In 1952, Geist, Amagno, and Mellon, writing on "Improved Portland Cement Mortars with Polyvinyl Acetate Emulsion"[8], described many laboratory tests which they had conducted. While their report contains numerous tables and graphs of experimental results, it does not mention any full-scale installations.

Meyer Immerman was issued U. S. Patent 2,768,563, in October, 1956, for a "resin-bonded Cement for Repair of Concrete". According to a brief abstract,[9] this process involves a mixture of organic solvents and one of several possible polymers, including polyvinyl acetate, designed to repair cracks and pits in concrete floors. So far as the writer knows, this patent does not include the use of emulsions.

The December issue of "Contractor's and Engineer's Monthly" carried a brief announcement of a "polyvinyl acetate concentrate" being marketed by the Surface Engineering Company, Inc. of Wichita, Kansas. Literature, received from this company in January, 1957, referred to this material as "Tite-Crete", and said that it would soon be available through dealers, but the writer has never seen it advertised.

CONCLUSIONS

A popular article on the work reported herein, "Concrete That Promises Miracles", appeared in August, 1952.[10] While no engineer is likely to refer to the effects of polyvinyl acetate on mortar as "miraculous", such mortar does have three outstanding characteristics: (1) it will bond to almost any type of reasonably clean, firm surface; (2) it has high tensile strength; and (3) it cures itself in the presence of air and light without special attention. In addition, it is easy to mix and place, and has good durability as a floor surfacing material.

The perfect material still to be found, this mortar has two major disadvantages: (1) it cannot be exposed continuously to water, although periodic wetting will not affect it seriously; and (2) it cannot be applied in thicknesses much greater than 1/2 in. without the danger of serious cracking.

The writer believes that there are many floor surfacing problems which may be solved very nicely by portland cement mortar containing polyvinyl acetate emulsion.

ACKNOWLEDGMENTS

The writer wishes to acknowledge, with sincere appreciation, (1) the sponsorship and valuable suggestions of Arthur C. Avril, President of Sakrete, Inc., (2) the guidance and help of Fred O'Flaherty, Director of the University of Cincinnati Research Foundation, and (3) the constant encouragement of Cornelius Wandmacher, formerly Head of the Department of Civil Engineering, and now Associate Dean of Engineering, University of Cincinnati.

---

[8] Industrial & Engineering Chemistry, v. 45, pp 59-67, April 1953.
[9] Chemical Abstracts, v. 51, col. 2247, Feb. 10, 1957.
[10] Popular Mechanics, August 1952, pp 112-113.

Journal of the
CONSTRUCTION DIVISION
Proceedings of the American Society of Civil Engineers

Paikowsky

(75)

CONTROL OF GROUND WATER IN EXCAVATIONS

By W. F. Swiger,[1] M. ASCE

SYNOPSIS

This paper presents a review of the basic principles and methods of controlling ground water in excavations. The factors which must be evaluated in selecting a water control system, the various methods available, their advantages and disadvantages, and basic principles of design are discussed.

Abel

INTRODUCTION

Effective control of the water encountered in excavations frequently is the deciding factor between success and failure in such work. Over the years, a number of different methods and equipment for control and removal of water have been developed by the construction industry. Sumps, possibly the oldest of all, sheeting, well points, and large diameter wells are commonly employed. Among the more exotic systems, which are used under special conditions or when difficulties are encountered with other methods, are freezing, grouting and electro-osmosis. No single system is satisfactory under all conditions. A wise selection of the method which will be most effective and most efficient under the conditions of the specific site considered will result in minimum expense, while unwise selection may result in heavy expense and possibly failure.

Among the factors which must be evaluated and considered in selecting a system are:

selecting a system

Note.—Discussion open until July 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. CO 1, February, 1960.

[1] Cons. Engr. Stone & Webster Engrg. Corp., Boston, Mass.

* See charts attached at the end. SGP

a. Soil characteristics, such as stratification, permeability of the various strata and degree of anisotropy of each stratum

b. The distance to a free water supply which will act to recharge the aquifers

c. Space limitations, such as property boundaries or interference with other structures or construction operations

d. The effects of lowering the ground water level upon adjacent structures, either because of settlement or deterioration of the piles which support them

e. The size and depth of the excavation

f. The dewatering equipment and facilities which are available

g. Time limitations

h. The methods and equipment with which the excavation will be made

A **successful system must stabilize the banks of** the excavation in order that slides or slumping will not interfere with operations or pose hazards to personnel or equipment. It must provide a suitable working surface with a dry bottom upon which equipment may move and on which construction operations may be carried out with a minimum of interference. It must prevent disturbance of the bottom caused by boils or piping: such disturbance may damage or destroy the capability of the soil, at and below the bottom of the excavation, to support the load of the structure and thus require piling or a more expensive type of foundation. These diverse requirements must be accomplished with minimum cost for equipment and installation, minimum operating charges, and without interference in construction operations.

