DEWATERING FOR SURFACE COAL MINES

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ABSTRACT

This paper examines the potential benefits to surface coal mining by predrainage of mine properties. Conditions are examined in the Interior Coal Province of the United States, where saturated glacial lake deposits, glacial tills and terrace stream deposits preclude or hamper coal mining activities. Available dewatering technology for predrainage is presented and several mine models exhibiting a range of predrainage problems are described. Technically capable dewatering systems are selected for the model mines, and the economic feasibility of predrainage is examined.

INTRODUCTION

Currently, a small percentage of surface coal mines in the Interior Coal Province of the United States experiences stripping problems, due to saturated overburden. Recognizing that such problems already exist, and that a bigger problem related to groundwater might appear as surface mining is extended to recover previously unattractive and difficult-to-mine coal reserves, the possibility of draining such areas before mining should be considered. Since predrainage does not appear to be practiced to any extent, if at all, in this region, or at any other surface coal mining regions in the United States, a study was carried out to identify the benefits and problems of predrainage, the available technology for accomplishing predrainage, and the economics of predrainage. The Interior Coal Province covers a wide range of geologic and hydrogeologic conditions. The dominant characteristics of conditions over much of the Province are the effects of past ages of glacial activity. This activity resulted in shallow to deep glacial till deposits, 2) glaciolacustrine (lake bed) deposits, and alluvium and terrace deposits. The first two deposits are often of low permeability, and there- fore difficult to drain, while the third type of deposit is usually of high permeability, but also of high yield, and therefore formidable to predrain. After discussing some of the benefits expected to be gained in the mining operation by predrainage, and comparing these with some of theoperational problems, the available dewatering technology for predrainage will be presented. Finally, order-of-magnitude costs will be given for predrainage of mine models that incorporate the various predrainage problems.

Mining Operation

Dewatering surface mine sites in advance of mining can improve operating conditions within the mine. Blasting, stripping, and hauling of overburden are operations that groundwater conditions can impact most directly so they represent areas in which the greatest potential benefits from dewatering may be realized. Other operations such as handling and processing of coal may derive some bene- fit from dewatering but would not necessarily be a pri- mary objective. Large-scale dewatering will necessarily involve logistical considerations to minimize interference between mine operations and the installation, operation and maintenance of the dewatering systems. Although the systems are intended to modify ground-water conditions in advance of mining operations, some dewatering operations may have to follow and be maintained within the vicinity of the active mining face. Among the factors which require consideration are drawdown time, stripping rates, power requirements and accessibility requirements. The impact of dewatering on mining operations and the logistics required to interface dewatering operations with other operations will be discussed. The discussion is primarily directed at strip-mining operations involving a single coal seam, 1½ m thick, less than 30 m of overburden, and one strip- ping dragline, an average condition in the Interior Coal Province.

Slope Stability - In the process of removing overburden to expose a coal seam, two types of slopes are produced - cut slopes (highwalls) and embankment slopes (spoil piles). The relevant slope angles influence the design of the operating benches and for given excavation equipment can control the types of activity that can take place on any bench or level at one time. The shear strength of the material, the angle of repose at which that material is stable, the effect of the prevailing climate on that material, the nature and degree of alteration, and the character of the geologic structures within the slope areas all influence the slope angle and must all be evaluated. Material shear strength and groundwater conditions are, however, the deciding factors in slope stability and the potential need to consider dewatering.

Depending on the degree to which the overburden has been consolidated, slope stability must be evaluated using either a rock mechanics or a soil mechanics approach. Since primary concern here is slope stability of unconsolidated overburden and spoil piles, a soil mechanics approach will be employed. This approach is illustrated in Figure 1 where a potential failure surface has been approximated as a circular arc passing through the toe of the slope. The volume of material above the failure surface may be visualized as a large number of thin slices, each of which has a weight vector resolved into two orthogonal components, one tangent to the failure surface and the other perpendicular to the failure surface. The tangential component of weight is a driving force, acting to cause shear along the failure surface. The resisting force along the failure surface is made up of cohesion and friction forces. Friction forces are mobilized by the normal component of weight on the failure surface. If there is a water table in the slope above the potential failure surface, then only the buoyant weight of the submerged soil is effective in mobilizing friction on this surface. Consequently, for a given slope angle, a dewatered slope is more resistant to failure than a saturated slope.

In addition to the analysis of gravity or weight forces on slope stability, seepage forces must be considered. Seepage forces are applied to the slope material through the frictional drag of moving water so that they can combine with soil weights to either improve stability or worsen it, depending on the direction in which the forces act. Water seeping toward the slope will promote failure while water seeping away from the slope will promote stability. Consequently, slope stability can be enhanced by inducing seepage forces which act in directions away from the slope e.g., employing dewatering systems behind the slopes.

Kenney (1972) presents a preliminary design chart (see Figure 2) which illustrates the effect of dewatering on the angle at which stable slopes can be maintained. The solid curve on the shear strength vs normal effective stress diagram can be assessed on the basis of laboratory tests of core samples. By estimating the range of normal effective stress along potential failure surfaces within the slope, the dashed line would be drawn to intersect the solid curve within this range and the angle *, between this dashed line and the horizontal axis would be selected for purposes of preliminary slope design. Plotted on the critical slope inclination vs. angle of shearing resistance diagram in Figure 3 are two curves. One curve corresponds to natural drainage in which groundwater is allowed to seep towards the slope, and the other curve corresponds to complete drainage by dewatering in which all groundwater has been diverted away from the slope. Noting that an inclination of 1 in 11 corresponds with an angle of about 5 degrees whereas an inclination of 1 in 1 corresponds with an angle of 45 degrees, dewatering permits much steeper slopes than does natural drainage. It follows that dewatering systems for strip mining operations should perform two functions: 1) lower the water table behind the slope, and 2) develop favorable seepage forces away from the excavation. Generally speaking, lowering of the water table should be initiated prior to stripping operations, and control of seepage forces during mining should be designed to maintain stable highwall and spoil pile slopes in the vicinity of the active mine face.

