Ground Failure Investigation over Abandoned Coal Mines: A Case Study

Marlo G. Karfakis
University of Wyoming, Laramie, Wyoming

Bruce A. Suprenant
University of South Florida, Tampa, Florida

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 2.21

Ground Failure Investigation over Abandoned Coal Mines: A Case Study

Marlo G. Karfakis
Assistant Professor of Mining Engineering, University of Wyoming, Laramie, Wyoming

Bruce A. Suprenant
Associate Professor of Civil Engineering, University of South Florida, Tampa, Florida

SYNOPSIS: The slurry backfill operation for the Rock Springs subsidence control project is briefly described. The extent of ground failure and building damage is presented. The scope of the ensuing geotechnical investigation to indicate any possible cause and effect relationship between the pumped slurry backfill operation and observed damage is described. The general and specific findings regarding the damaged area are discussed. Conclusions from the investigation are presented.

INTRODUCTION

Development of the City of Rock Springs, Wyoming, as a coal mining community began in the 1860's with the westward expansion of the Union Pacific Railroad through Southern Wyoming. What were once coal mine camps, built over or near abandoned coal mines, is the community of Rock Springs. Approximately 900 acres within the Rock Springs city limits were undermined by room-and-pillar coal mining, between 1869 and 1934, to meet the railroad's demand for coal. This method, compounded by the later removal or "robbing" of pillars, left insufficient support for the mine roof in many areas, which has resulted in the collapse and upward migration of mine voids (Karfakis et.al., 1987). Historical records indicate that subsidence has occurred in Rock Springs from the start of mining to the present day (Case, 1986). Collapse of these abandoned workings has caused extensive damage.

Rock Springs mine subsidence problems qualify for the highest priority of funding under the Surface Mine Control of Reclamation Act of 1977, in that they constitute extreme danger to public health, safety and properties. In order to stabilize the undermined areas and reduce the probablity of further mine subsidence, a large scale backfill project was undertaken. The Rock Springs Subsidence Control Project began in March, 1985. In mid-September, during the slurry injection, ground movement and building damage was reported. A geotechnical investigation was undertaken to evaluate and establish the potential cause or causes of damage to the residences and indicate any possible cause and effect relationship between the pumped slurry backfill operation and observed damage.

PUMPED-SLURRY BACKFILLING OPERATION

The method used to backfill the mine voids in the Rock Springs Subsidence Control Project was the pumped-slurry method of hydraulic backfilling (Colaizzi and Bithell, 1986; Colaizzi, et.al., 1981). In this process, a homogeneous mixture (slurry) of water and granular material is pumped from a remote plant site to the injection hole. The free falling slurry moves through a vertical steel casing to be deposited in subsurface voids (Fig. 1).

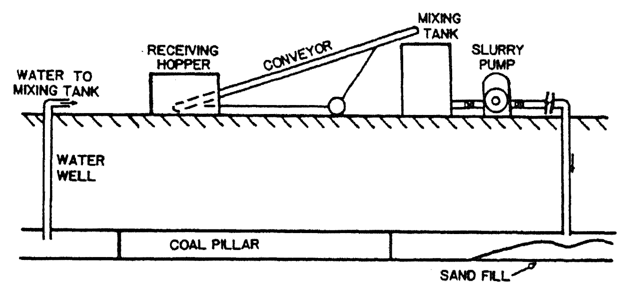

Fig. 1 Slurry Pumping System (Colaizzi et.al., 1985).

The degree of void filling is a function of the velocity of the slurry flow at the mine level. As the slurry first enters the mine void from the injection borehole, its velocity is greatly reduced due to the increased cross sectional area of the transporting conduct (Fig. 2). This

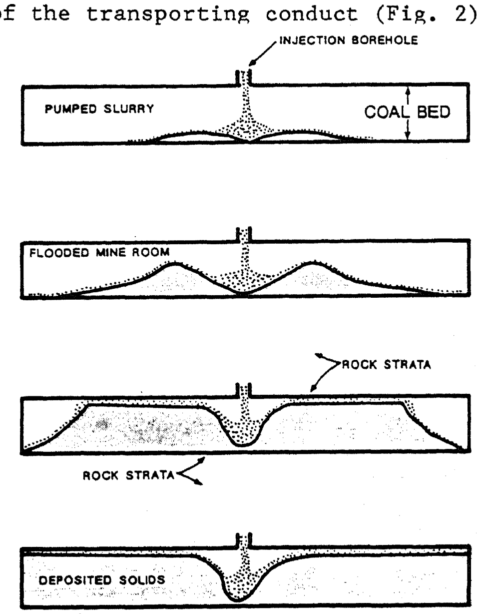

Fig. 2 Section View of Slurry Deposition (Colaizzi and Bithell, 1986).

rapid drop in velocity causes the solid particles to be deposited to form a doughnut-shaped mound on the mine floor. As the height of the mound approaches the mine roof, the velocity of the slurry increases through the narrowing channels, and the solid particles are transported to the outer limits of the mound. At the boundary of the mound, the velocity decreases abruptly and the solids are deposited on the advancing face of the pile. The process continues until the energy required to maintain the flow of the suspended particles becomes greater than the energy supplied by the available gravity head.