Systems of ground water control may be classified in two, broad, general classes. **In the first group** are those methods by which the ground water level, in and adjacent to the excavation, is depressed below the bottom of the excavation by a system which collects the water as it drains from the soil and pumps it away. **In the second group** are methods which interpose a barrier preventing the flow of ground water into the excavation. [illegible]

Well points, deep wells and sumps are the most commonly used methods of the first group. To assure bank stability, the drawdown line should be kept below the bottom and slopes of the excavation. For deposits of isotropic material, such as beach sand deposits, this can be achieved with relatively simple dewatering systems. However, where the material shows some stratification, that is, alternating strata of sand and gravel as is the case for most river deposits or glacio fluvial deposits, the permeability in a vertical direction may be only a small fraction of that in a horizontal direction. In these materials the drawdown curve is much higher than in uniform materials. Intersection of the water surface with the sides of the excavation may occur unless this factor is recognized in laying out the dewatering system. **Analytical methods for determining well point or well locations are usually based upon normal well formulae which assume uniform, isotropic soils in which the coefficient** of permeability is the same, both vertically and horizontally. A. Casagrande has shown[2] that anisotropic materials can be analyzed by the same methods, provided the drawdown curves and flow nets are plotted to a distorted scale in which horizontal dimensions are reduced in relation to vertical dimensions by the ratio $\sqrt{k_{max}/k_{min}}$ and the equivalent coefficient of permeability is given by $k_e = \sqrt{(k_{max})(k_{min})}$.

[illegible]

---

[2] "Seepage Through Dams," by Arthur Casagrande, Journal of the New England Water Works Association, Vol. LI, No. 2, June 1937.

[illegible]

In stratified materials which contain one or more strata of essentially impermeable materials, such as clay, silt or very fine silty sand, there can be no vertical migration of the water. Consequently, control of ground water in the upper aquifer, as by the well point system shown on **Fig. 1** will not relieve pressures in deeper lying aquifers. Drainage of aquifers which occur below the bottom of the excavation is essential to a substantial distance below the bottom of the excavation since, otherwise, pressures in these aquifers may cause boils in the bottom and possibly piping. To assure stability, it is necessary that the weight of materials above some aquifer whose top is at plane A-A exceed the hydrostatic pressure at plane A-A. For purposes of analysis, a thin impermeable membrane at A-A is assumed. Then per unit area

$$W_1 = Z\gamma$$

$$P = 62.5\,(h + Z)$$

and since the wet weight of soil is about 125 lb per cu ft and at balance

$$W_1 = P$$

from which for bare equilibrium

$$Z = h$$

in which W_1 is the downward unit pressure of soil and contained water and P is the hydrostatic pressure at given elevation. **It is apparent that the rough rule of thumb may be developed that any aquifer which lies at a depth below the bottom of excavation of less than 1.3 times the maximum height of ground water above the bottom of the excavation should be drained in order to prevent excessive bottom pressures.** Such drainage may require pumping of wells or well points, but frequently it may be accomplished simply by driving wells or well points to the stratum and permitting them to flow into the excavation where the water can be collected and pumped out.

Analyses of well or well point systems for use in highly stratified materials can **not** be based upon common well formulae for ordinary wells; rather they must be based upon artesian flow conditions. Formulae and methods of analyses developed[3] by P. T. Bennett may be used in the analyses of dewatering systems under these conditions.

[illegible]

The work horse of American dewatering practice is the common well **point**. This is a small diameter well which is jetted or driven to the desired elevation and connected to a header system, which in turn leads to a pump. It is relatively inexpensive to install. It is flexible in its operation since additional points may be added if experience indicates the necessity, and the equipment and facilities have been developed and proved over long years of experience. The equipment is readily available on a rental or purchase basis. There are a number of organizations in the country staffed with men trained in its use and operation, and capable of analyzing and developing the necessary systems.

However, well points have certain disadvantages. The maximum drawdown is limited to about 15 ft to 18 ft below the center line of the header; thus, for deeper excavations, two or even three stages of well points, headers and pumps

---

[3] Discussion by P. T. Bennett of "Relief Well Systems for Dams and Levees," by W. J. Turnbull and C. I. Mausur, Transactions, ASCE, Vol. 119, 1954, p. 862.

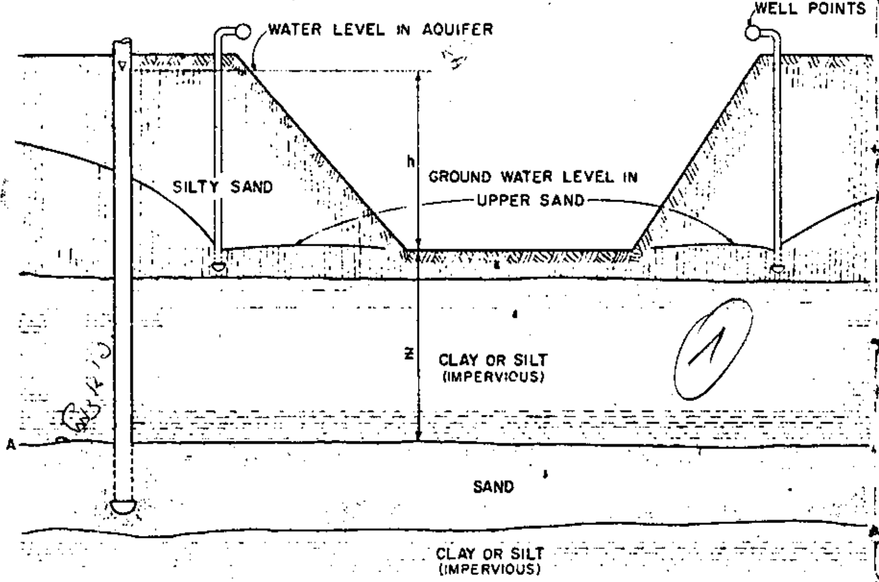
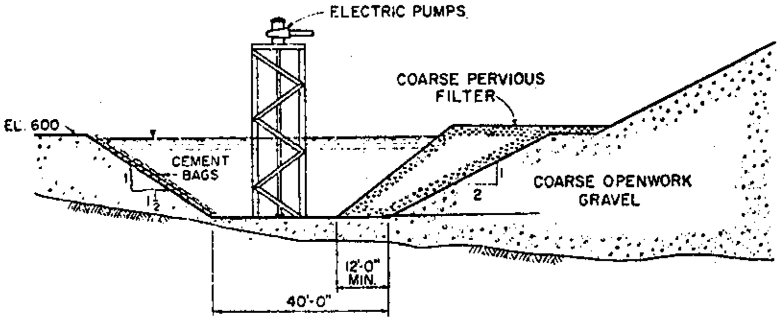