Materials Handling - Essentially two categories of material must be handled during coal strip-mining operations, i.e., overburden and coal. Water-saturation of unconsolidated overburden often necessitates the use of special overburden handling techniques to assure spoil pile and highwall slope stability, whereas saturation of the coal may cause handling problems during loading, transport and storage. For the purpose of this paper, however, only the overburden handling problems are considered. Referring to the previous discussion dealing with the effect of water on stability of slopes, it was noted that water not only increases shearing stresses but at the same time decreases shear strength, thereby promoting slope instability. While dewatering of slopes can counteract these adverse effects other methods are commonly practiced for slope stabilization. Several mining methods employed in strip-mining operations involve placing steep spoil piles of dry, stable material (buckwalls) so that piles of less competent spoil material can be placed and retained behind them. Unfortunately, use of such methods usually requires that materials must be rehandled and consequently mine pro- duction is decreased. Rehandle percentages associated with some mining methods in use in the Interior Province are reported as being on the order of 38 percent, though only part of the rehandle is due to a need to promote highwall and spoil pile stability in wet ground. For example, at one mine in a swampy area, average rehandle percentage is 35 percent. Much of the rehandle is attributable to the fact that this is a multiple seam mining operation in which, given the dragline range and overburden depth, about 20 percent rehandle would be required even if there was no mud. In addition, toxic interburden materials are required to be buried by the dragline, which necessitates some additional rehandle. Nevertheless, a significant amount of rehandle attributed to wet spoil remains at a mine located in the swampy area of southern Indiana and western Kentucky, more unique procedures are employed which require an average rehandle of 70 percent, and it has been as high as 200 percent (Cook and Kelly, 1976).

Due to the spoil instability and high rehandle percentages associated with strip-mining operations in "swampy" and heavily glaciated areas, the potential for dewatering to increase production can be significant in such areas. However, there are practical limits to which any dewatering system can remove "excess" water from the silts, clays and organics associated with such areas, so that the most likely aspect of any special mud handling procedure to be affected is the recasting of mud to the top of spoil piles. By virtue of decreasing the water content of this mud, less water will seep out through the slopes of the spoil piles and this will increase stability. Any improvement will necessarily be a function of the effectiveness with which the dewatering system can remove water from fine-grained materials.

Blasting - Dewatering of overburden can have both an indirect and direct influence on blasting operations. Indirectly, dewatering of saturated, fine-grained, cohesionless deposits can minimize the potential for blast-induced flow slides. Directly, dewatering of consolidated overburden may decrease blasting costs by allowing less expensive blasting agents to be used. When fine-grained, cohesionless overburden is subjected to vibrations (i.e., cyclic stresses), each reduction and reapplication of stress is accompained by an increase in strain. If the overburden is also saturated and in a loose condition, each cycle of stress reduction and reapplication will produce an increase in pore water pressure, provided that drainage of the pore water is inhibited. If a sample volume of sand is subjected to cyclic loading conditions of this type, it may remain stable for some number of cycles, and then suddenly lose all its strength with the accompanying development of pore-water pressure equal to the confining pressure. This complete loss of strength and the ability of the sand to undergo displacements without exhibiting resistance is known as liquefaction. Layers, seams and lenses of loose, relatively fine, uniform sand below the water table are susceptible to liquefaction during blasting, especially if the blasting is of sufficient duration and intensity to produce many cycles of large amplitude shear stress. Recognizing that liquefaction involves a build-up of pore water pressures, dewatering of overburden can minimize any liquefaction potential. At the least, when relatively fine, uniform sand deposits are penetrated by gravel drains (or the gravel pack around wells and well points), pore water pressures generated by cyclic loading can to some extent be disipated as they are created.

The choice as to which explosives will be used in a blasting program is strongly influenced by product costs and loading costs. For most operators the choice is one between dry blasting agents and slurries. Because of low product cost and efficient bulk-loading techniques, the overwhelming majority of operators favor dry blasting agents, commonly known as ANFO (Dick, 1973). However, as shown in Figure 3, these explosives have very low water resistance which makes them undersirable for use in wet conditions. To counteract this lack of water resistance of ANFO, holes must be dewatered and a plastic borehole liner used, which can increases costs but also increases the toxic fumes produced. Another approach is to use slurries or gelatin dynamites which not only increase water resistance but will also increase costs. Aside from minimizing the exposure of ANFO to water, dewatering will eliminate the problem of ANFO floating up in water-filled blast holes which causes loss of powder and sometimes requires that blast holes be redrilled. Ideally, then, blasting programs could be decreased in cost by a dewatering system which lowered groundwater levels to below the deepest blast holes, and maintained these levels during blast operations, allowing use of dry bulk ANFO exclusively. One drawback to lowering of groundwater levels below the deepest blast holes, is the loss of water as a couplant between the explosive and the rock. Reduced coupling will cause a decrease in the borehole pressure (pressure exerted on the borehole walls by the expanding gasses of detonation after the chemical reaction has been completed). To counteract this decrease it may be necessary to increase the amount of explosive used in blast holes. Essentially, this is a trade-off between: a) using smaller amounts of expensive blasting agents in wet blastholes, and b) using larger amounts of cheaper agents in dewatered blast holes.

