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Some Technical Aspects of Open Pit Mine Dewatering

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INTRODUCTION

In recent years the increase in development of new open pit mines, especially in the Western U.S., is evident. Most of the mining activity is concentrated on open pit mines for coal and uranium. Practically all of these mines have to deal with ground water problems either before, during or after mining. The presence of water in a mine has adverse effects on mine production, slope stability, safety, pollution control and therefore mining cost.

The efficiency of well designed and implemented dewatering of mines before and during mining, has been proven in many open pit mines worldwide (1)(2)(3)(4). The cost savings on the mining operations in these cases were substantial. Surprisingly, there are few published papers or textbooks dealing with the designed implementation of mine dewatering.

MINE DEWATERING METHODS

Because of the title and scope of this paper, the more feasible methods of open pit mine dewatering in typical geological conditions of the Western U.S. will be discussed. Following is a listing of these basic dewatering methods:

- Drainage ditches at the surface of the mine
- Drainage ditches at the bottom of the mine
- Horizontal drains
- Vertical wells drilled from the surface
- Vertical wells drilled from benches or pit bottom
- Dewatering shafts and galleries
- Combination of above listed methods

Selection of the proper method of dewatering is crucial to the success of the operation and depends on several factors discussed in the following section.

DEWATERING METHOD SELECTION

The proper and most feasible dewatering method depends upon the following factors:

- geology and hydrogeology of the mine site
- scope of dewatering
- mining method
- cost study

The hydrogeologic investigation of the mine site should be the basis for every dewatering design. Without knowledge of aquifer characteristics like recharge area, general flow direction, thickness and hydraulic conductivity, an efficient dewatering system is difficult to design and implement. The character of primary or secondary aquifer permeability, (intergranular or fractures) is important. Orientation of fracture system in an aquifer with secondary vertical or horizontal permeability can cause success or failure of a dewatering system.

There is a substantial difference in dewatering of confined and unconfined aquifers, especially regarding slope stability. Before the design of an open pit mine dewatering system, an estimate of water inflow into the pit should be performed.

Part of the hydrogeologic study should be the installation of a proper groundwater monitoring system capable of observing the oscillation of water levels; this monitoring system should be installed before the dewatering system is implemented and maintained during the entire mining operation. The fact that water is flowing from horizontal drains which have been installed for stability reasons does not mean that the pore pressure has been sufficiently relieved in strata which is detrimental to slope stability.

The scope of open pit mine dewatering may vary in individual projects. In cases where the ground water inflow into the pit is not high enough to impede the mining activity but high pore pressure in the water bearing strata affects slope stability or slope design, dewatering is oriented toward lowering the potentiometric surface within the zone of potential failures. This may be achieved without draining a great amount of water. Another reason for mine dewatering may be groundwater quality protection. By pumping water from vertical wells, the pollution of water that would otherwise seep into the pit and be pumped out from the sump, can be prevented.

In most cases, and typically in the Western U.S., the reason for mine dewatering would be a combination of the following (with decreasing emphasis as listed):

- improved slope stability
- improved mining conditions
- groundwater quality protection

The mining method to be employed in a new mine or as practiced in an existing mine is also a factor to be considered in a mining dewatering design. Drainage of temporary walls should be different from that of final pit walls. The degree of desired "drying" of the pit bottom depends on the type of equipment used for excavation.

The last, but not the least important, of the factors to be considered for selection of the dewatering method is the cost. Dewatering should be economically advantageous, resulting in steeper and safe pit slopes, higher production of rubber-tired equipment and better working conditions in the pit. The cost of design and implementation of dewatering should always be the dominant factor. There are known cases in the western U.S. where mine operators spent considerable amounts of money to deal with frequent slope failures rather than to spend a lesser amount on mine dewatering. I visited two underground coal mines in Wyoming and New Mexico where mine superintendents admitted loss of production from 30 to 35 percent of total production due to water inflow into the mine. In both cases the drainage of the mines would have been relatively simple and certainly cost effective.

SOME TECHNICAL ASPECTS OF DEWATERING METHODS

Following is a detailed discussion of some practical aspects of the dewatering methods that appear to be feasible in typical hydrogeological conditions of the Western U.S.