FIG. 1.—SECTION ILLUSTRATING THE DEVELOPMENT OF EXCESS HYDROSTATIC PRESSURES BELOW THE BOTTOM OF AN EXCAVATION

40' = 13mm
30' = 13/4 x 3



NOTE
SUMP EXCAVATED AND COARSE PERVIOUS FILTER PLACED THROUGH WATER

FIG. 2.—CROSS SECTION MAIN DRAINAGE SUMP ROCKY REACH HYDRO-ELECTRIC PROJECT

may be required. The berms necessary for these may significantly increase the width of the excavation, and the interruption of excavating during the times that the second and third stages of well points are installed may add to the cost and limit the types of equipment used. Entrance losses to the well points are appreciable and, since they are of small diameter, the quantity of water which can be handled by any individual point is limited. They are best adapted to sandy, or even finer, materials. In highly pervious materials, such as coarse gravels, the spacing required to handle the water may be so close that well points become impractical. In openwork materials, such as are occasionally encountered in the Columbia River area, they may not be usable. Because the well strainer is only 2 ft long, we consider the use of a sand drain around each point desirable practice in all except extremely uniform materials. A sand drain is mandatory in materials which are definitely stratified to assure that all strata within the limits of the well points are drained.

Large diameter deep wells have been used extensively in Europe and on a few jobs in the United States for dewatering. In these installations, the area to be excavated is surrounded by a number of wells driven through the various aquifers and to sufficient depth to protect against uplift pressures under the bottom of the excavation. A deep well pump is set in each, which discharges through a suitable header system. Well diameters used are commonly 6 in. to 15 in. and one job used 22 in. diameter wells. Wells may be spaced 25 ft to 100 ft or more apart, depending upon the conditions and the depth to which the water table is to be lowered. An adequate filter system through the aquifers is essential. Accordingly, the wells may be gravel packed or a gravel wall may be developed around them by surging the various aquifers.

Deep wells have the advantage that the entire system, including headers, can be spaced at some distance from the top of the excavation where it causes a minimum of interference with excavation operations. They are particularly useful for large excavations where the work will be done using earth haulers or large equipment. They have the disadvantage that the individual wells are relatively expensive and adding additional wells, in the event that the original number specified is inadequate, can be slow and difficult. Consequently, such systems require careful and detailed analysis prior to the start of construction, and driving and testing of one or more test wells may be necessary in order to arrive at an economical design.

Open sumps are possibly the oldest method of controlling ground water in excavations. As commonly built, simply by digging a small hole without providing for protection against erosion or piping or movement of the banks of the sump, they are limited to small drawdowns and modest quantities of water, and have little to recommend them. Properly designed, however, with adequate depth, size, and with the banks and bottom protected by suitable graded filters to prevent movement of the soil, they can be extremely useful, especially in dewatering very pervious material, such as openwork gravels.

Fig. 2 shows a section through the large sump used to dewater the first stage cofferdam of the Rocky Reach Hydro-Electric project. It intercepted and controlled water entering the cofferdam area through the pervious abutment on the east side of the river. The sump was excavated by drag line and the filters placed through water before the pumps were installed and the ground water lowered. This sump was approximately 30 ft deep. It was designed to collect and discharge a maximum quantity of seepage of about 160,000 gpm at a river stage of El. 650, the general floor of the excavation being El. 600. During the spring flood of 1957, it reached a maximum pumping rate of about 100,000 gpm at a river stage of EL 638.5. Fig. 3 is a general photograph of this sump in operation. The area within the cofferdam was completely dry.

Sheeted cofferdams are commonly used where space limitations preclude the use of an open excavation, where lowering of the ground water level to permit open excavation might damage the foundations of adjoining structures, or where open water surrounds or abuts the cofferdam on one side. Typical applications include bridge piers and the intake and discharge structures for the circulating water for large steam power stations.

Where sheeting can not be driven to a cutoff on an impermeable material, such as a clay stratum or bedrock, at reasonable depth below the bottom of the