The Rock Springs Subsidence Project began in March 1985, with exploratory and water well drilling. In the following three months, the slurry plant was erected, pipelines were laid, and injection wells were drilled and cased. In mid-June, the slurry injection began. In mid-September, during the slurry injection, ground movement and damage to residential buildings were reported in the Adams Avenue area.

SURFACE DAMAGE

The Adams Avenue residences exhibited architectural damage and some moderate to severe structural damage. The architectural damage usually consisted of vertical and diagonal cracking at window and door openings and at sheetrock joints; horizontal stairwell cracking of plaster covering wood sill plates; and mis-aligned doors and cabinets.

The structural damage was usually concentrated at basement level. The most common problem being vertical, horizontal and diagonal foundation wall cracking. A few cracks were as wide as 1 1/2 inches. Most of the observed foundation wall cracking was less than one-quarter inch wide.

The damage at the Adams Avenue area was evaluated to indicate possible causes. Most of the damage at the Adams Avenue residences was consistent with a downward movement of the structure.

Cracks in buildings caused by settlement are found predominantly at the basement of one story homes. This is because floors, roofs and walls interact to decrease crack widths in upper stories. By contrast, cracks due to construction practices and poor materials tend to increase with the structure height. More and wider cracks were observed in the basements, also supporting the conclusion of downward movement.

GEOTECHNICAL INVESTIGATION

Rather than evaluating pre-conceived ideas or thoughts as to the cause of surface damage at Adams Avenue, it was deemed preferable to evaluate each potential cause of vertical movements.

Vertical ground movements can be the result of surface erosion, frost action, collapsible soils, shrinking and swelling soils, fluid extraction and consolidation, densification by vibration, bearing capacity failures, settlement under surface loads and mining subsidence (GAI Consultants, Inc. 1983).

Positive identification of the mode of ground movement could be helpful in identifying its source. Subsurface exploration, ground surveys, instrumentation and testing may be required. Also, it is important to recognize that due to the complexities of soil structure interaction, the building movement is not necessarily the same as that of the ground.

An investigation was undertaken to evaluate and establish the potential cause or causes of damage to the residences and indicate any possible relationship to the pumped slurry backfill operation.

The extent of surface damage was assessed. Crack movements were monitored and measured. Surface ground cracks were surveyed and mapped (Fig. 3). Rotary and core drilling was performed around the affected area and the residences reporting damage. Boreholes were inspected with a video camera. Soil and rock samples from coring were tested.

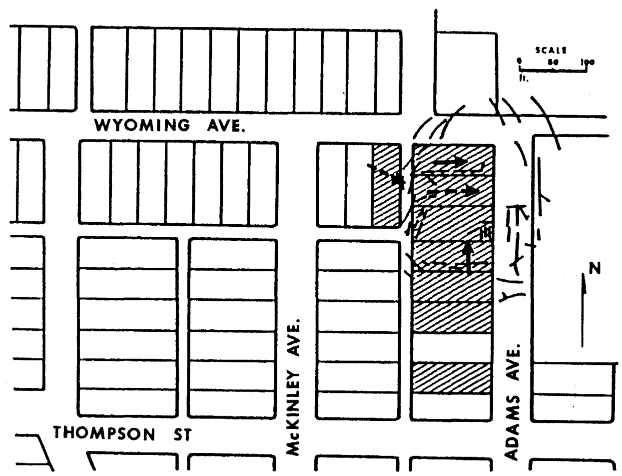

Fig. 3 Surface Damage Adams Avenue Area.

In light of all the information gathered, except for mine subsidence, all possible sources of ground movement were eliminated as the cause of the observed surface damage. The evidence obtained from the investigation indicate that the most conceivable cause of movement at Adams Avenue was mine subsidence (University of Wyoming, Suprenant, 1985).

The area surrounding the Adams Avenue area is undermined at a depth of approximately 90 ft. This mine is in a coal seam which is seven to eight feet thick, dipping at 6°, and was mined by the room-and-pillar method. The mine map in this area is ambiguous, showing only that the area is mined out. Nevertheless, based on data colleted through drilling, video camera interpretation, and study of the mine map, it is believed that the area of Adams Avenue overlies a room-and-pillar section. The extent of mining in this pillar section probably varies from 60% extraction to near total extraction.