Where dewatering systems will be in operation both during and after blasting, the susceptibility of system components to damage must be considered. Ground vibrations may damage pumps and header pipes. Fracturing the consolidated overburden may damage well casings and screens as well as well point pipes. Flyrock could damage pumps and header pipes. Logically, the potential for damage will increase as the number of susceptible dewatering system components (within the vicinity of a blast) increases. Some useful guidelines are available from experience. For a Canadian open pit iron ore mine (Stubbins and Monro, 1965) the rapid recovery of the water table in some areas of a dewatered mine necessitated close coordination between the dewatering division and the mine operating staff. Drilling the blast was done with the pump and pipeline in place. In areas where rapid water table recovery was expected, plastic liners were used to waterproof the explosives even if the holes were dry when drilled. Sufficient width of rock was left in front of the well so that the force of blast would cause little or no displacement of the casing. No holes were drilled closer than 9 m from the well, and the closet holes were delayed to direct the shock away from the well. When the blast was with in 30 m, the motor and discharge head were removed, the pump column supported on the top of the casing, and a steel bell put over the well and covered with rock. At greater distances, wooden ties and straw were used to protect the motor against flyrock.

Resource Recovery - The impact which dewatering may have on resource recovery is reflected in the previous discussions of slope stability, materials handling and pit flooding. Whereas pit flooding may cause mine shutdown in extreme cases, sloughing of highwalls and spoil piles onto exposed coal necessitates cleanup operations and may cause loss of coal. Additionally, these factors will impact secondary recovery operations initiated when the economically strippable overburden depth is reached. It has been suggested by some authorities that mine operators prefer to keep an inventory of exposed coal in the pit to allow loading to continue even when the stripping machine is down. Field survey data indicate otherwise. General practice in the Interior Province is to load out coal as close behind the stripping machine as is practical. One reason for this practice is to minimize coal losses and cleanup work caused by sloughing or sliding of spoil into the open pit (Cook and Kelly, 1976). Development of inventories of exposed coal would be facilitated if dewatering of overburden in advance of stripping can improve spoil pile stability. This translates into increased resource recovery not only by virture of coal remaining exposed, but also by improving the possibility of increased production due to less cleanup work. Additional gains in primary recovery may be possible at mines where coal is usually left as a fender along the toe of highwalls and spoil piles to minimize slope failures. When the final cut has been made in an open-cut coal mine the coal seam remains exposed in the bank and three secondary recovery methods are available to recover of much as the coal as can be economically won: a) coal augers, b) push-button miner and c) punch mining by underground machines (Weimer and Weimer, 1973). The secondary recovery of coal will require that the highwall bank remain stable over the unmined coal. Also, any adverse effects of static or flowing water in the coal seam itself would ideally be controlled by means of dewatering in advance of mining operations.

Logistics Considerations

The impact of dewatering on mining operations will probably be greatest with regard to the logistics involved. The design and implementation of a dewatering system must consider several factors including power requirements, accessibility requirements, time needed to lower watertable, flexibility of system to move with the active mine face, and interference of system components with any advance stripping operations. Conceivably, even the simplest dewatering system may present logistics problems so complex as to make largescale dewatering in advance of mining unfeasible. The major requirements in a good power distribution system, so as to supply ade- quate electricity to all equipment and provide maximum protection to personnel and equipment, are portable units adaptable to relocation. The costs of electric energy for powering machines in stripping operations in itself is not great, but the cost of the delivering the energy to the equipment is of major significance (Weimer, 1972). This is also expected to be true for operating dewatering systems at a mine.

At the active mine face, dewatering operations will directly impact stripping operations in two ways: 1) the rate of face advance will be impacted by the amount of time it takes to alter groundwater conditions (e.g., lower the water table), and 2) it will be necessary to remove some dewatering system components prior to advancing the face. Ideally, based on preliminary tests (i.e., pump tests), the response of groundwater conditions to dewatering operations would be known over the entire mine site. With this information, production schedules for dewatering operations near the active face could be established. That is, how long would dewatering have to be maintained before stripping, and how close to the active face must it be maintained? However, it must practically be anticipated that such information will be approximate at best and there must be enough flexibility in dewatering and stripping operations to adjust to unanticipated conditions.

During the design and layout of a dewatering system, permanent stationary components should be located outside the limits of planned stripping activity. For example, if treatment of discharge water is required, holding basins might be located above areas where coal seams are unfavorable for mining and away from haul roads. Discharge and header pipes will have to be located away from haul roads or buried beneath the roads. It is only by careful planning of such details during design that troublesome difficulties can be avoided during mining.