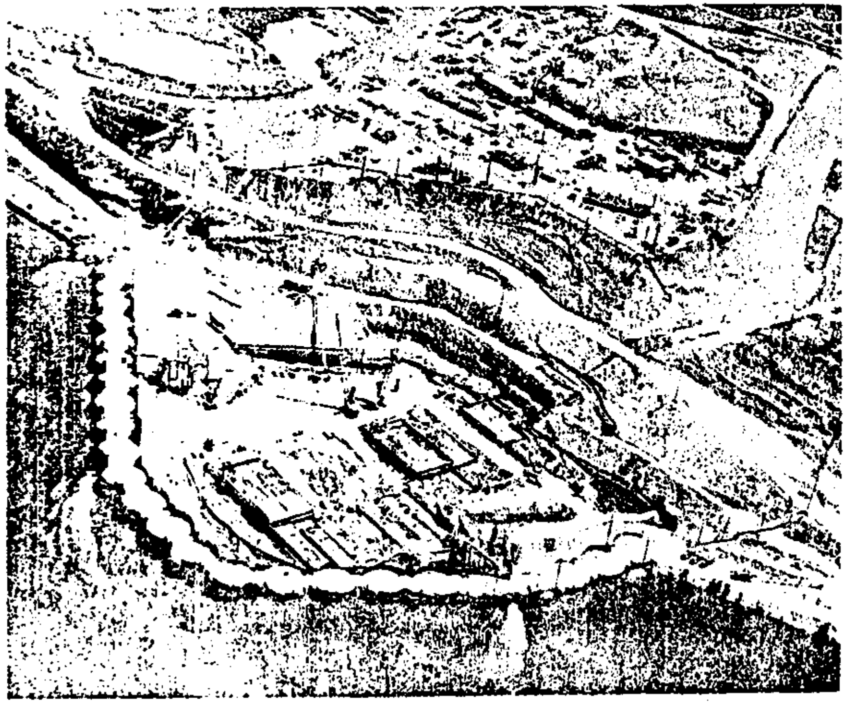


FIG. 3.—VIEW OF EAST BANK COFFERDAM OF ROCKY REACH HYDRO PROJECT DURING FLOOD OF 1957. LARGE SUMP IS AT UPPER LEFT CENTER ABOVE CRANES.

excavation, seepage under the sheeting and up into the excavation must be controlled and removed. It can be shown by a simple flow net that in uniform material a penetration of the sheeting below the bottom of the excavation equal to the height of the water above the bottom of the excavation is adequate to provide protection against piping or other disturbances of the bottom.

This is not true in stratified material and such a depth of sheeting penetration may be inadequate. A typical condition along many rivers is shown o Fig. 4. Because of the relative permeabilities of the two strata, A and B, vertical seepage flow is restricted and the pressure at point X may be almost equa to the full hydrostatic pressure at that point, the entire loss of head occurrin between points X and Y. To prevent piping or boils, it is essential that th

