GROUND-WATER PROBLEMS IN HIGHWAY ENGINEERING

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GROUND-WATER PROBLEMS IN HIGHWAY ENGINEERING

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Occurrence of ground water

Before considering specifically the application of ground-water problems in the field of highway engineering, it might be well to summarize the occurrence of water in the ground.

The water that enters from the surface into the rocks, usually by infiltration from rainfall, streams, and lakes, is drawn downward by gravity, except a portion which adheres, by molecular attraction, to the walls of the grains composing the rocks. Below a certain level the interstices of the rocks are filled with water. These rocks are in the "zone of saturation," the top of which is known as the water table. The rocks above this zone--which are not saturated--are in the "zone of aeration." (See fig. 1.)

Ground water has been defined by Meinzer (1923a, p. 22), as the water in the zone of saturation, as distinguished from water in the zone of aeration. Water that is drawn from the ground by wells and springs occurs in the zone of saturation.

The occurrence and availability of ground water is dependent upon a source of supply for the water, and on two important characteristics of the water-bearing material, porosity and permeability. The porosity of a sedimentary formation--the amount of open space it contains--depends to a large extent on the packing and on the size distribution of the grains of which the formation is composed. It is important to note that the size of the component grains, other things being equal, has practically no effect on the porosity, thus silt and clay are about as porous as sand and gravel.

Figure 2 represents sections of spheres of equal size in three packing arrangements. The porosity of the closest arrangement, as indicated by A, is 25.95%, according to Meinzer (1923b, p. 5), and the porosity of the least compact arrangement, C, is 47.64%. Several types of rock interstices, showing the relation of rock texture to porosity, are shown in figure 3.

Porosity alone, however, is insufficient to cause a formation to be considered as a good water-bearer or aquifer. A more important attribute is the permeability of the material, or its ability to allow water to flow through it. The size of the grains has a very definite relationship to the permeability. Thus a clay, which may have the same porosity as a sand, is almost impermeable to water relative to the sand, because the openings in the clay are so small that the water is held among them by molecular attraction.

Much research has been carried on in recent years relating to the hydraulics of wells, and considerable quantitative information can be derived from measurements of the fluctuations of the water table near discharging wells. Thus, by carefully measuring the water levels in nearby observation wells tapping a formation from which a well of known yield is discharging, it is possible to predict fairly closely the amount of lowering of water levels that will occur at any place in the ground-water basin, after any pumping period.

In some areas, relatively permeable rocks are overlain by relatively impermeable rocks and, locally, conditions may be that the water in the zone of saturation beneath the impermeable layer is under artesian pressure. Such water, when tapped by wells, rises above the base of the confining impermeable layer until it reaches hydrostatic balance with the pressure within the water-bearing formation beneath the confining layer. If this level of hydrostatic balance is above the land surface--as in parts of the Virginia Coastal Plain--the water in the wells will overflow.

The water table is, in general, higher beneath hills and lower on the sides of hills--until it falls to the level of streams and swamps on low ground in the valleys or coastal reaches. Thus, the shape of the water table is a subdued replica of the topography.

Many of the general principles here outlined are concisely treated in two important papers by Meinzer (1923a and 1923b): Water-Supply Papers 494 and 489 of the U. S. Geological Survey. A thorough understanding of the principles set forth in these and other papers will greatly facilitate the work of the highway engineer or geologist in his study of the occurrence of ground water in relation to highway construction.

For the present discussion, the chemical constituents of ground water are of only minor interest. It may be mentioned, however, that all ground water contains inorganic mineral matter in solution. These dissolved solids generally are present in amounts less than 1/10 of 1 percent by weight (1,000 parts per million). In some localities, the quality of shallow ground water is rendered inferior by contamination with mineral matter or pollution with organic wastes.