DEWATERING SYSTEMS

In order to evaluate the state-of-practice in dewatering, a large volume of published literature from the construction and mining industries in the United States and foreign countries on dewatering system design and experience was reviewed. Additonally, the practice of employing groundwater cutoff curtains as a groundwater control technique was reviewed. Among the available systems, those considered of potential use to needs in the Interior Coal Province are: Deep Wells, Wellpoints, Suction Wells, Eductor Wellpoints, Sand Drains, and Surface Ditches. These are more or less conventional systems in practice, though a number of innovative techniques have been developed in recent years to increase efficiency and decrease costs. For example, the construction industry has developed hole punching techniques for economical installation of deep wells, featuring rapid driving of hole-forming steel casings into the ground. One method for cohesionless, fine materials involves hammering the casing down with the help of an inner, water-jetting mandril. Another method for unconsolidated, gravel and boulder formations uses a percussion-hammered, double-walled mandril inside the driven casing, and uses compressed air down through the double wall to blow cuttings up to the surface through the core of the mandril. Sometimes instead of installing a well casing through the temporary hammered casing, the hammered casing is left in place and slotted near the bottom with down-hole torches or mechanical cutters to serve as a well casing itself. In moderate depth wells, economical slotted plastic pipe is sometimes put down as well casing when withdrawing the outer, hammered casing, and these plastic well casings can be abandoned to an excavating machine as the excavation approaches.

In addition to the dewatering systems mentioned, there remained a need for a system that could be used to dewater the glaciolacustrine, or soft lake bed deposits, which overlie some coal deposits in the Interior Province. Fine-grained, low permeability soils, such as silts and clays, have been effectively dewatered for important construction sites using techniques which partially dewater and consolidate the in situ material and which include 1) electrosmosis, and 2) large surcharge fills over the in situ material in conjunction with sand drains. Both are time consuming and expensive methods, and are not believed well suited to strip mining. Another method was studied, a vacuum- consolidation technique, which is still in a research stage (Johnson, 1977), for use in consolidation of soft, dredged materials to make more efficient use of increasingly scarce land areas available for dredge spoil. The modified vacuum-consolidation technique selected for mines incorporates a system of eductor well points installed in vertical sand drains which can fully penetrate the lake deposits and intersect the thin, horizontal layers of more permeable material that are characteristic of these deposits. A sand blanket is placed over the surface of the lake bed and the installed eductor well points, and is itself covered with an inpervious geofabric membrane. Short eductor well points in the sand blanket create a vacuum. Atmospheric pressure acting on top of the geofabric membrane simulates a surcharge load of over 5 m of soil, thus acting with the deep eductor well points and vertical sand drains to consolidate the soft lake bed deposits.

The range of application and capabilities of the dewatering systems reviewed from actual practice, plus the vacuum-consolidation technique, are shown in Figures 4 and 5 in a Dewatering System Bounds Model. The model is a useful aide to preliminary selections of dewatering systems and cost estimating for feasibility studies, such as was done for the mine models to be discussed next. The groundwater control techniques selected as having use for some special cases in the Province include slurry trench cutoffs, sheet piling cutoffs, and grout curtain cutoffs. These are shown in Figure 6. More complete detail and guidelines for use of all the mentioned dewatering systems and groundwater control systems are found in O'Rourke and O'Connor (1979).

Dewatering Costs for Models

Based on the evaluation of known and potential dewatering problems of subsurface coal mines in the Interior Province, three hypothetical surface coal mines can be characterized to represent the most significant dewatering problems expected. Each mine property is about 2100 m wide by 1525 m long. The mines are excavated by dragline, with pit dimensions of 30 m width and 1525 m length, and depth to coal varies from 15 m to 22 m. The life of the mines is about 15 years. The mines and the preliminary selection of dewatering sys- tems are described next, with a summary of the estimated costs of dewatering:

Mine Model A - Glacial Lake Deposits. The setting is characterized by 10 m to 12 m of glacial lake deposits overlying 7 m to 10 m of consolidated overburden. The lake deposits are interfingered with channel deposits. The vacuum consolidation technique was selected as a technically feasible dewatering system, and the necessary educator wells, header pipes and membrane-covered sand blanket are installed in 90 m x 90 m grids, at least 5 months before mine stripping reaches the grid area. Up to 19 grid areas are dewatered simultaneously, and then the dewatering system is moved to the next 19 grids ahead of the highwall. The buried channel deposits are isolated from groundwater recharge by slurry trench cuttoffs before being dewatered by well pumping.

A summary of the dewatering system features and costs is as follows:

	Item	Cost
1.	Install drainage blanket, drain swampy areas, establish two major lateral surface discharge ditches and a discharge basin	$8,207,423
2.	Stabilize glacial lake deposits using vacuum-consolidation technique	$243,152,530
3.	Isolate and drain buried channels	$3,196,200
4.	Total spoil pile drainage	$2,211,300
	Total cost of system over Life of Mine =	$256,767,453

Volume of coal = 4.19×10^6 m^3
Weight of Coal = 4.92×10^6 tons
Normalized Dewatering Cost = $37.11 portion

Mine Model B - Draft-Filled Preglacial Valleys. The setting is characterized by 10 m to 12 m of glacial till overlying 7 m to 10 m of consolidated overburden. Other features include channel fills cut into consolidated overburden and covered by glacial till; the occurrence of lenses of sand and gravel throughout the till; and two small surface streams crossing the property. All subsurface features have moderate hydraulic communication. This type of setting is amenable to dewatering with gravity drainage techniques, but its variability leads to pockets of high permeability materials within a general matrix of moderate to low permeability. Consequently, a flexible system of deep wells, eductor well- points and sand drains were deployed over the site. Surface streams were diverted around the property.