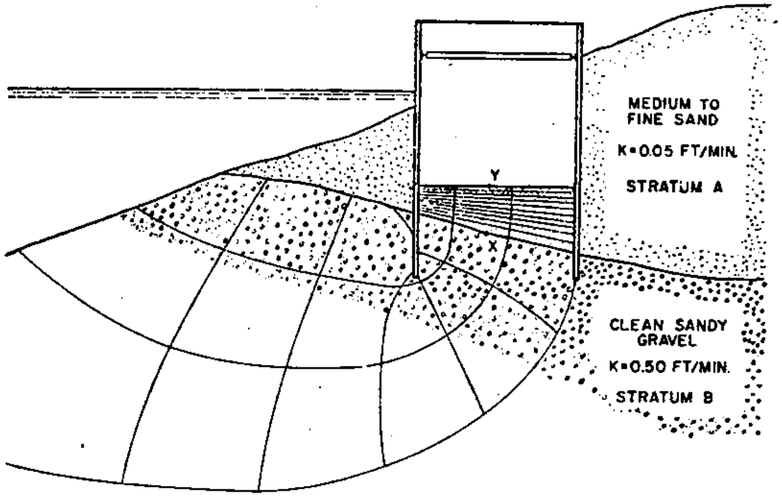


FIG. 4.—EFFECT OF VARIATIONS IN PERMEABILITY IN SHEETED COFFERDAMS

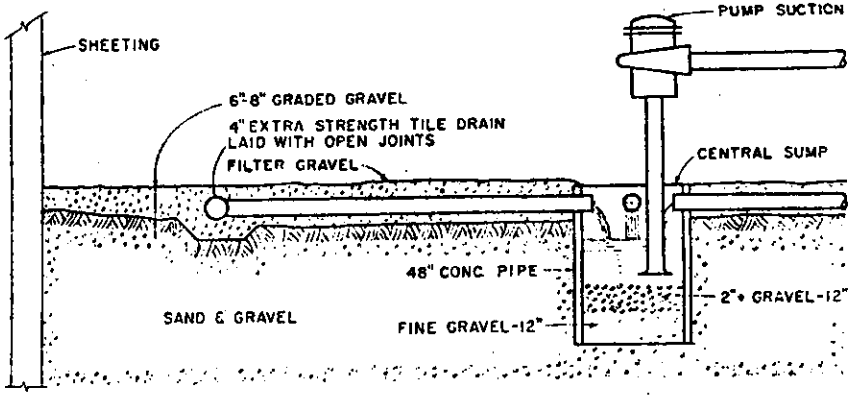


Fig. 5 : Drain system in cofferdam Elrama Steam Station

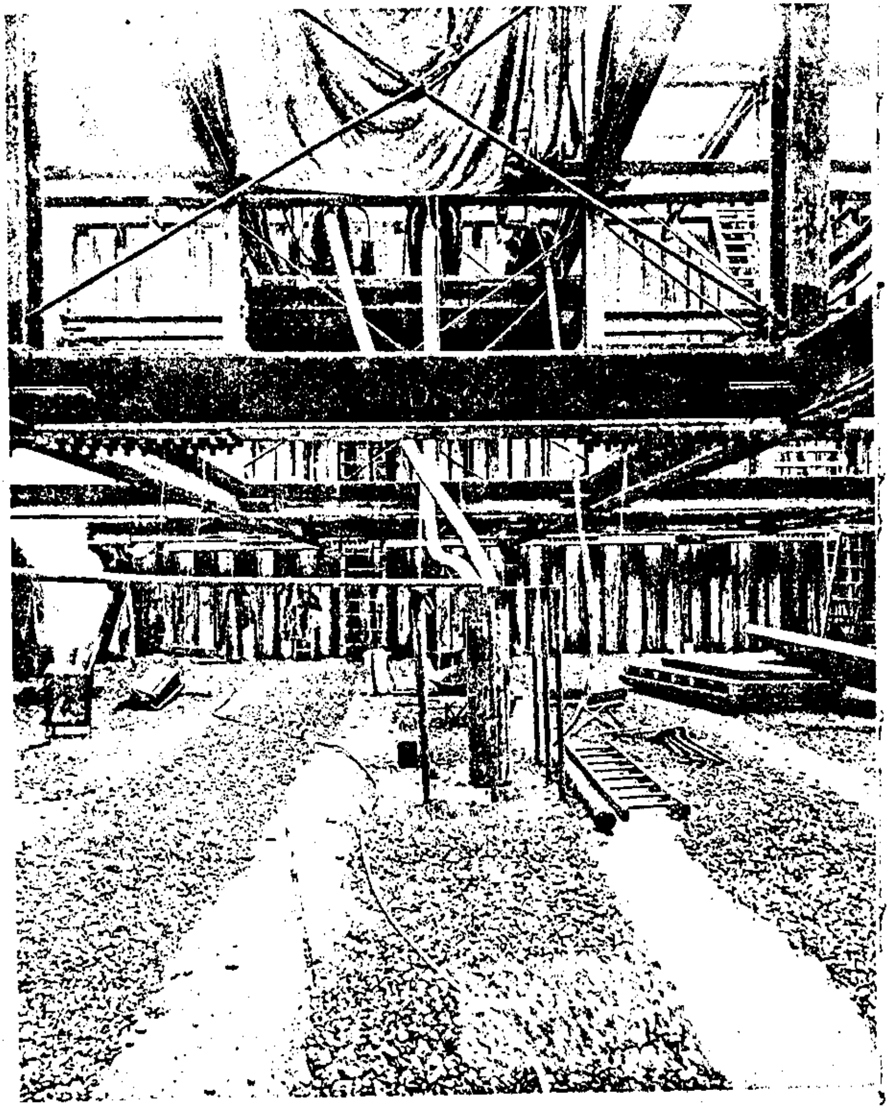


FIG. 6.—INTERIOR OF COFFERDAM, ELRAMA STEAM STATION. CENTRAL SUMP IS SHOWN AT CENTER WITH PUMPS ABOVE. TWO INCH THICK CONCRETE STRIPS HAVE BEEN PLACED IN TOP OF GRAVEL FILL TO SUPPORT CHAIRS FOR REINFORCEMENT.

Sheeting

sheathing be driven deeper in stratified soils, or that a suitable relief system, such as well points or wells must be provided to reduce the pressure in the aquifers underlying the bottom of the excavation. Also, in stratified soils, leakage through the interlocks may cause excessive pressures in aquifers below the bottom of the excavation and relief by drainage may be necessary.

Except when the sheeting can be driven to a cutoff, provision must be made to collect and discharge seepage which enters the excavation in such a manner as to prevent its interference with construction operations, especially concreting. This may be done by a system of well points within the cofferdam or the seepage may be collected at the bottom of the excavation. A typical collection system at the bottom of the excavation is shown on Fig. 5. This was the system used in the circulating water intake cofferdam of the Elrama Station of Duquesne Light Company, near Pittsburgh, Pa. The cofferdam was over-excavated by about 6 in. and a layer of gravel suitable graded to serve as a filter was placed over the entire bottom. An open-joint tile drain was then constructed in this gravel layer leading to a single central sump, approximate location and cross section of this drain being shown. Fig. 6 is a picture within the cofferdam during construction. The bottom of the excavation was completely dry and concrete was placed directly over the surface of the gravel without interference from water percolating upward through it.

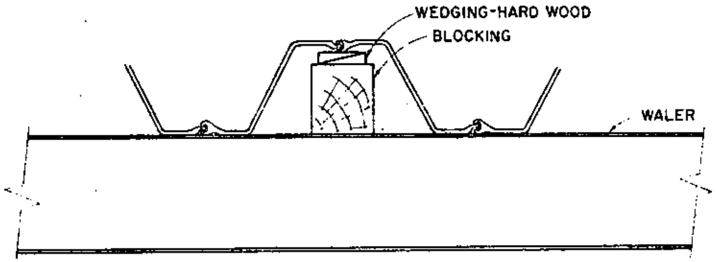


FIG. 7.—BACKING OF STEEL SHEET PILING TO PREVENT DISTORTION

The material at this site is somewhat stratified. To protect against pressures beneath the bottom of the excavation, especially in the event of high water in the river, open piezometers were installed at various locations within the excavation and instructions given the construction organization to flood the cofferdam in the event the piezometers overflowed.

Bracing of sheeted cofferdams requires careful analysis, especially when the cofferdam extends into river banks, in which case the soil loading on one side may be significantly different from that on the other. Occasionally, in order to permit the use of light sheeting and bracing, it may be found desirable to dewater around the outside of the cofferdam, using well points or a similar system. We have generally found, however, with deep section Z sheeting that the cost of dewatering systems, including their installation, maintenance and operation, exceeds the cost of the heavier bracing required if no attempt is made to dewater outside the cofferdam and the sheeting is designed for the full soil pressure and hydrostatic pressures. To prevent distortion which might cripple it, heavily loaded deep arch or Z sheeting should be blocked at each waler, as shown on Fig. 7. This blocking should be set carefully and tightly wedged to assure that it will carry loads with a minimum of movement.

