AN ANALYTICAL AND GRAPHICAL TECHNIQUE TO DETERMINE THE SPACING OF DRAINAGE WICKS FOR PRESSURE RELIEF IN AN OPEN PIT COAL MINE

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ABSTRACT

Open-pit mining is sometimes conducted in areas where the artesian pressures contained in aquifers underlying the pit's floor are great enough to cause floor heave. In order to reduce this pressure several methods are commonly used. One of these methods is a pressure relief well or depressurization wick. The wick consists of a borehole which is filled with gravel and cased at the surface. The wick is allowed to flow freely, thus reducing pressure near its location. The spacing and depth of these wicks can be determined by a simple analytical and graphical technique which considers the weight of material overlying the aquifer and the artesian force within the aquifer. An example of the technique using data from a Colombian coal mine is presented.

INTRODUCTION

A simple, analytical and graphical technique can be used to design the depth and spacing of pressure relief wells (also known as drainage or depressurization wicks) in a open pit mine. Such a technique is the subject of this paper. Pressure relief may be required during mining in areas of high, artesian pressure which is contained in one or more aquifers underlying the floor of the mine. The presence of this pressure, depending upon ground conditions, may cause instability or failure along the floor and/or footwall of the pit. This instability is termed floor heave.

The process by which floor heave occurs is rather simple. Prior to mining, the force resulting from artesian conditions is in equilibrium with the lithologic and fabric forces within the rock mass overlying the aquifer. As the rock mass is removed between the top of the aquifer and the bottom of the pit, the lithologic and fabric forces are diminished by reduction in rock mass and weakening of shear forces by mining operations such as blasting. Failure occurs when the artesian force is greater than the sum of the lithologic and fabric forces. The result is floor heave which can be noted by the following observations along the pit floor and/or footwall:

- Buckling
- Cracks or ruptures
- Flowing water along cracks or ruptures

The consequences of such conditions can be categorized into the following areas:

- Economic and operational
- Safety
- Engineering
- Environmental

Loofbourow (1973) discusses these categories in more detail.

The control of floor heave is best done prior to failure. This control is commonly accomplished by depressurization or as it has also been misnamed dewatering. Depressurization consists of the reduction of the artesian pressure within the aquifer. An artesian aquifer is one whose potentiometric surface (pressure head) lies above its top. Dewatering begins after the artesian pressure is removed and actual removal of water from aquifer storage begins. The aquifer at this point is under water table conditions. Dewatering aids in the reduction of the potential for slope failure by reducing the saturation of the rock mass. Both depressurization and dewatering aid in reducing flooding potential.

PRESSURE RELIEF METHODS

Pressure relief or depressurization can be accomplished using several different methods. Those methods are:

- Pumped wells
- Well points
- Tunnels and long holes
- Pressure relief wells or drainage wicks

The choice of which method is used is dictated by a number of factors including the mining method, available time, and economics. The design of the system is dictated by the degree of depressurization which is required. These methods are discussed in Powers, 1981; Sharp et alia, 1977; Loofbourow, 1973; UOP Johnson, 1972; and Departments of the Army, the Navy, and the Air Force, 1971.

The pressure relief well or drainage wick is a borehole which is drilled into a flowing artesian aquifer or series of aquifers and is commonly filled with gravel and capped at the top with a short piece of casing which is cemented into the annulus. Figure 1 illustrates a schematic of this construction. The drainage wick is passive in operation, allowing flowing artesian conditions to provide the discharge. The drainage Wick technique is the most inexpensive of the four pressure relief methods mentioned although it is the least effective overall. Nevertheless, it can provide sufficient depressurization under many applications.

ANALYTICAL AND GRAPHICAL TECHNIQUE

The analytical and graphical technique used to determine the spacing of drainage wicks is based upon the balance between the artesian pressure within the aquifer and the pressure resulting from the weight of the rock overlying the aquifer and the shear forces. For a conservative analysis all shear forces are neglected so that the weight (and resulting pressure) of a unit column of rock is in equilibrium with the opposing artesian force and resulting pressure. As overburden material (rock mass above the aquifer) is removed, this equilibrium is disturbed until the artesian force exceeds that of the weight of the overburden, causing upward movement. This condition is floor heave or artesian burst.

The above condition is represented as:

$$W - F_W - R = 0 \qquad (1)$$

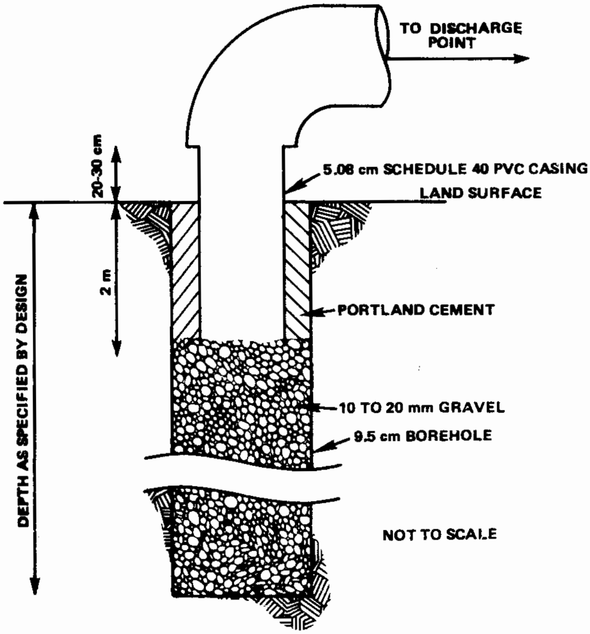
Where

W = Weight of rock above aquifer
F_W = Water force (artesian force)
R = Reaction force