A summary of the dewatering system features and costs is as follows:

	Item	Cost
1.	Reroute streams, establish to major lateral surface drainage ditches and a discharge basin	$2,240,865
2.	Dewater sand lenses and buried valley	$718,298
3.	Dewater glacial till	$29,539,756
4.	Establish spoil pile drainage	$1,501,500
	Total cost of system over life of mine	$34,000,419

Volume of coal = 4.22×10^6 m^3
Weight of coal = 6.33×10^6 tons

Normalized Dewatering Cost = $5.37 per ton

Mine Model C - Alluvium and Terrace Deposits. The setting is characterized by 12 m to 15 m alluvium and terrace deposits overlying 3 m to 7 m of consolidated overburden. These materials have high storage capacity and are easily recharged by a nearby stream. The dewatering study included using deep wells, arranged in a system of stationary perimeter wells around the mine property and temporary wells along the moving highwall. The cost study also considered potential cost benefits of disposable vs. reuseable well casings, and the use of a sheet pile cutoff wall to minimize recharge of the dewatered zones from the stream. The total cost per ton did not change significantly with any of the alternatives:

	Item	Cost	
		Alt 1	Alt 2
1.	Establish permanent lateral wells, drainage ditches and discharge basin	$4,036,388	

2. Establish sheet pile cutoff and surface drainage ditches		$11,981,502
3. Dewater alluvium with deep wells	$11,137,504	$ 2,837,000
4. Establish spoil pile drainage	$ 1,173,900	$ 1,173,900
Total Cost of System Over Life Mine	$16,347,792	$15,992,402

Volume of Coal = 2.79×10^6 m^3

Weight of Coal = 3.07×10^6 tons

Normalized Dewatering Cost = $5.27 per ton

SUMMARY AND CONCLUSIONS

It has been discussed how dewatering can benefit mine operations, and mine models representing major dewatering problems in the Interior Coal Province were evaluated for costs of predrainage. The selected dewatering sys- tems were chosen from a system bounds model composited from industry experience.

Generally speaking, the simplest systems were found adequate to deal with coarse-grained unconsolidated deposits, and these are the least expensive to dewater. fine-grained unconsolidated deposits require the most sophisticated dewatering techniques, and these are the most expensive to dewater (i.e., stabilize). The mine models in this comparison tend to emphasize major dewatering problems which are shown uneconomical to deal with in the Interior Coal Province. However, it would appear that the less severe problems, involving coarse-grained deposits, might economically be handled in specific situations using presently available technology.

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LIST OF FIGURES

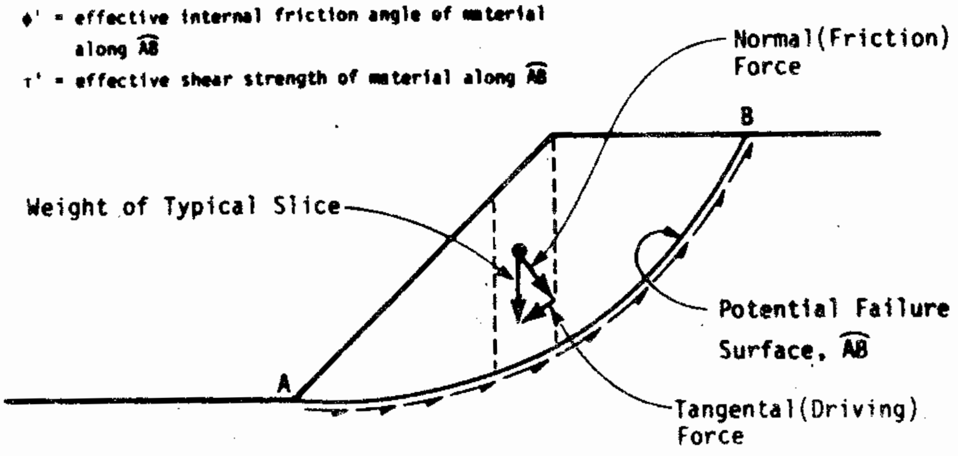
c' = effective cohesion of material along $\widehat{AB}$

σ_n = applied normal stress due to weight of material and surcharge and water above $\widehat{AB}$

u = pore water pressure along $\widehat{AB}$

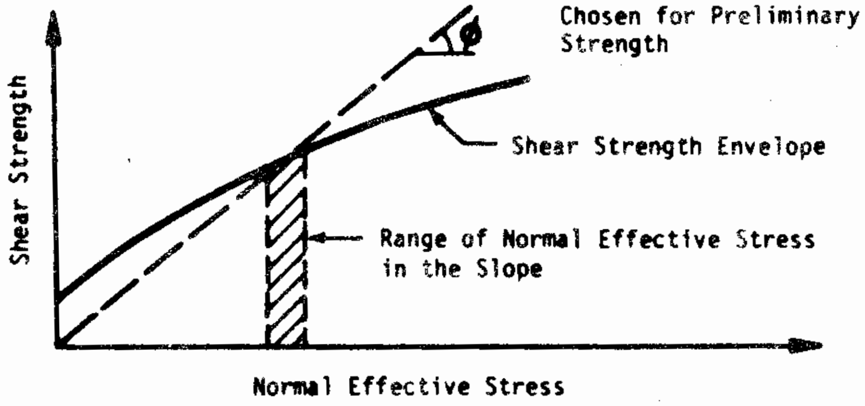
ϕ' = effective internal friction angle of material along $\widehat{AB}$