Subsidence above abandoned room-and-pillar mine workings is either chimney or through subsidence (Karfakis 1987). In the Adams Avenue area, it was determined that subsidence was a through subsidence (University of Wyoming, Abel, 1985).

Through subsidence develops when several pillars fail in the underlying workings. Normally, pillars of sufficent size are left during room-and-pillar mining to prevent their failure. However, pillar failure may occur as the result of long-term pillar deterioration, increased pillar height accompanying roof collapse, or as the result of load redistribution due to boundary condition changes.

The Adams Avenue subsidence event developed a nearly classic mining induced subsidence trough, i.e. an ovaloidal surface fracture pattern (Fig. 3). The size of the ovaloid defined by tensile surface cracking indicates a pillar failure area in the mine approximately 100 ft. wide and 260 ft. long.

Using the NCB (1975) and the Abel and Lee (1984) method, room and pillar subsidence strain predictions were performed (University of Wyoming, Abel, 1985). The predicted maximum super critical vertical surface subsidence was 12.4%, corresponding to 1.0 ft. vertical displacement, and the maximum predicted tensile strain was 7220 μE.

The predictions appear reasonable in terms of the Adams Avenue observations and measurements.

The next task of the investigation was to determine if a reasonable interpretation of all factors indicate a cause and effect relationship between the slurry backfill operation and the subsidence event.

CAUSE AND EFFECT RELATIONSHIP

The backfilling operation in the vicinity of Adams Avenue stopped on September 17, 1985. The first damage report was made two days later on September 19, 1985.

The first step in assessing a cause and effect relationship between the slurry backfill operation and the subsidence event is to determine first, whether the slurry was present under the affected area and second, how the slurry may have triggered the subsidence.

The slurry injection hole location with respect to the subsidence site is critical to slurry backfill reaching that location.

The nearest injection hole to the Adams Avenue site is SI-8A (Fig. 4). The injection hole is located over a NW-SE entry across the fault pillar. The south side of the fault pillar has about 40 ft. of upthrow. The mine floor elevation at this location is approxiamtely at 6320 ft. This injection hole received 32,439 tons of slurry.

As the slurry is released, the solid particles will be deposited equally in all directions until the energy required to maintain the flow of the suspended particles becomes greater than the energy supplied by the available gravity head (Colaizzi et.al. 1981).

The pressure at the base of hole SI-8A, approximately 90 ft. below the surface, was about 39 psi during active slurry injection.

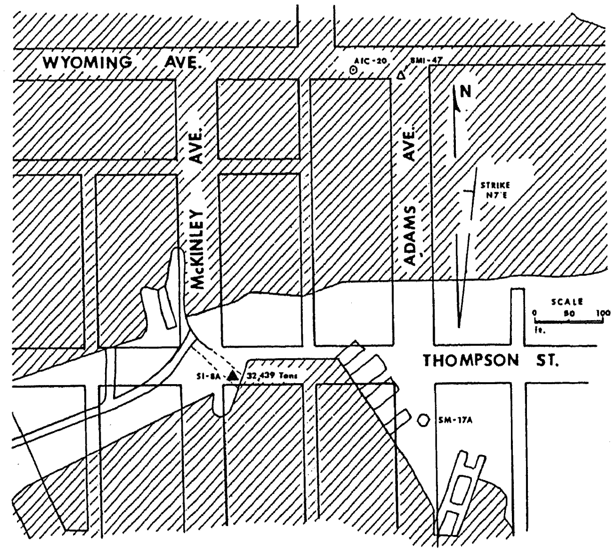

Fig. 4 Mine Workings Overlay.

This pressure is more than sufficient to push slurry 20 ft. vertically, which corresponds to 140 ft. horizontally in the updip direction.

Reports form the pilot backfill project conducted by the Bureau of Mines (Colaizzi et.al. 1981), indicated that flow can occur in a single channel updip over long distances after fill material is deposited up to roof level. Furthermore, hydraulic model studies support the observations made in the field (Carlson, 1975). In the model studies, as deposited, backfill material reached the quantity and pattern to build up back pressure in the injection system, one final break out may occur. A channel would be formed along on unobstructed corridor between rows of pillar. Fill material is carried along this channel in suspension or as bedload according to basic sediment transport principles. With the full flow of the injection pipe discharging along a channel, an equilibrium condition develops for sediment transport. Fill material deposits at intersections to essentially block side corridors and confine the flow along the one channel. Deposits build in the channel until the cross-sectional area reduces and the velocity increases to cause critical transport conditions. In all sloping mine floor models, the breakout channels formed updip. In a dipping mine floor, backfill material will fill up to the roof more rapidly in the downdip direction, presenting greater resistance to channel breakout.

From the above discussion, it is evident that slurry and/or water from the slurry can reach the Adams Avenue area. The next step is to determine the path the slurry and/or water followed to reach the mine workings under Adams Avenue.