Bracing systems for sheeted cofferdams may be either of wood or steel, the former being generally used only for the smaller cofferdams of limited depth. Steel walers may be field-assembled, using either welding or high strength bolts. Since sheeting can never be driven perfectly to line or to length, provision must be made for adjustment in field connections. The bracing system must provide adequate space for the operation of the excavating equipment and must be so arranged and walers so located in elevation as not to interfere with construction of the permanent structures within the cofferdam. Removal of the lower bracing systems may be necessary as the permanent structure is constructed, the load being shifted from the bracing to the permanent structure by backfilling between it and the sheeting, or by pouring the structure directly against the sheeting.

Occasionally, materials other than wood or steel are used for cofferdam bracing. Fig. 8 shows the circular cofferdam used for the second circulating water intake on the Venice No. 2 Power Station of the Union Electric Company. This cofferdam, which was 100 ft in diameter and 75 ft deep, was supported entirely by two reinforced concrete ring wales. The interior of the cofferdam was completely open, there being no cross bracing. Excavation was by means of a small dredge floating in the cofferdam. W. S. Colby has presented[4] a complete description of the design and construction of this cofferdam.

Water contained in a semipermeable mass will move toward the cathode in the presence of an electric field. If the cathode is a well point, the water which collects at it can be removed by pumping. It is on these principles that electro-osmosis is based. It is used primarily with fine grained soils, such as silts, where the electrical forces added to the gravitational seepage forces can greatly increase the rate at which water can be removed from the soil mass and thereby stabilize it. It has not been used widely in this country and the techniques of application are relatively undeveloped here. Expert advice and guidance should be employed both for analysis and design of the system if electro-osmosis is considered.

Grouting of permeable strata to effect a cutoff against ground water has been used in Europe both under dams and temporary structures, such as cofferdams for hydroelectric development and around excavations. Grouting has been used to a much lesser extent in this country. However, interest in the process is increasing and we may expect to see greater use of it, especially since new chemical grouts specifically adapted to this purpose have been developed. Several firms have entered the field and it is anticipated that continued use will result in greater experience and acceptance. Grouting materials used include cement, clay or mixtures of the two, asphaltic products and chemical grouts, such as soluble silica with a suitable reagent to cause gelling, chrome-lignin and, most recently, acrylamide monomers, such as AM-9, which polymerize after injection into the soil.

At the present time, grouting is relatively expensive and its use is generally limited to special problems or as an adjunct to other methods. It had been planned to construct the east abutment of the spillway section of the Rocky Reach Dam within a sheeted cofferdam driven to rock. Boulders, however, were encountered which prevented driving the sheeting to rock, with much of the sheeting hanging up 8 to 10 ft above the bedrock surface. Further, the rock surface was extremely irregular and seating the sheeting upon the rock surface, to form a tight joint, even when it reached, was virtually impossible.

---

[4] "Design and Construction of a Circulating Water Intake," by W. S. Colby, Journal of the American Concrete Institute, V. 21, No. 7, March 1959, p. 497-508.

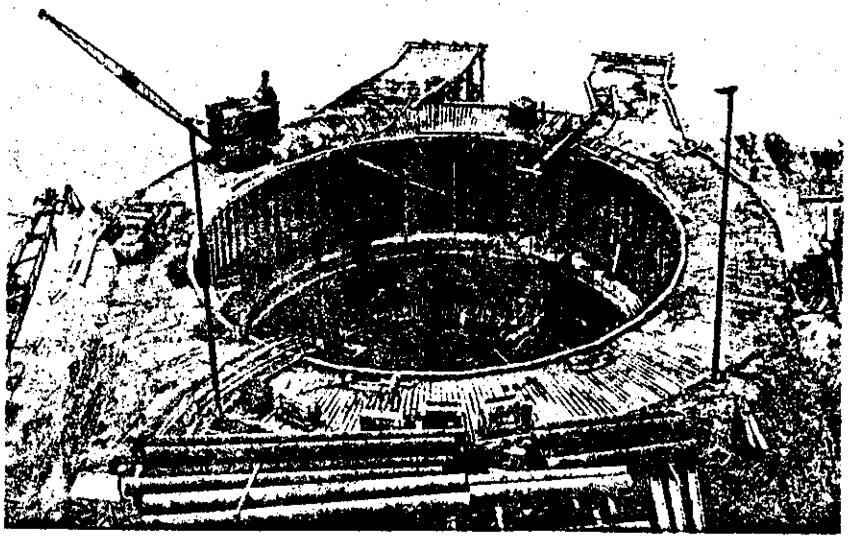


FIG. 8.—CAISSON FOR INTAKE STRUCTURE OF VENICE NO. 2 POWER PLANT. THE UPPER CONCRETE RING WALE IS IN PLACE AND THE LOWER ONE IS BEING FORMED.

