

Mitigating Inflow Due to Both Primary and Secondary Permeability in Mining

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Groundwater infiltration can be due to either primary or secondary permeability. When both types of permeability are present, mitigation requires versatility and cooperation between multiple project participants.

Overview

Most underground operations must deal with groundwater at some point during their operations. Understanding the geologic factors that affect the permeability is the key to successfully dealing with the groundwater inflow. There are two principle types of permeability that can be found in geologic masses: primary and secondary.

Primary Permeability

Primary permeability is a function of the formation of the geologic mass whereas secondary permeability is a function of forces exerted on the geologic mass after formation. It is derived from the interconnection of void space within a geologic mass. This type of permeability is most often associated with soils. Within soil, the permeability is derived from the interconnection of pore space between soil grains. Although less frequent, this type of permeability can also be encountered in rock. Typically, primary permeability is most frequently associated with sedimentary rocks. Examples of these may be poorly cemented sandstones or vuggy limestones. Less frequently, it may be found in igneous masses where gas bubbles form and interconnect during formation.

This article will focus on primary permeability in rock masses instead of in soil masses. This is because much of the mining or tunneling takes place within rock masses and because dealing with unconsolidated ground has been covered in numerous other articles.

Secondary Permeability

Secondary permeability is derived from discontinuities within the rock mass associated with forces applied to the rock after formation. These discontinuities may be in the form of faults, bedding plane separations, fractures, etc. These features represent open pathways which allow water to pass through the rock. Secondary permeability can be present in any type of rock mass which has undergone brittle deformation. Most rock masses have secondary permeability present on some scale.

Occurrence

The majority of mining operations will only experience groundwater inflow from secondary permeability. This is due to its prevalence in most rock masses. However, this means mining operations which experience inflow from primary permeability will also likely experience inflow from secondary permeability. Generally, primary permeability will be limited to an individual rock formation(s) on site. However, within the formation, the problem may be complicated by zones that are controlled entirely by primary permeability, zones controlled entirely by secondary permeability, and zones where both are present.



ABOVE: Light zone between the two yellow lines is cross section of grout hole with microfine cement, which did not permeate rock.
BELOW: Sandstone with primary permeability. Note reflection of water as it seeps through rock.

Mitigation Techniques

Mitigation of groundwater inflow within rock masses which contain both primary and secondary permeability is often much more complicated than within rock masses that contain only one type of permeability. This is because rock masses which contain

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Quarry wall demonstrating secondary permeability. Large fractures are located just above yellow lines in the picture (note vegetation growing in fracture fill).

both types of permeability often require multiple remediation techniques and multiple variations of those techniques. Generally, five mitigation techniques are available for rock masses containing both permeability types: avoidance, dewatering, drainage, grouting, and freezing. Most mitigation programs will incorporate two or more of the mitigation techniques.

Avoidance

Avoidance is generally considered if the other four mitigation techniques make the cost of mining prohibitive because the factors that contribute to primary and secondary permeability are pervasive on a macro-scale across the formation. In mining operations, the location of the ore body will control the location of mining. Limited avoidance may be an option as the depth of the mining may be varied to eliminate or limit the exposure to the problem formation.

Dewatering

Dewatering involves the installation of wells through the problem formation. Pumps are placed within the dewatering wells to remove water from the formation. This option can be effective as it generally can be used to reduce the groundwater head; therefore, reducing the volume of water which can enter the excavation. However, if used solely, this technique can become very costly as it must be maintained over the life of the mining. Additionally, the cost of dewatering will increase with depth, as the cost of drilling and pumping increase.

Drainage

Drainage is most often deployed in shafts and slopes. This method involves allowing groundwater inflow to enter the excavation where it is collected and dealt with in a controlled manor. Examples of control methods are water rings cast into shafts or diversion ditches cast along the sides of slopes. The water is allowed to flow under gravity to sumps and is then pumped to the surface. The depth of the mine will affect the costs associated with drainage as the height of pumping will affect the pumping costs.

Grouting

Grouting is a mitigation technique which seeks to limit the groundwater inflow into the excavation. This is accomplished by injecting a grout into the rock mass which fills the pore space or discontinuity, decreasing the permeability, either reducing or eliminating the groundwater inflow. Different grouting types must be used to deal with primary and secondary permeability. Permeation grouting is utilized to address primary permeability while consolidation grouting is utilized to address secondary permeability. Generally, grouting requires more of an upfront investment than the other mitigation techniques. However, over the life of mining, the cost of grouting may be less since there are no maintenance costs.

Freezing

Ground freezing is a method which employs drilled freeze pipes through which a refrigerant is passed to freeze the water within the rock mass. It is the only mitigation technique which guarantees elimination of groundwater inflow into the excavation when properly employed. However, it is the generally considered the more expensive remediation technique as it requires a large initial investment and maintenance costs during the freeze. Additionally, the freeze is temporary, as refrigeration equipment is required to maintain the freeze, so one or more of the previously mentioned techniques must be utilized to deal with the groundwater inflow long term.