Ground-water problems in highway construction

With regard to ground-water problems in highway construction, consideration should be given to the occurrence of ground water along the entire proposed route (just as is customary with surface water). In so doing, unforeseen difficulties may frequently be avoided. After the best route is chosen consistent with other requirements, something should be learned of the depth to the water table and its range of fluctuation. This can be done by obtaining water level measurements in nearby shallow wells, or, better still, by putting down a series of drive points--small diameter casings having drive heads and screens at their lower ends--and making a series of water-level measurements in these observation wells over an extended period. The longer the period during which the measurements can be made, the better. With this information, the highway engineer can learn, in advance of construction, the maximum height to which the water table is likely to rise, and can plan accordingly.

When the probable maximum water level in a section of highway is determined, a decision can be made as to whether it would be most feasible to provide a porous subgrade fill of sufficient thickness beneath the roadbed to allow for natural gravity drainage, or whether the water table should be lowered by means of drainage channels or drainage wells. Controlling ground water by building up over it with thicker fill may prove costly over long sections of highway, although it may be the most practical method for short sections; however, availability of low-cost fill material is a controlling factor. Also, in limestone terrane, filling sinkholes constitutes a problem as mentioned later.

In some localities, the desired lowering of the water table beneath the roadbed may be obtained by digging gravel-filled drainage ditches parallel to the highway to drain both ground water and surface water. In limestone terrane, however, as in Florida, the large quantity of water in the limestone might make it impractical to lower the water level.

The proper conditions permitting the use of drainage wells are shown in figure 4. However, if a zone of high artesian pressure is tapped, the water level in the well constructed for drainage might rise above the water table, and even the land surface. Thus, if the artesian pressure is sufficiently great, a flowing well would be produced instead of a drainage well. This is precisely what happened near Orlando, Florida, some years ago. Drainage wells tapped a zone which, after the early summer rainy season, developed sufficient artesian pressure so that the wells began to flow, flooding the road bed, and making the drainage problem even worse than before. In regions where deeper zones of high artesian pressure are suspected, careful preliminary study of the area by a specialist in ground water can usually forestall trouble of this sort.

In some regions, unconsolidated surficial deposits may be underlain by limestone beds of considerable thickness. Locally, these limestone beds may contain solution channels, many of which are interconnected. The regional water table in these channels may frequently be lower than the local water table of the shallow ground water which is causing the difficulty in the highway construction. Drainage wells may be constructed to connect the shallow ground water with the lower zone in the solution channels in the underlying limestone beds, as recently pointed out by LaMoreaux (1949) for part of the Tennessee Valley area in northern Alabama, and as done in many parts of Florida (Stringfield, 1936, pp. 161-16). (See fig. 5.) If the deeper ground water is used for public supplies, drainage wells in the vicinity of such supply wells would obviously be undesirable, and proper caution should be exercised in using this method near towns and wells are used for human consumption.

The Corps of Engineers of the U. S. Army employs a method of subgrade drainage for airport construction which has also been applied to highway construction (Corps of Engineers manual, 1946; see ref.). Briefly, this method consists of placing porous drainage pipes in the subgrade fill near the shoulder of the airport pavement. The drainage pipes are placed at least a foot beneath the base of the pavement material. Thus, the water table is lowered at least 1 foot, and is maintained by this means everywhere a foot or more beneath the base of the pavement, providing adequate drainage within the porous subgrade. (See fig. 6.)

A recent important application of soil physics to engineering and ground-water problems is the technique of electrical drainage, employing the principle of electro-osmosis (also termed "electrosmosis"). Briefly, this method involves passing a direct electric current through the ground required to be drained. The water contained in the soil then moves from the positive electrode (anode) to the negative electrode (cathode). If a well point is used as the cathode, the application of the current will draw moisture from the surrounding soil to the well point, ~~by means~~ THROUGH of which it can be removed at intervals by pumping. With a large current, considerable heating occurs at the anode, the resulting temperature gradient increasing the water movement caused by the electro-osmosis. The weight of the water expelled is proportional to the quantity of electricity (in coulombs) passed through the soil, until the moisture is removed. The weight of water per coulomb is greatest for sandy soils and least for heavy clay soils. The usefulness of this method of drainage is readily apparent because drainage of clayey and silty soils by well points alone, without electric treatment, is practically impossible. The method is outlined in several recent papers, two of which are given in the list of references below (nos. 3 and 4).