τ' = effective shear strength of material along $\widehat{AB}$



$$\tau' = c' + (\sigma_n - u) \tan \phi'$$

(a) SLIP CIRCLE ANALYSIS



(b) SLOPE DESIGN PARAMETERS

Figure 1 - FACTORS WHICH INFLUENCE SLOPE STABILITY

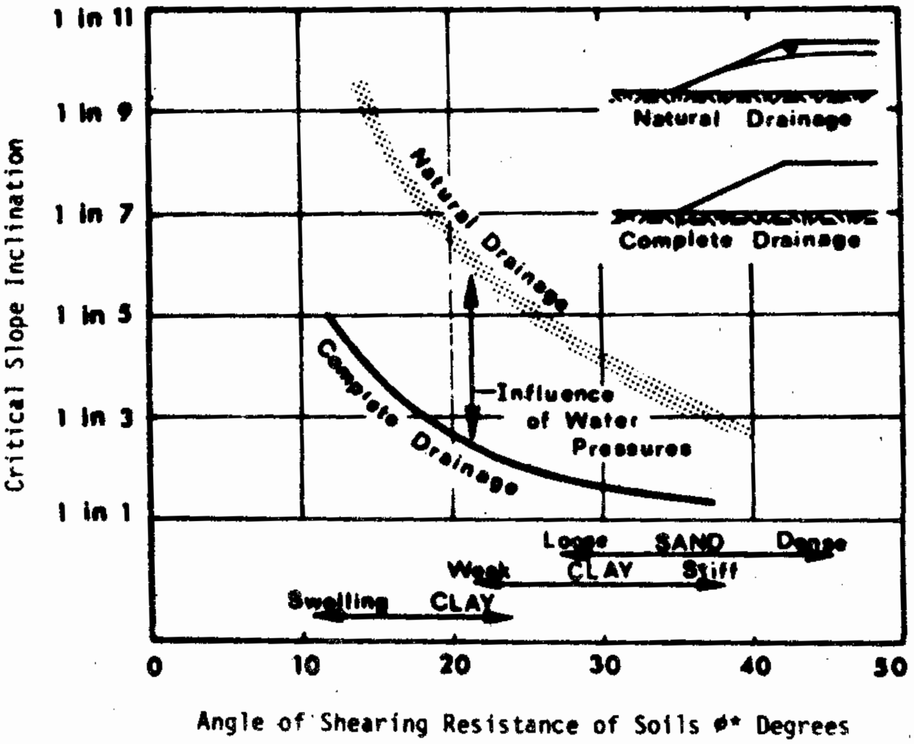


Figure 2 - SLOPE DESIGN AND DRAINAGE EFFECTS
(Kenney, 1972)

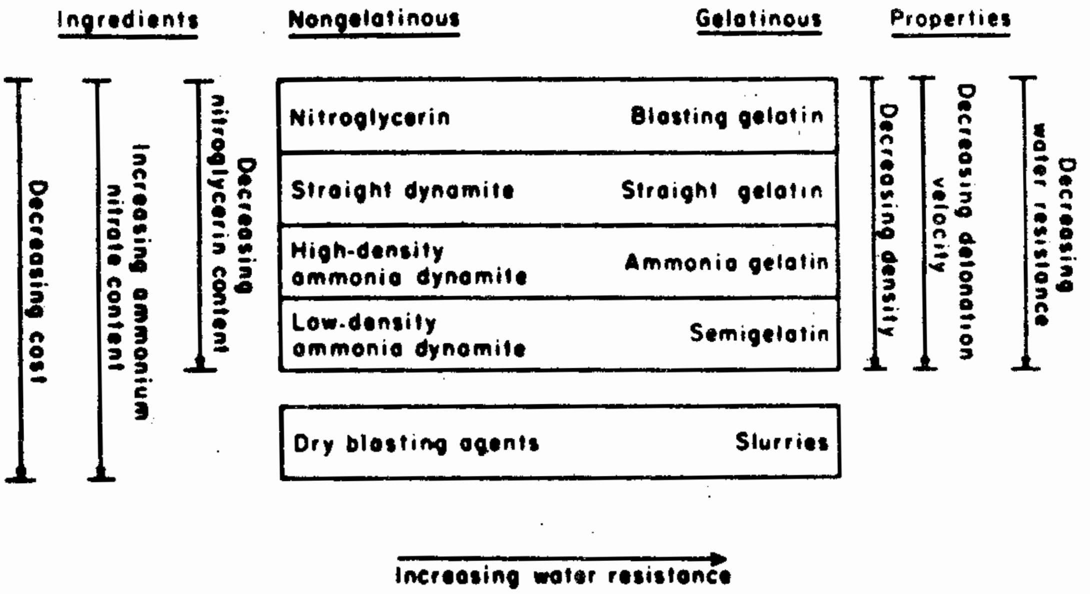


Figure 3 - SOME RELATIVE PROPERTIES AND INGREDIENTS OF COMMERCIAL EXPLOSIVES (Dick, 1968)