Case Study

Groundwater inflow can be managed effectively and economically in rock masses which demonstrate both primary and secondary permeability. The following project exemplifies how the problem was successfully handled. The project is located within the Illinois Basin in the U.S. mid-continent. The Illinois Basin is a Paleozoic depositional and structural basin. The Basin consists of inter-bedded sequences of sedimentary rock, primarily limestone, dolomite, sandstone, and shale. Bituminous coal is present within the Pennsylvanian rocks of the basin. Primary and secondary permeability are present within some sandstone layers within the basin.

White Oak Resources – Mine #1

White Oak Resources LLC (WOR) Mine #1 is located within the Illinois Basin near Dahlgren, Illinois. WOR is currently in the process of developing a longwall operation in the Herrin No. 6 Seam. Development work consists of a shaft for employee access and ventilation, a slope for coal and material handling, a 2,000-ton-per-hour Preparation Plant, and underground works. This case study focuses on work associated with the new slope being constructed by Pittman Mine Services LLC (Pittman). The 16 degree slope will be 3,700 feet long to reach the seam which lies at a depth of approximately 960 feet. The slope is excavated at 22 feet by 21 feet.

Initial boring data indicated groundwater inflows to be encountered during construction could be managed by typical collection and pumping methods without the need to grout any of the water bearing layers. However, after excavation of the slope began, drilling for drop-holes, used for power and concrete pours, along the slope centerline revealed groundwater inflows much greater than the initial boring data indicated, requiring WOR to reassess how to manage water inflows encountered during construction. Once the slope excavation reached the water bearing layer, significant water inflows were encountered that could not



Surface area over slope zone, which encountered the Mt. Carmel Formation. Five dewatering wells were placed on each side of the slope. This picture provides a general idea of the area of slope, which had to be treated, and the spacing and location of dewatering wells.

be managed by the collection and pumping method. WOR decided to dewater and grout the water bearing layer.

Site Geology

The groundwater bearing formation which was encountered at the WOR Mine #1 site is known as the Mt. Carmel Formation. At this site, the Mt. Carmel is a sandstone layer lying at a depth of approximately 350 feet and approximately 70 feet in thickness. The top of the formation is a transitional inter-bedded sequence of sandstone and shale. The bottom of the formation is bound by a competent limestone with underlying shale and claystone layers. The Mt. Carmel is poorly graded and incompletely cemented. Site data indicated a hydraulic conductivity of approximately 1×10^{-4} cm/s. Additionally, the upper boundary shale formations acted as a confining layer resulting in a confined head of approximately 320 feet.

Once the slope encountered the formation, approximately 350 lineal feet of excavation would be within the Mt. Carmel sandstone.

Dewatering Wells

The initial step in the groundwater mitigation program was the installation of ten dewatering wells. The goal of this activity was to decrease groundwater inflows into the slope to a level which would not significantly impact construction. Dewatering wells were installed approximately 50 feet apart, alternating approximately 30 feet off slope centerline, along an approximate 400 feet long section of the slope which would encounter the Mt. Carmel Formation. Dewatering wells were installed to a depth of approximately 430 feet, which corresponded to the bottom of the formation. The number of dewatering wells as well as the distance which they could be located from the slope

was limited by the initial plans included in the water discharge and surface disturbance permits. This resulted in only 10 of the 20 desired wells being installed at less than optimum locations.

Upon initial startup of the dewatering wells, approximately 300GPM of water was pumped. This resulted in a 250-ft reduction of hydraulic head from 300 ft to 50 ft. After the wells had been operating for 30 days, a steady state pumping rate of 60 GPM maintained the hydraulic head of 50 ft.

Grouting

Although dewatering reduced the potential for groundwater inflow based on the reduction in pumping volumes and hydraulic head, WOR still had concerns about dealing with the remaining groundwater associated with the Mt. Carmel formation. To accomplish this, WOR evaluated and chose to proceed with a grouting program. After meeting with various contractors, Ground Engineering Contractors (GEC) was selected to design and implement the grouting program. GEC contracted Paddy Cochrane Pressure Grouting Consultant (PCPGC) to design the grouting program.

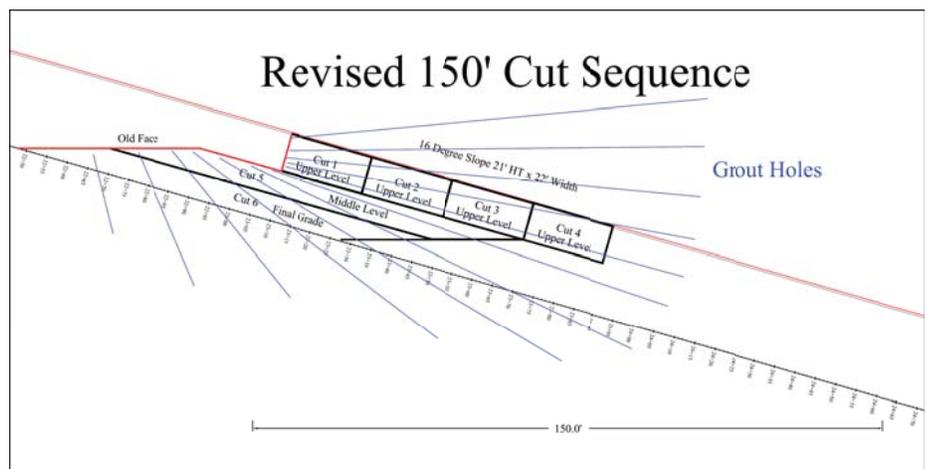
The goals of grouting were as follows:

Primary Goal: Reduce the potential for groundwater inflow volumes which would significantly affect safety or production rates of slope excavation.