In conclusion, it may be stressed again that highway departments should, where possible, avail themselves of personnel or consultants skilled in the application of groundwater knowledge to practical engineering problems. In this way, costly mistakes can many times be avoided.

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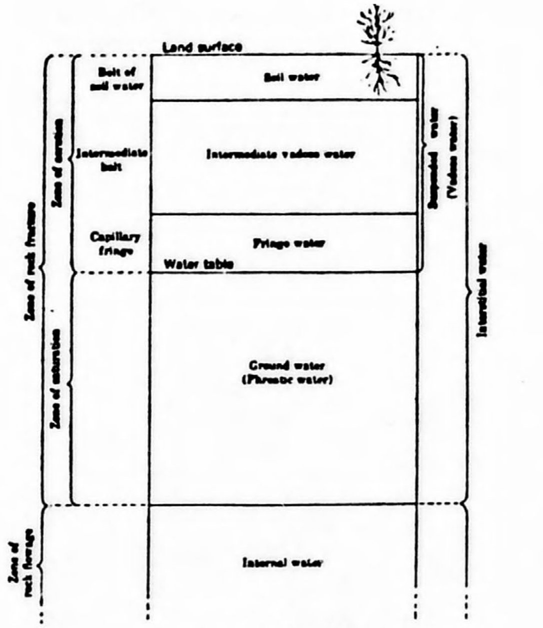
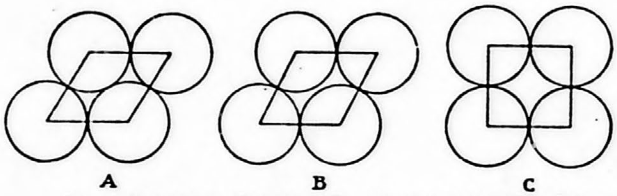


Diagram showing divisions of subsurface water.

(Meinzer, 1923a, Fig. [illegible])

FIGURE 1



Sections of four contiguous spheres of equal size. A, Most compact arrangement; B, less compact arrangement; C, least compact arrangement.

(Meinzer, 1923b, Fig. [illegible])

FIGURE 2

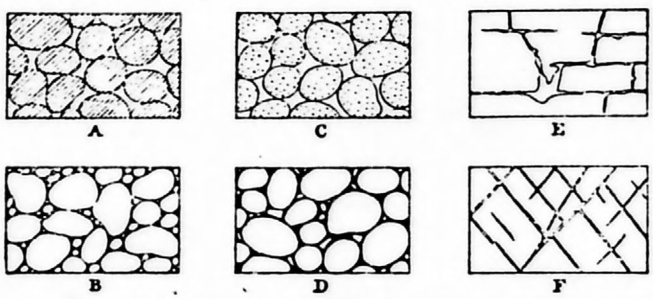
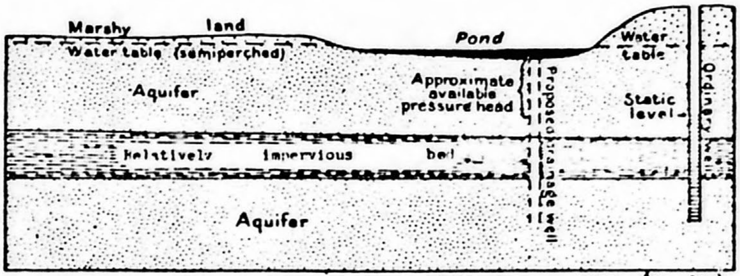


Diagram showing several types of rock interstices and the relation of rock texture to porosity. A, Well-sorted sedimentary deposit having high porosity; B, poorly sorted sedimentary deposit having low porosity; C, well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; D, well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; E, rock rendered porous by solution; F, rock rendered porous by fracturing.