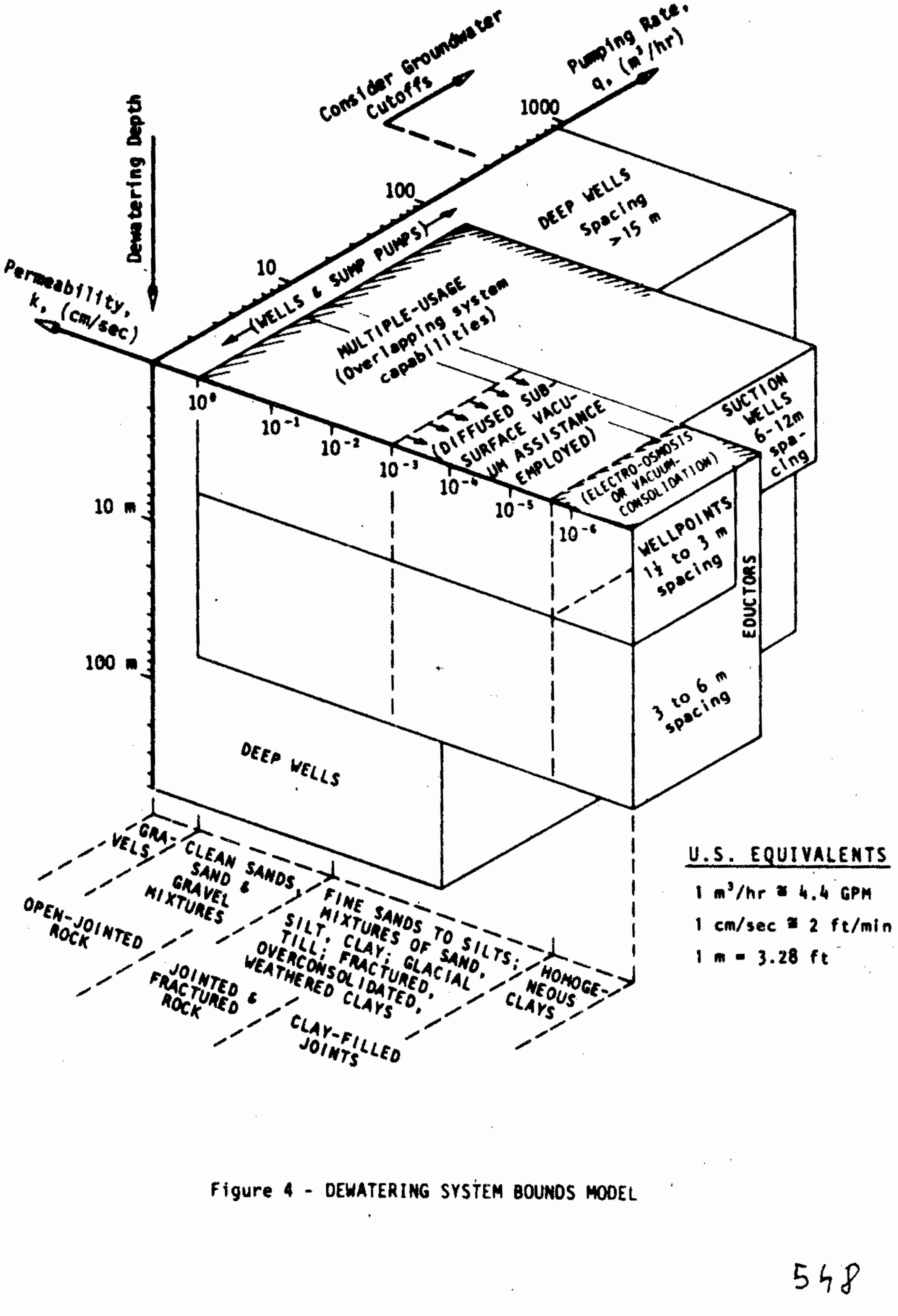
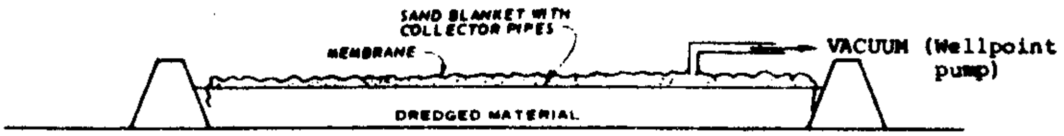
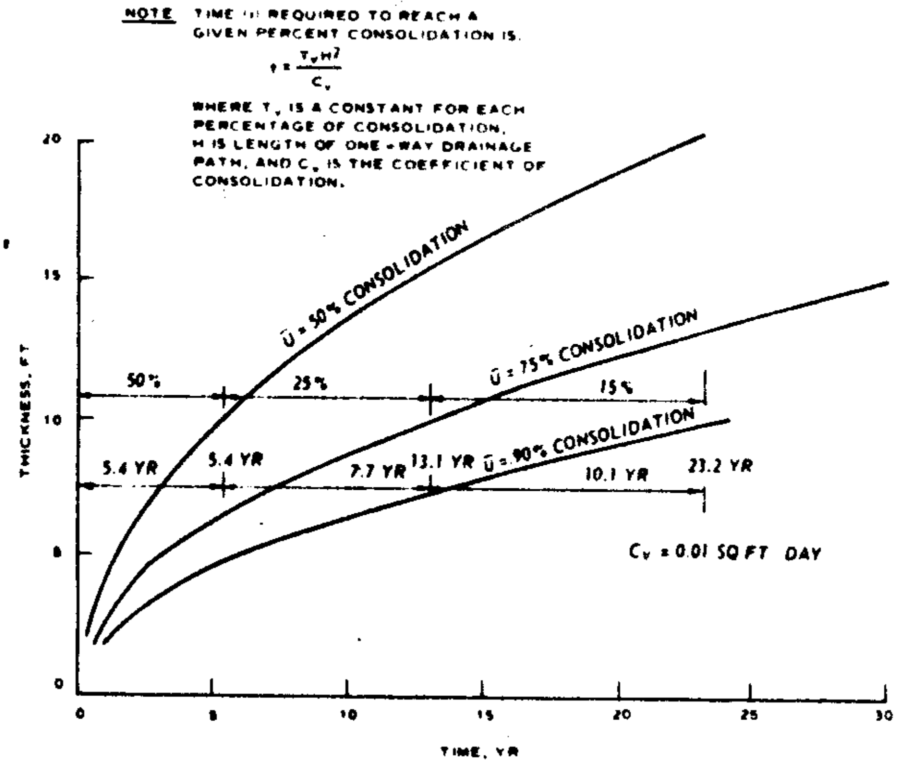