Secondary Goal: Provide a long term mitigation measure to groundwater infiltration into the slope excavation to minimize long term pumping and treatment of water during mine operations.

Groundwater inflow was initially believed to be associated with secondary permeability based on groundwater inflow which had been observed from fractures at the top of the Mt. Carmel Formation within the adjacent shaft during mining. Based on this assumption grouting began with US Grout Microfine cement supplied by Avanti International (Avanti). Grouting began approximately ten feet above the Mt. Carmel Formation. Good grout penetration was recorded during the first grout cover and verification holes indicated limited residual groundwater inflow. However, after low grout penetration during the second grout cover, PCPGC and GEC recommended changing to AV-100 Acrylamide Grout (also supplied by Avanti). This decision was based on the assumption that as the formation had graded from an inter-bedded sandstone/shale to a pure sandstone, the contributing permeability type transitioned from secondary to primary.

BELOW: Figure demonstrating the general grout hole layout and slope mining sequence for one grout cover. Similar grout cover layout geometry was utilized for treating both primary and secondary permeability, however, more grout holes were required per cover when treating primary permeability.





ABOVE: Microfine grout being delivered to agitator / pumping plant for grouting of secondary permeability features at the top of the Mt. Carmel Formation



LEFT: Set acrylamide grout sample. The upper half of the sample is pure acrylamide with dye. The lower half of the sample is play sand that has been permeated and solidified with the grout.

The third grout cover was constructed utilizing permeation grouting as recommended. After relatively low groundwater inflow had been encountered during mining of the first three grout covers, it was decided that mining would continue

beyond the third grout cover without grouting. Although groundwater inflow within the area past the third grout cover was not significant enough to stop mining, this area did exhibit the highest groundwater inflow rate within the formation. Therefore, the decision was made to install the fourth grout cover which extended through the remainder of the Mt. Carmel Formation. This final zone also targeted the transition zone where the roof of the excavation was in the water bearing sandstone and the floor had progressed through to the underlying shale and claystone layers.

The following quantities of grout holes and grouting materials were installed:

- 12,689 lineal feet of grout hole drilling
- Injection of approximately 22,050 pounds of microfine cement
- Injection of approximately 22,000 gallons of acrylamide grout
- The grouting program and the dewatering wells limited the steady state groundwater inflow into the slope to approximately 50 GPM during the mining process. Inflow after the completion of mining and backfilling the slope zone within the formation was less than 30 gpm.
- Unique Challenge of Utilizing Grouting in Proximity to Dewatering

A highly unique aspect of the overall project was grouting in close proximity to dewatering wells. WOR sought to maintain the dewatering wells in operation during the remainder of slope construction (as this was one aspect of the groundwater infiltration mitigation program). GEC and WOR were concerned the grouting project and associated grout covers could intercept these wells, rendering them useless.

PCPGC and GEC developed monitoring programs for detection of both cementitious and acrylamide grouts to determine if grout was entering the wells. The monitoring program for cementitious grout was based on elevated pH levels within the wells while the monitoring program for acrylamide grout was based on detection of fluorescein dye which was placed in the grout prior to injection. This monitoring program resulted in only two wells being lost to grouting.

Summary

Dealing with primary and secondary permeability is one of the most difficult issues in groundwater control. Complicating projects, often it is not known that both types of permeability are present until programs undertaken to address one type of permeability (often secondary) are only partially successful in controlling groundwater inflow. It is not until this occurs that it is realized the second type of permeability (generally primary) is also present. Common testing techniques for determining hydraulic conductivity do not differentiate between the two permeability types. Therefore, knowledge of the local geology and experience with handling inflow associated with both types of inflow is critical. This will allow the problem to be addressed more quickly and will allow the versatility to employ the most efficient mitigation options.

Successful projects often require the consideration and implementation of numerous mitigation processes and procedures. This requires all parties involved to entertain ideas and to work together to implement those ideas in a cooperative manner. The project must include a team which is experienced with employing multiple techniques and project owners which are willing to listen to the other project participants and determine a plan of action which is best for the project.

Ultimately, on the project described in this paper, the mitigation program allowed construction to proceed through formations exhibiting both primary and secondary permeability. While construction schedule was impacted, the impact was minimized due to the mitigation techniques employed. Production was able to proceed efficiently with no major events. The success of this project is attributable to the significant amount of planning, technical expertise, investment, and cooperation between all of the project participants.

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