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Please note

Groundwater has been mentioned in several previous Digests dealing with soils and foundations. Despite its importance in subsurface work it is often found to be a matter almost of mystery even to those acquainted with engineering fundamentals. The widespread acceptance of "dowsers" as a means of finding water is in keeping with this lack of appreciation of the simple principles that govern the occurrence and movement of groundwater. This Digest is devoted to a discussion of these principles, with special reference to the importance of groundwater in foundation work. Many excavations are dry and so raise no questions about the occurrence of groundwater. When, however, water is encountered in excavation work, the problems it presents will be much less troublesome and costly if its character is understood and the necessary methods of control are properly applied.

The Hydrological Cycle

Water exists in some form beneath almost the entire surface of the earth. It is almost always in movement, normal groundwater being dynamic, not static. Its dynamic character becomes evident as soon as the *Hydrological Cycle* is appreciated. This title is used to describe succinctly the natural circulation of water - a phenomenon that should be at least generally understood by all informed people. The increasing importance of clean water in the public domain, and the associated problems now being caused by pollution, are warrant enough for this assertion. It should be thoroughly familiar to all who have to deal in any way with subsurface conditions.

When rain falls on the surface of the earth, some of it can be seen to run off directly into drainage gullies, stream courses, or other depressions that will lead it, as surface water, into rivers and so eventually to the sea. Some rain, however, does not flow away on the surface but sinks into the ground. Some of it will be held in the top-soil by capillarity, giving the damp feel to surface soils that is always found except after prolonged drought. Most of the rain that sinks into the surface, however, will percolate slowly through this upper "zone of aeration" (air being present as well as water in the voids of the soil) until it reaches the body of water that has accumulated in the ground from previous rainfall. It is this natural reservoir of water held in the voids of the ground - whether soil or rock - that is called groundwater.

When viewed in this way, groundwater loses its mystery; it can be recognized as a natural phenomenon of extreme importance to human welfare. For the water so held in the ground is not static. It moves under the influence of gravity in the direction of the prevailing hydraulic gradient. This gradient will often be determined by the surface contours of the ground above, but the moving water will eventually reach a point at which it will emerge from the ground - by seeping into the beds of lakes, rivers or streams, or by appearing as springs on a hillside. Springs are a certain indication of the level of the groundwater in the hill from which they emerge. Spring water will follow the normal route for surface water, along streams, then into rivers and finally into the sea. water is continually returned to the atmosphere by the transpiration of vegetation and by evaporation from water and ground surfaces. This will lead to the formation of clouds and they, in turn, will result in rain or snowfall. In this way, this quite wonderful "hydrological cycle" continues ceaselessly (Figure 1).

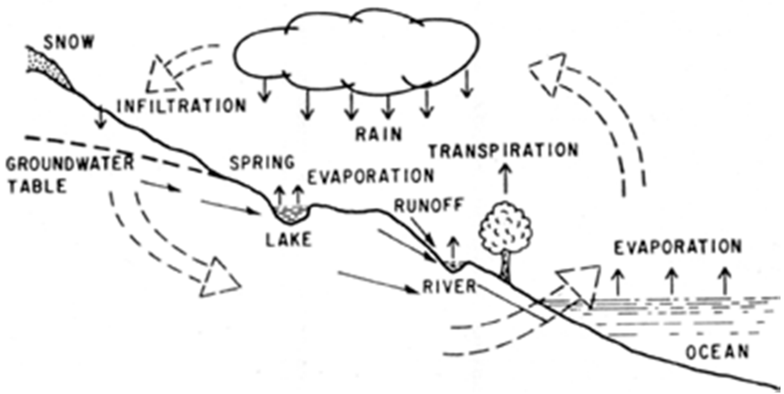

Figure 1. Hydrological cycle.

The Water Table

The upper surface of the vast hidden reservoir of groundwater is approximately defined by the water level in wells, although in some cases this may be an over-simplification. Correspondingly, it is shown by the level of standing water in a test boring after equilibrium has been reached. This upper surface of groundwater is called the *Water Table*. In some ways it is an unfortunate name, since it suggests a perfectly level surface, whereas a water table is almost never perfectly horizontal. It may be very slightly inclined - just enough to permit the slow lateral movement of the body of water below - but some variation from the horizontal is essential in view of the dynamic character of groundwater.