Drainage Ditches at Surface

This relatively inexpensive method is applicable, mostly together with surface water drainage, when the aquifer to be dewatered is shallow. In this system, water from the ditches around the perimeter of the mine is typically collected at the lowest point in a sump and pumped out. From European experience (4) this method is most effective with aquifers 6 to 10 feet thick at a depth to 60 feet and with hydraulic conductivity of 6-20 feet per day.

An alternative to this method is to fill a drainage ditch, which completely penetrates an aquifer, with bentonite slurry to eliminate the flow toward the mine. This method has not yet been used in the Western U.S., to my knowledge, but could be considered applicable in highly permeable aquifers such as alluvial deposits.

A typical schematic example of a surface drainage ditch is shown in Figure No. 1.

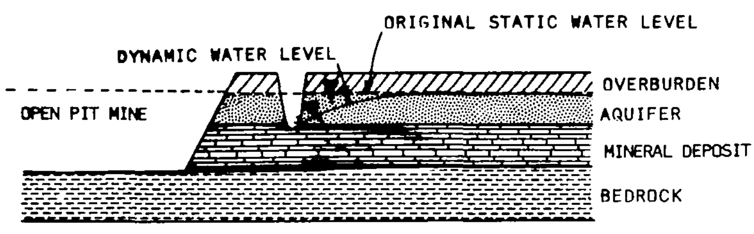

FIGURE 1. DEWATERING BY THE MEANS OF SURFACE DITCHES

DRAINAGE DITCHES AT THE BOTTOM OF THE PIT

A technique similar to that used for ditches at the surface of the pit can be used at the pit bottom. The difference is mostly in the type of aquifer to be dewatered. While surface ditches are mostly applied to drain unconfined aquifers, bottom ditches are used to drain confined aquifers. Maintenance of this type of ditch is more difficult than for surface ditches. The purpose of the ditches, as shown in Figure No. 2, is not only to accomplish drawdown of the potentiometric surface in the pit walls but also below the pit floor. Maximum efficiency is achieved when the ditches can fully penetrate the thickness of the aquifer; but this is often difficult to accomplish. In many practical cases it is difficult to draw down the potentiometric surface beneath the pit bottom in the central part of the pit (as shown in Figure 2).

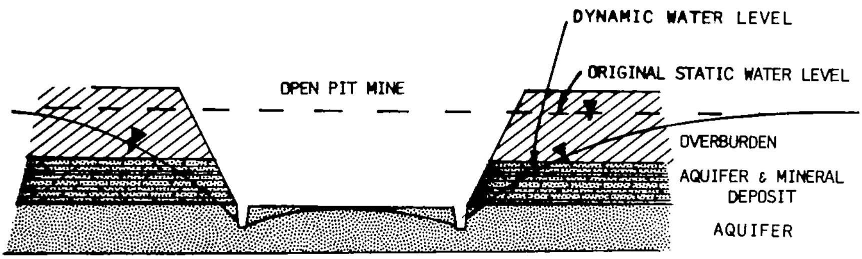

FIGURE 2. DEWATERING BY THE MEANS OF BOTTOM PIT DITCHES

HORIZONTAL DRAINS

Installation of horizontal drains (See Figure No. 3) in an aquifer affecting the stability of a slope in an open pit mine is a very efficient means of dewatering. The main advantage is a relatively low installation cost, no energy consumption for water discharge and low maintenance cost.

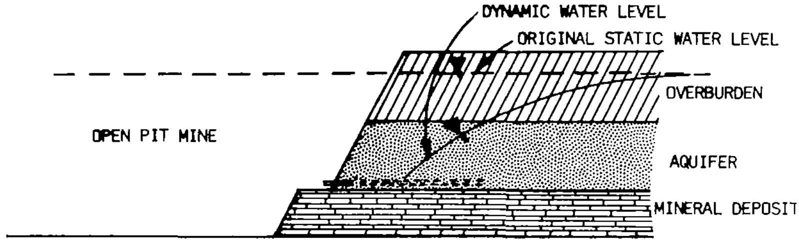

FIGURE 3. DEWATERING BY THE MEANS OF HORIZONTAL DRAINS

The principal limitation in the use of horizontal drains is the fact that it can be economically installed only after the completion of an excavation rather ahead of excavation. In many cases the time necessary for installation of an effective horizontal drainage system is sufficient for the occurrence of a slope failure.