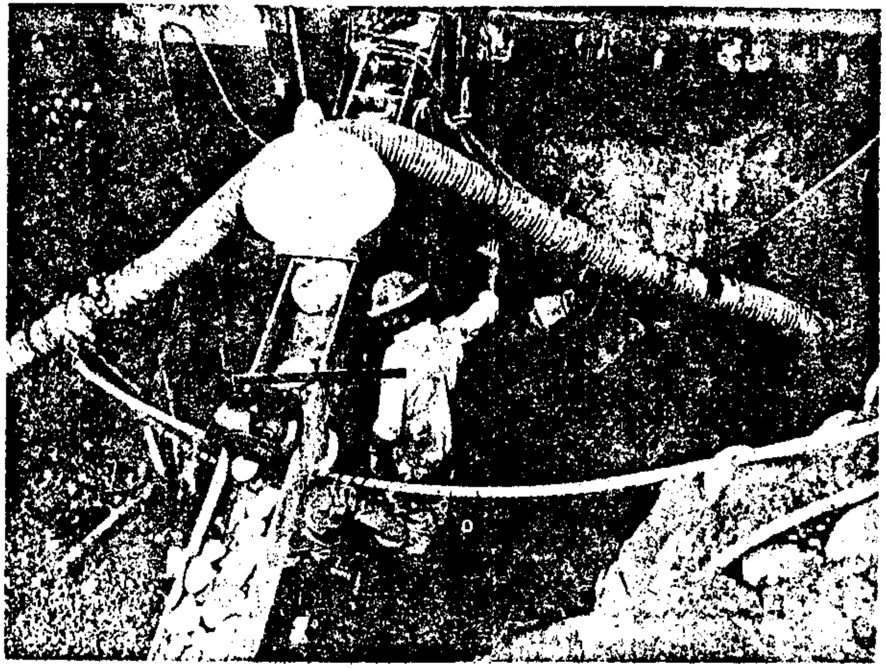


FIG. 9.—EXCAVATING FOR FOUNDATION OF EAST ABUTMENT OF ROCKY REACH PROJECT. A WALL OF GROUTED GRAVEL IS SHOWN ALONG LEFT SIDE OF PICTURE. ONE OF THE LARGE BOULDERS WHICH IMPEDED DRIVING SHEETING IS SHOWN IN THE RIGHT CENTER.

Material supporting the cofferdam was a highly pervious, open work gravel, which was, in turn, overlain by clay. Ground water level was approximately 25 ft above the bedrock surface. Under these conditions, the Contractor elected to grout the gravel around the cofferdam to permit excavating to bedrock and placing the concrete. Fig. 9 shows a photograph taken inside the cofferdam during the construction of the abutment. The tip of the sheeting is about 8 ft above bedrock surface. The wall against which concrete is to be placed is an unsupported wall of grouted gravel with approximately 20 ft to 25 ft of headwater behind it.

Freezing has been used to a limited extent in this country for control of ground water. The most recent and largest application has been for excavation of the foundation of the Gorge High Dam on the Skagit River for the City of Seattle, Department of Light and Power. Here an ice cofferdam was constructed in an arch shape to permit excavating to a depth of about 170 ft below groundwater level. The first of two of these installations has been completed and the second is being started.

There is little data available on the relative cost of the freezing processes, but it is believed this method is expensive. In the design of ice barriers, it must be kept continuously in mind that any leakage is a heat source and the greater the leakage the more heat is brought to a restricted area. Consequently, such barriers tend to be dynamically unstable. To protect against this and against irregularities in seepage characteristics of the soil, it is essential that the refrigeration system have a large margin of capacity above that theoretically necessary to freeze the material. The power source obviously must be dependable and provision of a suitable standby power source may be highly desirable if any possibility of interruption exists.

The effects of ground water lowering on adjacent structures are so well known that they need little discussion. Briefly, lowering the ground water level in a stratum of soil effectively loads it and all strata below it, since the effective stresses are increased. Thus, lowering the ground water level by 10 ft is equivalent to placing over the area a surcharge load of 625 psf. Settlements from such loads can be considerable and they may extend over wide distances where the ground water level is lowered over an extensive area by a large and long continued dewatering system. Possible effects of such ground water lowering on adjoining structures must be considered in every problem involving its use.

The second effect is possible deterioration of the foundations of adjoining structures, such as deterioration of wood piles if untreated, which would be exposed by lowering the ground water level. This is a serious problem for major construction, such as subways, where ground water levels in an area may be down for long periods of time or where drainage provided along such structures may cause a permanent lowering of the ground water level.

While discussion thus far has been directed toward the control of ground water, control of surface water adjacent to excavations is also important. It is essential that the surrounding area be properly drained; otherwise, water seeping into the soil may add appreciably to the quantity of water which must be handled in the dewatering system. Provision must be made in the dewatering system to discharge the water removed at a safe distance away from the excavation and in such a manner that it will not find its way back. To do otherwise may add considerably to the pumping costs. Severe erosion of banks may occur with resulting collection of debris and loose material in the bottom of the excavation, unless proper drainage is provided to prevent the water from collecting and discharging down the slopes. With sheeted excavations, it is essential in the event of long or intense rains that surface water be collected and discharged away from the sheeting, since water percolating downward along the sheeting may result in developing hydrostatic pressures upon the sheeting substantially in excess of design loadings.