Nor is the actual level of the water table constant. It will vary depending upon the quality of water being stored at the location in question. In temperate regions characterized by winter rains (and possibly snowfall) the water table will probably be at its highest late in the winter or early spring, gradually falling throughout the summer. This normal decrease in the quantity of groundwater is what keeps streams and rivers flowing throughout the year when rain is not falling. A falling water table during the summer is, therefore, a natural feature of groundwater movement. Only when the drop in level is due to excessive pumping does the movement of a water table become a matter of public concern.

The conditions so far described are those found when geological strata near the surface are normal. With certain distorted geological arrangements, it is possible for groundwater to be "trapped" in a water-bearing stratum overlain by an impervious bed. The buried water may then be under considerable pressure. If this pressure is released, as by the drilling of a well through the impervious stratum from the surface of the ground, the water may shoot up and even flow out of the drill hole. This pressure is called artesian pressure. If the water is forced up to a level just below ground surface, then it is described as sub-artesian. These special conditions do not occur very often in excavation work, but when they do they can be very troublesome, always requiring expert advice for their control.

Groundwater Movement

The dynamic character of groundwater is shown not only by variation of the level of the water table but also by the actual horizontal movement of the water, of which the water table is merely the upper surface. The ease with which the water moves will depend upon the permeability (or, in more popular terms, the porosity) of the material in which it is held. Groundwater will be encountered in many types of so-called solid rock, especially sandstone, which can be quite porous. Even rocks such as granite may be water-bearing due to fissures or joints that provide channels for groundwater flow. It is easier, however, to imagine groundwater flowing through sand or gravel, materials that are so obviously permeable.

Convenient methods exist for calculating in advance of excavation (for example) the rate of flow of groundwater at any location, on the basis of field tests or tests upon soil samples carefully taken. This permits evaluation of the quantity of groundwater that will enter an excavation and the manner in which it will appear. The direction of flow is of particular interest. Downward flow will stabilize the walls of the excavation, but upward or inward flow will decrease their stability.

In foundation work the annual variation to be expected in the level of the water table is of much significance. Provided that enough time is available before the start of construction (and in most cases this can be achieved with some reasonable planning), this information can readily be obtained as a part of the general program of preliminary subsurface investigation. In the absence of artesian pressures, but where the water table is above the level to which test borings are taken (as will normally be the case), its elevation will be shown by the water level in the mill holes after they have come to equilibrium. If a few holes can be selected in advance at key locations, they can be cased with porous pipes (possibly fitted with special fine screens where needed in fine sand), the casings being left in place and suitably capped. At regular intervals the caps can be removed and the water level measured, in this way a continuous record of water table variation being readily obtained.

Quality of Groundwater

Water stored in the ground, although filtered to a degree by its passage through the soil from the surface of the ground, is still not "pure water." It will contain small amounts of some chemicals. If there are soluble salts in the ground itself, these will also enter into solution under appropriate conditions. Of special importance in Western Canada is the amount of sodium sulphate that may be present in groundwater. When such water is in contact with concrete, as in the foundations of buildings, deterioration of the concrete may occur, with serious results. The quality of groundwater should, therefore, usually be checked in advance of construction. If sulphates are present, the use of special sulphate-resisting cement for all concrete that is to be placed below ground surface will become essential.

Groundwater and Foundations

Where deep excavation is necessary for the construction of a foundation structure, it is clear that the most complete information possible about local groundwater conditions is essential before even the excavation work is planned. Correspondingly, for the design of foundation structures knowledge of groundwater conditions and possible variation in the level of the water table is imperative if designs are to be satisfactory and economical. If the groundwater table is below the bottom level to which excavation has to be taken, all doubt will be removed before work starts, with consequent economy in design and construction.

If the water table at any time of the year will be above the elevation of the bottom of the foundation walls, provision will have to be made for drainage around the foundation, if this is possible. If not, then allowance will have to be made for hydrostatic pressure against the foundation structure. Of equal importance will be the allowance to be made in the design of the bottom of the foundation structure, since the upward hydrostatic pressure that may be exerted against a large expanse of concrete floor can have a profound effect upon the structural design of the floor system. A 3-foot head of water, for example, will exert sufficient force to float one storey of an ordinary reinforced concrete building.

When a structure is to be founded upon timber piles, there arises another reason for accurate predetermination of water table variation. Wood is an excellent structural material with a very long effective life if it is kept either always wet or always dry. Alternate wetting and drying can, however, cause deterioration of most species of wood, including those regularly used for piles. If, therefore, it can be shown in advance of construction that the water table at a building site will vary throughout the year, or in other ways, between levels that include any portion of timber piles proposed for a foundation design, it will be essential to reconsider the design in order to eliminate this undesirable feature. There are on record enough cases of trouble from this cause to warrant even extra expenditure in order to avoid such an undesirable feature of design.