Horizontal drains can be installed in most types of aquifers and are highly efficient in confined aquifers with high pore pressures. They are also the best means of dewatering bedrock aquifers with a well developed vertical fracture system.

Typically, horizontal drains consist of 1 1/2 to 2 inch PVC slotted pipe installed inside the drill rods. In most cases, for slope stability protection, drains 250 to 500 feet deep are sufficient. Hydraulic and economic efficiency sharply decrease with drains deeper than 400 to 500 feet; therefore, deeper drains should be installed only in special cases. The deepest horizontal drains ever installed by the author were over 800 feet deep in relatively difficult geological conditions.

The size of slots in the PVC pipe should be designed according to the drained material. From practical experience, a maximum slot size which would allow discharge of a reasonable amount of sand particles, should be used, especially in cases where chemical incrustation in the pipe can occur.

The drains can be drilled from the bottom of the pit or from a bench, but always from the lowest part of the aquifer to be drained. The drains should be installed at a gentle upslope angle (1 - 5 degree) for the following reasons:

- minimal hydraulic losses
- water does not freeze at the drain mouth so easily
- elimination of drill rod bending effect as per following discussion

During the drilling of horizontal drains the hole is bent down by the weight of drill pipes. Zaruba (5) states that a drain at a depth of approximately 200 feet, can deflect 7 to 10 feet. The opposite effect can also occur. From my personal experience, the drain can be bent drastically up by application of excessive pressure during drilling by a driller who is paid by the foot. During one installation of a 600-foot deep drain at a 3 degree upslope angle in coal waste materials, the drill pipe and bit bent to a 90 degree angle and broke the ground surface about 250 feet above the elevation of the drilling. Similar circumstances can explain why many drains installed without the supervision of an experienced engineer are discharging much less water than calculated. The cost of an experienced supervisor is, in my opinion, well justified. In an average installation of 600 feet of drains per day, the cost of supervision is only about $0.8 per foot. The actual average cost for installing 1 1/2 inch PVC horizontal drain is between $8 and $10 per linear foot.

Drilling of downslope drains downslope is also used (7)(9), but for the above mentioned reasons is recommended only in cases where there is high incrustation potential of drained water.

From a practical point of view, drains are usually installed in a fan-shaped layout, typically four to six drains fanning from one location. This setup is advantageous because of easier preparation of the drilling pad, less time for drill rig movement and also because it means a simpler water discharge collection system.

Proper design of a dewatering system by means of horizontal drains is necessary. The calculation of distances between drains, depth of drains and average discharge from drains should be based on a good knowledge of hydrogeologic characteristics of the site.

Vertical Wells Drilled from the Surface

Dewatering by means of vertical wells (See Figure No. 4) drilled from the surface is a common mine drainage practice (1)(4)(6). The water from the wells can be discharged by pumping, gravity flow or artesian flow. In most case, submersible type pumps are utilized in vertical perimeter wells.

