of the project and project timetables; 2) goals, objectives, and concerns of all parties; 3) roles and communication framework; and 4) a procedure for rapid resolution of disputes to minimize conflict. Based on information received in the initial meeting, the contractor developed an outline to identify goals and objectives, timetables, and a communication and issue resolution framework. Subsequent workshops were to be held as needed, including a post-construction workshop to evaluate the success of the project in meeting goals and concerns.

Project Drilling

To supplement the exploratory drilling, the contractor is required to drill approximately 20,000 feet of rotary borings, approximately 2000 feet of specialty (interior) borings and 150 feet of coring. Rotary drilling near structures and along roadways may be angled up to 15 degrees from vertical in order to diagonally intercept mined workings directly beneath them. This is accomplished by placing bridge planks under the drilling rig’s leveling jacks. Vertical and angle drilling should be adequate to intercept all mine cavities beneath the KHOL Radio building and the road segments in this project area. Figure 2 shows angle drilling near an occupied dwelling.

Interior drilling is required inside the Manny’s building complex. Figure 3 shows interior drilling inside a commercial building. The Manny’s building complex is so large (approximately 13,500 square

feet) that several mining rooms are located underneath it. Therefore, vertical and angle drilling cannot intercept all mined cavities beneath the building complex. Approximately 20 holes will be drilled inside and through the floor of the building. Special drilling equipment capable of drilling under an eight foot ceiling was required for this work.

Interior drilling and grout pumping will generally be conducted during non-business hours in consultation with the business owners. The contractor is required to protect property by isolating drilling and grouting equipment with plastic sheeting, tarpaulins, and plywood sheeting. Drilling equipment exhaust must be vented outside the building. The contractor is liable for any damages caused to any property as a result of drilling or grouting activities. Complete replacement of carpeting in the building was anticipated.

Grout Injection

The estimated volume of grout required to complete this project was 9250 cubic yards. However, due to budgetary constraints the grout volume specified in the contract was 5500 cubic yards. It is probable that this project will need to be phased over a period of more than one year. If so, the remainder of the work will likely be bid as separate contract in 1998. The Manny's site is the highest priority, therefore, work will proceed there first.

Grouting will begin in the Manny's parking lot and driveway in order to allow the contractor to get a "feel" for safe and allowable pressures. The contractor will determine grout injection pressures and is responsible for any damages caused by grouting activities. Injection pressures in non-critical areas may be as high as 300 pounds per square inch (psi). However, injection pressures directly under buildings will probably not exceed 50 psi. Surface lifting or "jacking" is a very real hazard in this technique. If this occurs in the driveway it's not a serious problem, but if it occurs inside the building complex it could ruin the foundation and result in difficult and costly repairs for the contractor. The contractor is required to submit a detailed, quick-response plan of action in the event sudden surface jacking occurs during pressure grouting activities.

The grout utilized in this project is composed of (per cubic yard): 100 lbs. Portland Cement, 600 lbs. Flyash, 70 ounces Superplasticizer, approximately 2200 lbs. fine aggregate (sand) as required to meet yield requirements, and approximately 80 gallons of water as required to achieve the slump requirements. Each component of the grout mix has its specific requirements. Cement must meet industry standards. Flyash from only two generating plants in North Dakota is approved for use by the North Dakota Department of Health. Sand must meet gradation requirements with 100% passing a 3/8 inch sieve, 90% passing a 4 mesh sieve, 40-80% passing a 30 mesh sieve, and 5-15% passing a 200 mesh sieve. The superplasticizer used in this formulation (ASTM C-494 Type F) is a high range water reducer that improves flowability and set-up strength, and only one brand, Conchem SPL, is presently approved for use by the State Department of Health. Wald and Beechie (1996) described the research that led to development of the grout formulation presently used for pressurized grout remote backfilling in North Dakota. This paper provides details on each component of the grout mix and physical and chemical characteristics of the grout in a simulated wet mine environment.