As the slurry discharges, in the NW-SE entry, solids would be deposited equally in the downdip and updip direction. On the south side of the fault pillar, the slurry can easily reach the area where blocked entries are shown on the mine map. Based on the drilling experience in the region, the mine maps proved to be inaccurate. It is possible to have one of these entries crossing the fault pillar to the north side under the Adams Avenue area. Mine floor elevation at the entry on the south side would be at 6330-6340 ft. and on the north side at 6300 ft. updip from the Adams Avenue area. Following this path, it would be possible to have slurry and/or water from the slurry in the mine workings under the area reporting subsidence damage. The inspection hole SMI-47 at the intersection of Adams Avenue and Wyoming Street, which was dry before the start of backfilling, had six feet of water above mine level immediately after the first damage report.

The next question is, what are the mechanisms by which the presence of slurry or water from the slurry could induce subsidence?

The most probable scenario is that collapse chimneys had occured and stabilized by bulking prior to the introduction to slurry water. When slurry water was introduced, the bulked rubble supporting the roof was softened. Low durability shales and other argillaceous rocks would, under stress, tend to fall apart when water was added. The low durability rock fragment would weaken in water and be crushed under the same stress they were able to carry before water was introduced. The finer fragments produced would tend to filter down into the underlying rubble pile, filling voids between more durable sandstones. This process would shift load onto the coal pillars, potentially triggering pillar failure and subsidence. This appears to be a possible scenario for the Adams Avenue subsidence event in view of the slake durability tests run on the overburden and the presence of rubblized zone in the mine.

Slake durability tests were run on 12 different shale samples recoved from coreholes. One sample exhibited very low durability, five low durability, three medium durability, two medium high durability, and one high durability.

The drill logs before and after the subsidence event indicate the presence of rubble in the Adams Avenue area.

It can be stated that some of the rock formation present in the overburden would tend to deteriorate if stressed or agitated in water and that collapsed roof rock was present. The resulting load transfer could trigger a pillar failure and thereby a surface subsidence event.

The result of the detailed analysis indicate the possiblity that the slurry backfilling operation caused the subsidence event at the Adams Avenue site.

CONCLUSION

The architectural and structural damage exhibited by residences in the Adams Avenue has been caused by mine subsidence. It is possible that the mine subsidence has been triggered by the water from the slurry. Nevertheless, there is no evidence to prove or disprove the chain of events hypothesised above.

During the investigation, water from inspection hole SMI-47 after the subsidence event should have been analyzed to determine its origin. Furthermore, exploratory drilling should have been done to determine if additional entry ways across the fault pillar were present. These two tasks would have helped in the assessment of cause and effect relationships between the slurry backfill operation and the subsidence event of Adams Avenue.

REFERENCES

Abel, J. F., Jr., and Lee, F. T., (1984), "Lithologic Control on Subsidence", Trans. SME-AIME, V. 274.

Carlson, E. J., (1975), "Hydraulic Model Studies for Backfilling Mine Counties", Bureau of Reclamation, REC-ERC-75-3

Case, J. C., (1986), "Overview of Coal Mine Subsidence in Wyoming", Proceedings of the Governor's Workshop on Mine Subsidence, ed. M. G. Karfakis, University of Wyoming, Laramie, WY, October.

Colaizzi, G. J., and Bithell, L.M., (1986), "Methods of Controlling Abandoned Mine Subsidence", Proceedings of the Governor's Workshop on Mine Subsidence, University of Wyoming, Laramie, WY, October.

Colaizzi, G. J., Whaite, R. H., and Donner D. L., (1981), "Pumped-Slurry Backfilling of Abandoned Coal Mine Workings for Subsidence Control at Rock Springs, Wyoming", USBM, IC 8046.

GAI Consultants, Inc., (1984), "Survey of Ground Surface Conditions Affecting Structural Repsonse to Subsidence", Bureau of Mines Open File Report 12-84.

Karfakis, M. G., (1987), "Subsidence Over Abandoned Coal Mines - Mechanisms and Prediction", Proceedings of the 23rd Symposium on Engineering Geology and Soil Engineering, Logan, Utah, April.

Karfakis M. G., Beach, G., and Case, J., (1987), "Subsidence Problems in Wyoming and Their Social Impact", Proceedings of the 1987 National Symposium on Mining, Hydrology, Sedimentology and Reclamation, Springfield, Illinois, December.

NCB, (1975), "Subsidence Engineer's Handbook", National Coal Board, Mining Department, England.

University of Wyoming, (1985), Suprenant, B. A., Karfakis, M. G., Edgar, T. V., Basham, K. D., Abel, J. F., Jr., "Investigation of Residential Damage in Rock Springs, WY", DEQ - State of Wyoming, December.