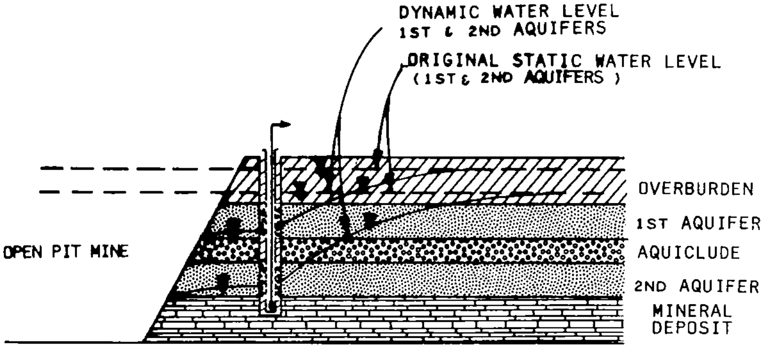

FIGURE 4a DEWATERING BY THE MEANS OF VERTICAL WELLS FROM SURFACE

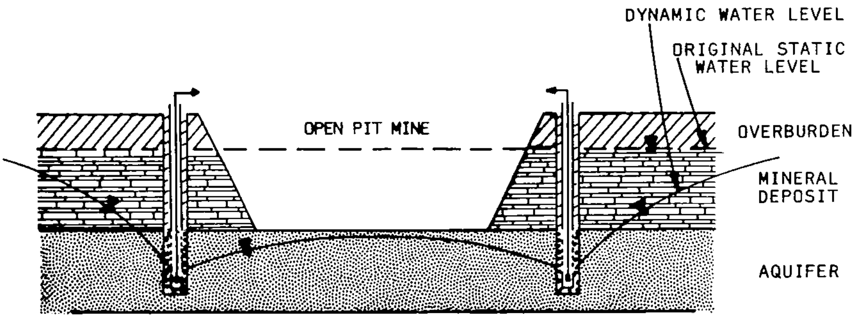

FIGURE 4b DEWATERING BY THE MEANS OF VERTICAL WELLS FROM SURFACE

The major advantages of such systems are the possibility of dewatering ahead of pit excavation, prevention of water pollution and practically no interference with the mining operation. Also, the possibility of draining several aquifers with a single well is not readily achieved with the other methods discussed.

Disadvantages of this method are the cost of energy limitations in drawdown achieved and cost effectiveness in dewatering more impervious aquifers. From experience in dewatering unconfined aquifers in unconsolidated materials in open pit coal mines (6) it is possible to accomplish drawdown of only about 65 to 85 percent of the saturated thickness of the water bearing strata. Other experience (4) shows that cost effective dewatering by pumping the water from vertical wells is feasible when the hydraulic conductivity of the drained strata is not less than about 10 feet/day for unconfined aquifers and not less than about 1.0 to 1.6 feet/day for confined aquifers. Attempts to use vertical wells to dewater a bedrock aquifer with predominantly secondary permeability caused by vertical fractures usually result in failure.

The scope of dewatering wells is different from a water supply well because the well yield is not as important as the drawdown achieved. The spacing of dewatering wells is therefore different from that of water supply wells. The optimum distance between dewatering wells is calculated from the results of aquifer tests usually performed during the hydrogeologic investigation. The second well should be placed within the steep part of the cone of depression developed by pumping the first well. As a rule (6), the effective radius of dewatering of a well is usually equal to one-third of the radius of influence of the pumped well.

For most vertical dewatering wells, the water supply well technology is applied. Five- to six-inch PVC casing with slots or PVC screen and proper gravel pack in drained materials are usually used. The cost to drill, install and properly develop a dewatering well to a depth of about 600 feet is in the range of $15 to 18 per foot, including the cost of supervision, which amounts to approximately $2 per foot.

Vertical Wells Drilled from Benches or Pit Bottom

Most of the technical aspects discussed in previous sections are valid for wells drilled from pit benches or pit bottom. The advantage of locating dewatering wells at a lower elevation is reduction of pumping head, and therefore lower energy costs. Limitations are more difficult access to the drilling locations and interference with mining operations.

In cases of water seepage from an aquifer located beneath the pit floor (8), pressure relief wells can be drilled at the pit bottom. Such wells relieve excessive hydraulic pressure without the necessity of pumping.

Dewatering Shafts and Galleries

Because of the high cost of dewatering shafts and galleries, this method is usually applied only in complicated hydrogeologic conditions where other dewatering means are not effective. In the sedimentary coal and uranium deposits of the Western U.S., dewatering shafts and galleries are not used in open pit mine dewatering. A conservative estimate is that dewatering galleries are at least five times more expensive than drainage borings (5).

Combination of Various Dewatering Methods

In many dewatering projects, a combination of two or more previously discussed dewatering methods have been used. In this way, the advantages of various dewatering methods may be combined. For example, with initial dewatering by means of vertical wells before mining activities begin, safe and effective excavation can be achieved. In a later phase of mining, a series of horizontal drains may be installed on the final pit walls to eliminate the necessity of energy consuming pumping.

In every case the mine dewatering design must be based on the knowledge of site hydrogeology and on an overall cost study.

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