The grout formulation was designed for maximum flowability and adequate set-up strength. Grout is required to attain an unconfined compressive strength of at least 150 psi within 28 days. Slump, or thickness of the grout mix, is adjustable by adding or reducing water. Generally a fairly thin mix, in the range of 6-11 inch slump, is utilized because a thicker, or lower slump, mix is less flowable and may cause plugging of the injection pipe or poorer fill of the mine cavity.

Material testing for this project is conducted by the engineering firm, Maxim Technologies, Inc. The material tester samples all components of the grout mix, makes regular batch plant inspections, and also samples the grout at least every 50 cubic yards for slump and for compressive strength. Samples for compressive strength are divided into three specimens and are broken at predetermined time intervals to determine strength. Payment for grout depends on compressive strength of the samples. If they do not

achieve a strength of at least 150 psi within 28 days, payment is reduced. If the strength is less than 80% of the this standard, no payment is made for the 50 cubic yards of grout represented by that sample.

Grouting equipment includes mixing and batching facilities, a pump specifically designed for pressure injection of grout, and pipe, hose, and fixtures to convey the grout into the mine cavities. Figure 4 shows a portable batch plant and grout pump. Calibration of all equipment is required before beginning work. The grout pump must have a liquid-filled diaphragm in-line gauge so that pressures can be continually monitored. The general method for grout injection is bottom-up tremmie grouting. In this method, the grout pipe (tremmie) is lowered to the bottom of the mine cavity and the cavity is filled progressively in two-foot increments from the bottom to the top. This method may be varied depending on site specific conditions. Grout pumping continues either until refusal (when no more grout can be pumped), until surface jacking occurs, or until grouting pressures reach a pre-determined maximum. Confirmation drilling and coring is done after grouting to ensure that mine cavities are completely filled.

Structural Surveys and Stress Monitoring

The possibility of surface jacking and damage to buildings and structures posed by pressurized grout remote backfilling necessitates detailed structural surveys and a comprehensive system of monitoring. The material testing firm is required to conduct pre- and post-construction interior and exterior inspections of the Manny's building complex and four nearby mobile homes, and the KHOL Radio building. Any evidences of stress such as cracking, settlement, or any other structural imperfections or deformities will be measured and recorded graphically, photographically and in narrative form.

Crack monitors (see Figure 5) were installed in predetermined locations on visible cracks in structures or foundations and these were monitored periodically during proximal grout pumping. The grouting contractor was also required to install an interior laser level inside buildings during grout pumping to monitor movement in the structure. This type of laser level is capable of detecting very minute structural movements and multiple targets can be used to monitor a fairly large area. If any monitoring equipment detects structural movement, grout pumping would immediately be discontinued in that area. The inspections and installation of crack monitors must be done by or under the supervision of a certified professional engineer. After the project, the engineer will submit a report containing all observations, measurements, maps, sketches and photographs, and must indicate whether grouting activities have caused any significant damages.

CONCLUSION

Pressurized grout remote backfilling is an effective reclamation technique for subsurface stabilization of undermined roads, buildings and other structures. It is a relatively high cost technique. Therefore, it is only practical in areas where underground mine subsidence presents a serious hazard to the public such as high-use commercial and residential areas and public highways. This technique has been used successfully in North Dakota since 1991.

This was a case study of a pressurized remote backfilling reclamation project that was conducted at three sites near the cities of Beulah and Zap North Dakota. This project marked a final step in a process of identifying, classifying, investigating, and reclaiming some serious AML hazards. The project was notable because a number of different approaches were used and because drilling and grouting activities were conducted inside a commercial building. Participation of affected parties and continual structural monitoring during all phases of the project were especially important. The project was ongoing at the time of this publication and it is possible it may take more than one year to complete it. However, it will certainly reduce the likelihood of death or injuries to property owners and the public resulting from collapse of underground mine workings. The approximate total contract costs for this project were $450,000.

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