Control of Groundwater

This precautionary note serves well to introduce the final section of this Digest. The fact of groundwater must, naturally, be accepted in connection with all foundation designs that are to involve the use of subsurface strata for the support of any structure. Exact information on groundwater conditions at the building site must be obtained as an essential part of preliminary subsurface investigations, including as accurate an estimate as possible of the maximum variation in the water table to be expected. Whenever possible, and to the extent that appears desirable, this information should be provided to prospective tenderers in the regular contract documents.

In planning the construction methods to be used, there are available alternative ways of dealing with groundwater during excavation. If the anticipated quantity near the bottom of an excavation in relatively stable soil is small, drainage by means of peripheral trenches leading to one or more sumps, from which water can be pumped, may be adequate. Even in such simple cases, however, the possible effect of drainage upon the surrounding ground and buildings must be investigated. In regions of compressible subsoils the lowering of the water table may cause serious settlement of the ground and of the structures founded on it.

This usually requires that excavation should be carried out without undue interference with groundwater conditions except at the building site itself. This can be achieved, if ground conditions are suitable, by a special type of pumping involving the use of ingenious but simple units called *well-points.* These are small-diameter pipes with specially designed fine screens at their lower ends. These can be jetted into the ground at relatively close intervals all around the site of a planned excavation. They are then connected with suitable header pipes which, in turn, are connected to a special pumping system. Pumping is usually started before excavation so that removal of soil can proceed in the dry, the ground being "dried out" ahead of excavation. This is possible by reason of the way in which water flows in porous media.

A simple diagram, Figure 2, shows what happens to the water table when pumping is carried out in such media, as, for example by a well-point. If the three-dimensional character of this "draw-down" of the water table is visualized, it will readily be seen why the effect of such a pumping operation is the creation of what is called a *Cone of Depression*. If the properties of the ground in which the pumping is to be carried out are known, the extent of the cone of depression can be calculated. When well-points are so spaced that the individual cones they form intersect one another, it will be seen that a complete building site can be surrounded by a water table sloping (as shown in the diagram) towards the line of well-points, but unaffected beyond the range of the pumping from each point. within the excavated area, the direction of flow will be altered, the water table will be lowered to a depth determined by the original design of the well-point system, and it will remain at this depth as long as pumping continues. When designed and installed by experts, a well-point system can be of immeasurable assistance in excavation work, illustrating vividly the application of scientific principles to a somewhat mundane construction operation.

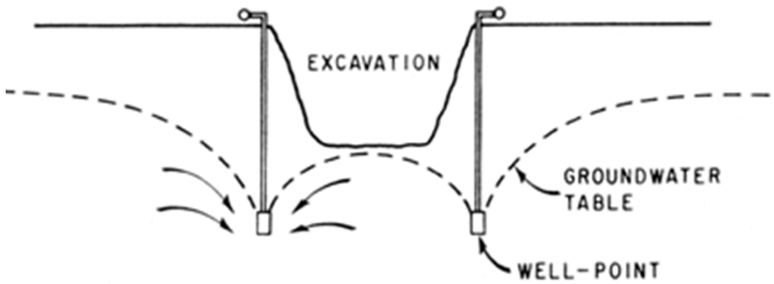

Figure 2. Groundwater table lowered by pumping.

Some of the effects of groundwater upon foundation design have already been mentioned. Deep foundations where drainage is impossible will require waterproofing of basement concrete, the best of all methods being the specification, production, placing and curing of absolutely first class concrete with effective construction joints, again carefully placed and well inspected before being concreted in. In these cases, the structural design must allow for substantial hydrostatic pressures.

For shallow foundations that can be drained, such as the basements for ordinary houses, a well-placed and accurately-graded circumferential drain connecting with a sewer or other outfall will have, in effect, the same result as the more elaborate well-point installation. Backfill above such mains must be carefully placed and properly compacted, porous material being preferable. The fact that so many house basements are damp is a sad reflection upon the inadequate attention all too often given to this detail of house foundation design. Correspondingly, it is convincing evidence of the need for better appreciation of what groundwater is and how it can be dealt with, an understanding it is hoped this Digest will promote.