(Meinzer, 1923b, Fig. 1.)

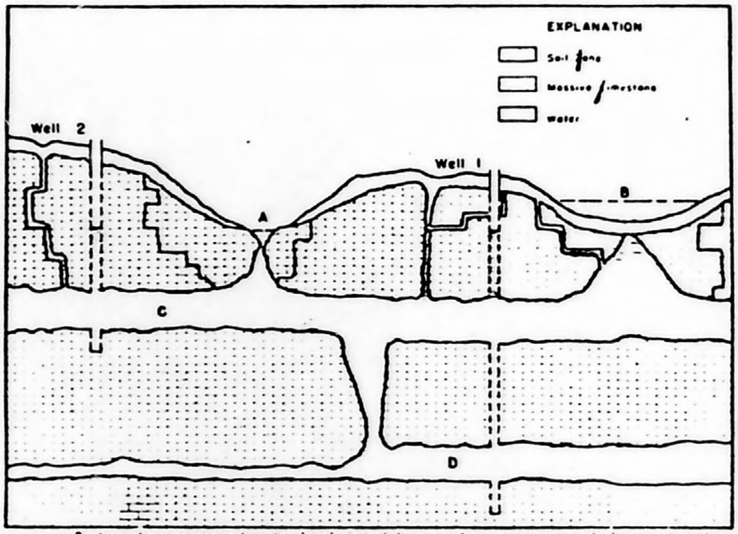
FIGURE 3



(Modified from Meinzer, 1923a, fig. 34.)

Diagrammatic section showing conditions that will permit drainage of marshy land through inverted wells. Drainage through wells would also be practicable if the marshy land had a perched water table.

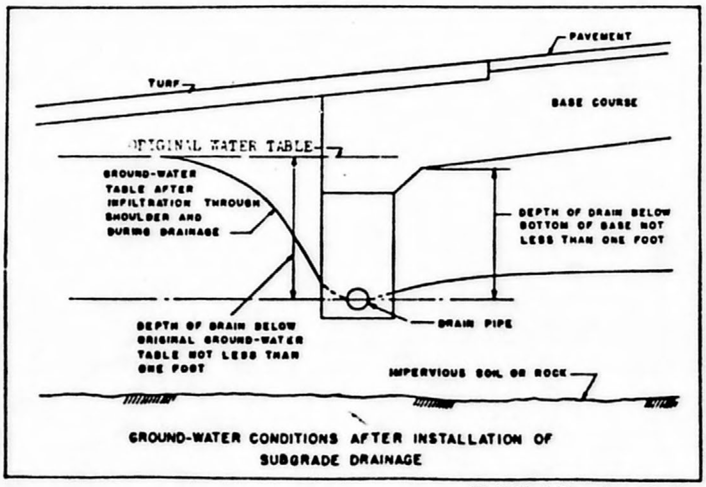
FIGURE 4



Section showing ground-water levels in solution cavities in an area underlain by limestone

A, Surface and subsurface drainage at same level in bottom of sink hole; B, opening in sink hole plugged by impermeable weathering products and alluvium, allowing local perched water table to remain at higher level than A; C, upper-level cavity, dry part of the year, as is also well 2, which has been drilled only to this level; D, lower-level cavity, in which there is water all year, so that well 1, drilled through both cavities, never runs dry. Pond at B could be drained during periods when water table at A and in wells 1 and 2 is at level shown, or lower. (LaMoreaux, 1949, fig. 2.)

FIGURE 5



(Modified from War. Dept. Eng. Man. - 1946 - Pt. XIII, Chapt. 2, figure 8.)

FIGURE 6