At a certain depth, Z, equilibrium is reached and the reaction force R is zero, and $W = F_W$

The weight of the rock above the aquifer is:

$$W = (Z)\ (SPG)\ (Y_W) \qquad (2)$$



SCHEMATIC DIAGRAM OF DRAINAGE WICK

FIGURE 1

And the upward water force is:

$$F_W = (H + Z)\ (Y_W) \qquad (3)$$

Where

Y_W = Unit weight of water
H = Water head at excavated level
Z = Depth below excavation to equilibrium
SPG = Specific gravity of rock

Substituting W and F_W and solving for Z results in:

$$Z = H/(SPG-1) \qquad (4)$$

A depressurization wick will depressure an aquifer to a level that is the same as the top of the wick. As one moves radially away from the wick, the pressure will increase. This pressure sink is called the cone of depression. If more than one wick are used, their effects will be cumulative at any point where their cones of depression coincide. Mathematical formula such as that developed by Theis (1935) can be used to describe this effect. All flowing artesian aquifers which are intercepted by the wick will have their pressures reduced to the same level (top of the wick).

The methodology of the technique is to superimpose a profile of the drawdown over a geologic cross section of the aquifer system. By converting the weight of the overlying rock (F_W) to equivalent head or water pressure, one can measure the equivalent distance (graphically) from the bottom affected aquifer to the drawdown profile. Distance from the depressurization wick is represented on the horizontal axis, and depth is represented on the Y axis. At the distance along the horizontal axis that the weight of the rock (converted to head) equals the water head, a new depressurization wick is installed. This method insures that the weight of the rock will always equal or be less than the water force. The following example of a Colombian open pit coal mine illustrates an application of the method.

EL CERREJON MINE CASE HISTORY

The El Cerrejon mine is a 15 million ton per year open pit coal mine currently being developed in the Department of the Guajira of Northeastern Colombia, South America. The mine is being developed by International Colombian Resources and operated by Morrison-Knudsen Company, Inc.

Geohydrologic investigations revealed the presence of a series of dipping, artesian aquifers (the coal seams themselves) underlying the floor of the proposed pit. The elevation of the potentiometric surface is 10 meters below land surface but potentially could be over a hundred meters above the floor of the excavated pit of not depressured. Aquifer testing indicated that the hydraulic conductivity of the aquifers ranged from 0.056 to 0.45 m/day. The storativity ranged from 1×10^{-4} to 1×10^{-6}. Floor heave along the footwall was determined to be a potentially serious problem, and drainage wicks were chosen to depressure as the pit was initially constructed because of their low cost and low maintenance. The high wall was to be dewatered using horizontal drains and pumped wells.

The design of the wicks was to fill a 9.5 cm diameter borehole drilled to a prescribed depth with 10 to 20 mm gravel to within 2 m of the footwall's surface. Surface casing (5.08 cm inside diameter) would be installed from that point to 20 to 30 cm above the footwall's surface. The annulus would be sealed with Portland cement. Figure 1 illustrates a schematic of this installation. Wicks were to be installed initially at 150 m spacings along strike with the provision for other wicks to be placed in between these if floor heave developed.

The depth of each wick was determined using equation 4. The mean specific gravity at El Cerrejon is 2.4 ± 0.15. Therefore equation 4 becomes:

$$Z = \frac{H}{2.4 - 1} = (0.714)(H) \qquad (5)$$

where

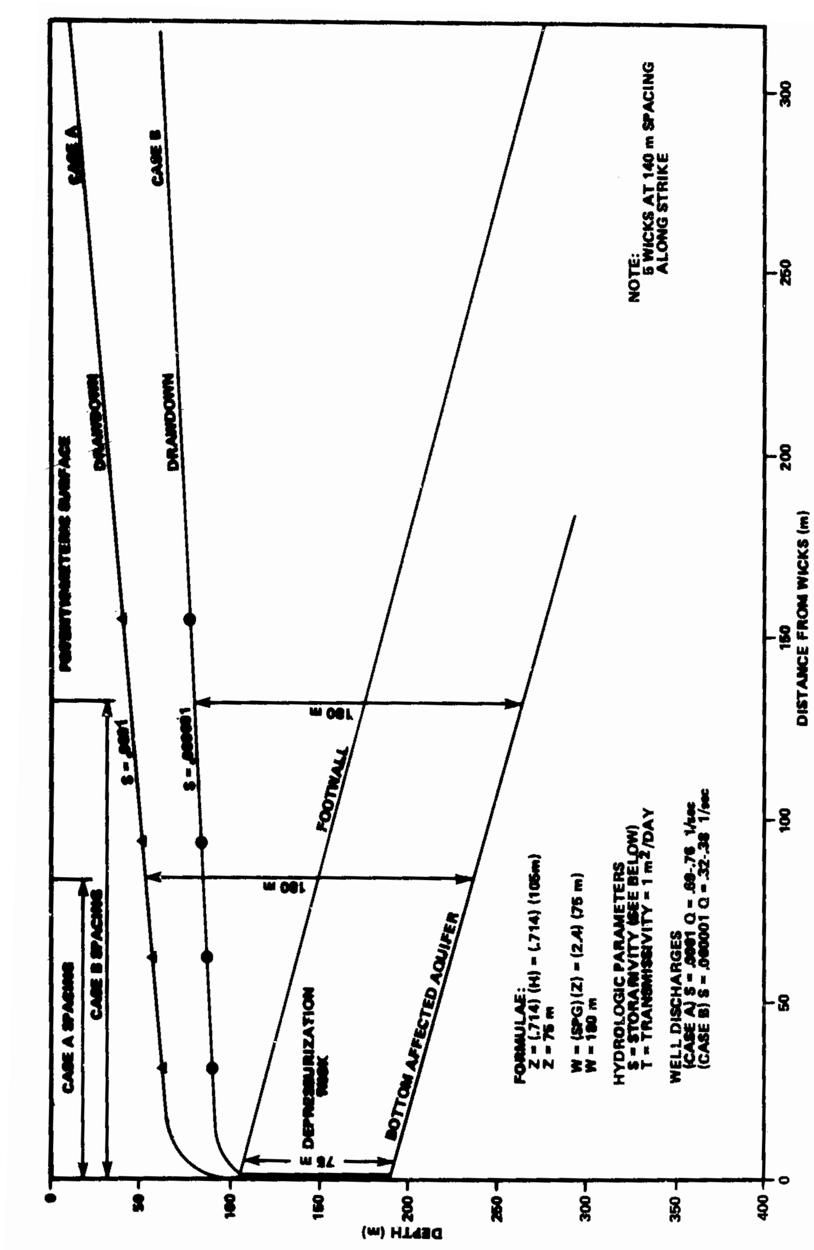
H = the difference between the elevation of the potentiometric surface and the elevation of the footwall where the wall will be drilled.

The actual depth (Z) will vary depending upon wick location but assuming a footwall elevation of -5 m and a potentiometric surface elevation of 100 m:

$$Z = [100 - (-5)][0.714] = 75 \text{ m} \qquad (6)$$

Using a series of hand-held calculator codes for determining discharge from a well and the resulting drawdown profile (Prickett and Voorhees, 1981), discharges from the wick were estimated, and drawdowns as a function of distance from the wick were calculated.

Figure 2 illustrates an example of the graphical representation of the method. Datum is the potentiometric surface which is assumed to be flat. The footwall lies 105 m below the potentiometric surface at the location of the depressurization wick. The wick is 75 m deep. The footwall follows the dip of the aquifers (which are coal seams). Therefore, the bottom, affected aquifer (the deepest depressurized aquifer) lies 75 m below the footwall as



GRAPHICAL REPRESENTATION OF DEPRESSURIZATION WICK SPACING

FIGURE 2

indicated. Setting equations 2 and 3 equal to each other and dividing by the unit weight of water results in:

$$(Z)(SPG) = (H + Z) \qquad (7)$$

or

meters of rock weight = meters of head

Using this relationship, the equivalent meters of head for a given rock mass (equivalent head) can be calculated. For our example:

$$(Z)(SPG) = (75\ m)(2.4) = 180\ m$$

The equivalent head is scaled off using the Y axis scale. The drawdown profile is plotted as a function of distance from the wick. At the point where the scaled length of the equivalent head is the same as the distance between the drawdown profile and the bottom, affected aquifer, the forces are in absolute equilibrium. If one moves further to the left (further from the wick), the water force is greater than the weight of the rock and floor heave may occur. Therefore, this distance from the wick to where the forces are in absolute equilibrium is the location of the next wick. The distance on the horizontal scale is the wick spacing for this particular set of wicks.

Two cases are illustrated on Figure 2. Case A assumes a storativity of 1×10^{-4}, and case B assumes a storativity of 1×10^{-6}. The transmissivity is 1 m^2/day for both cases. Note that the drawdown profile for case A and the drawdown profile for case B differ. The wick spacing for a case A is approximately 85m, and for case B it is approximately 130m.

Once the first sets of depressurization wicks are placed, the procedure is repeated, proceeding down the footwall. The depressurization wicks can be placed in the pit floor if necessary. The same technique will apply for spacing those depressurization wicks.

CONCLUSIONS

Based upon this study, The following conclusions concerning the use and spacing of depressurization wicks are made:

- o Excessive artesian pressure in aquifers underlying an open pit mine may cause serious problems, requiring a reduction in that pressure
- o Depressurization wicks are an inexpensive means of pressure relief to open pit mines although their effectiveness may be less than other forms of pressure relief

- A simple design can be used for the wicks, and a simple analytical and graphical method can be used to locate the wicks in order to insure their effective operation.

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