Figure 4 - DEWATERING SYSTEM BOUNDS MODEL



a) VACUUM CONSOLIDATION METHOD
(Add Vertical Drains and Wellpoints in Dredged Material if Required to Accelerate Consolidation)

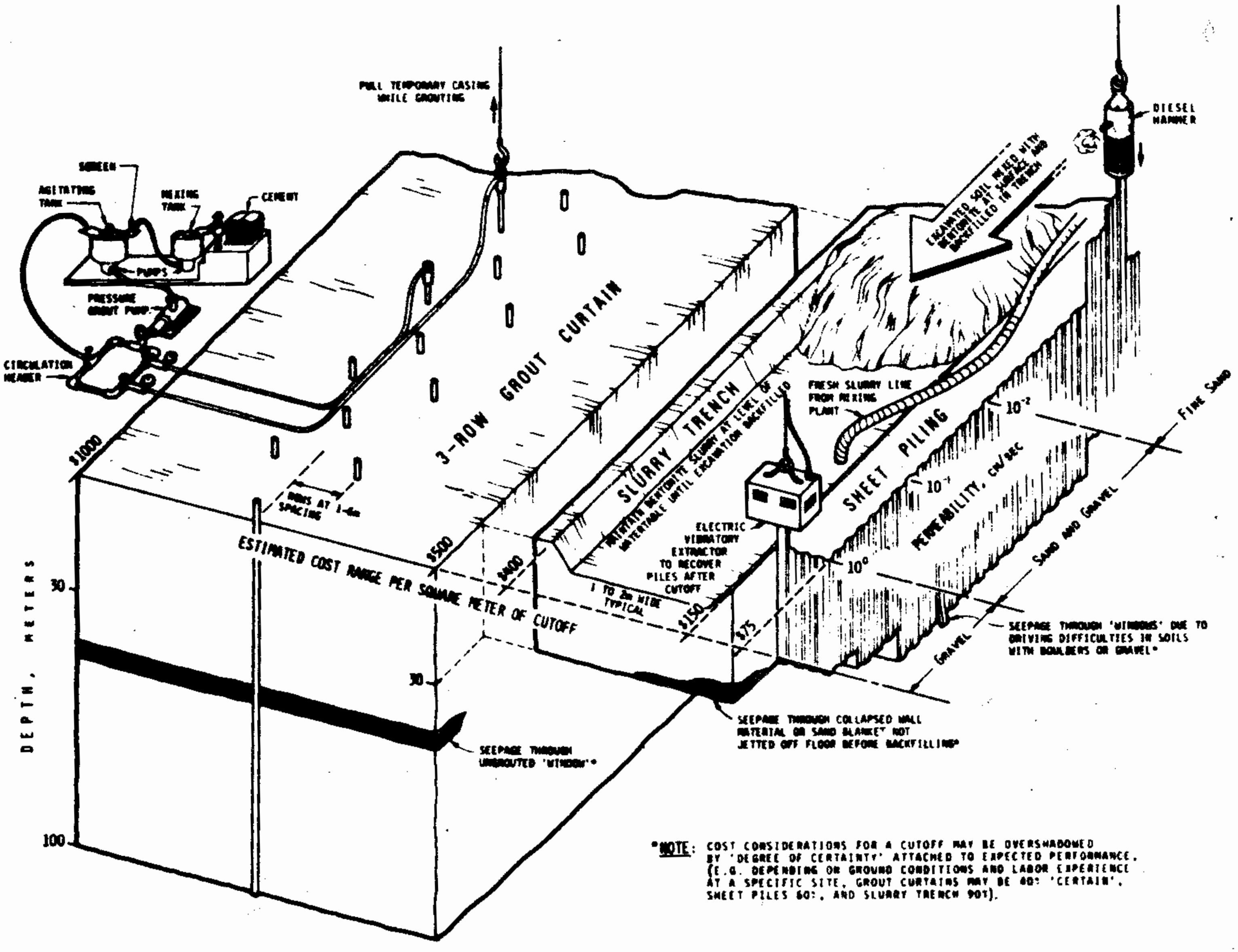

NOTE TIME (t) REQUIRED TO REACH A GIVEN PERCENT CONSOLIDATION IS.

$$t = \frac{T_v H^2}{C_v}$$

WHERE T_v IS A CONSTANT FOR EACH PERCENTAGE OF CONSOLIDATION, H IS LENGTH OF ONE-WAY DRAINAGE PATH, AND C_v IS THE COEFFICIENT OF CONSOLIDATION.

b) EFFECT OF THICKNESS ON CONSOLIDATION OF DREDGED MATERIAL

Figure - 5 DEWATERING FEASIBILITY FOR FINE-GRAINED DEPOSITS (Johnson, 1977)



*NOTE: COST CONSIDERATIONS FOR A CUTOFF MAY BE OVERSHADOWED BY 'DEGREE OF CERTAINTY' ATTACHED TO EXPECTED PERFORMANCE. (E.G. DEPENDING ON GROUND CONDITIONS AND LABOR EXPERIENCE AT A SPECIFIC SITE, GROUT CURTAINS MAY BE 40% 'CERTAIN', SHEET PILES 60%, AND SLURRY TRENCH 90%).

Figure 6 - ELEMENTS OF CUTOFFS WITH APPROXIMATE BOUNDS AND COST RANGES (1978)