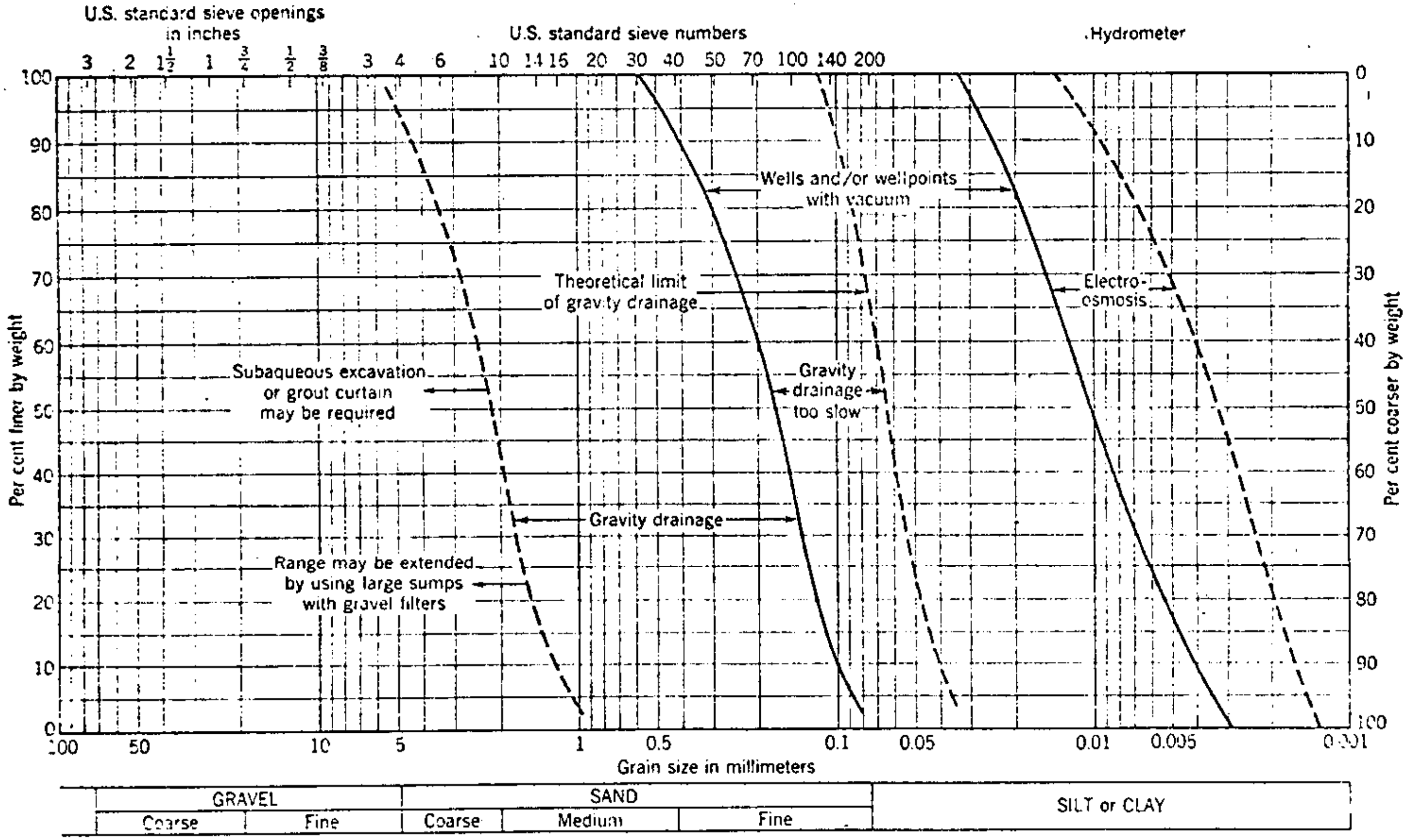
The broad general principles of dewatering and the factors which must be considered in any dewatering system have been summarized in this paper. Probably the most important of the several factors listed are detailed data on the character and physical properties of the soil to a substantial depth below the bottom of the excavation and evaluation of piezometric levels which may occur during the construction period in the various aquifers. Succeeding papers will discuss these matters in greater detail, including investigations, methods of analysis for various types of ground water control systems, observations on the practices and principles of installing and operating ground water control systems and several papers covering actual installations, illustrating the application of these theories and methods to practical problems.

<table>
<tr><td></td><td colspan="12">Coefficient of Permeability k in cm per sec (log scale)</td></tr>
<tr><td></td><td>10^2</td><td>10^1</td><td>1.0</td><td>10^{-1}</td><td>10^{-2}</td><td>10^{-3}</td><td>10^{-4}</td><td>10^{-5}</td><td>10^{-6}</td><td>10^{-7}</td><td>10^{-8}</td><td>10^{-9}</td></tr>
<tr><td>Drainage</td><td colspan="6">Good</td><td colspan="2">Poor</td><td colspan="4">Practically Impervious</td></tr>
<tr><td rowspan="2">Soil types</td><td colspan="2" rowspan="2">Clean gravel</td><td colspan="3">Clean sands, clean sand and gravel mixtures</td><td colspan="4">Very fine sands, organic and inorganic silts, mixtures of sand silt and clay, glacial till, stratified clay deposits, etc.</td><td colspan="3" rowspan="2">"Impervious" soils, e.g., homogeneous clays below zone of weathering</td></tr>
<tr><td colspan="2"></td><td colspan="5">"Impervious" soils modified by effects of vegetation and weathering</td></tr>
<tr><td rowspan="2">Direct determination of k</td><td colspan="6">Direct testing of soil in its original position—pumping tests. Reliable if properly conducted. Considerable experience required</td><td colspan="6"></td></tr>
<tr><td colspan="5">Constant-head permeameter. Little experience required</td><td colspan="7"></td></tr>
<tr><td rowspan="2">Indirect determination of k</td><td colspan="2"></td><td colspan="3">Falling-head permeameter. Reliable. Little experience required</td><td colspan="3">Falling-head permeameter. Unreliable. Much experience required</td><td colspan="4">Falling-head permeameter. Fairly reliable. Considerable experience necessary</td></tr>
<tr><td colspan="5">Computation from grain-size distribution. Applicable only to clean cohesionless sands and gravels</td><td colspan="4"></td><td colspan="3">Computation based on results of consolidation tests. Reliable. Considerable experience required</td></tr>
</table>

After A. Casagrande and R. E. Fadum

FIG. 2.8 Permeability and drainage characteristics of soils. (Table 6, p. 48, of *Soil Mechanics in Engineering Practice,* K. Terzaghi and R. B. Peck, Wiley, New York, 1948.)

Fig. 5.1 : Dewatering systems applicable to different soils



Corps of Engineers, U.S. Army, Classification

FIG. 3-11. Dewatering systems applicable to different soils. (*Moretrench Corp.*)