Groundwater Investigations

Course Number: GE-02-604

PDH: 2

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CHAPTER 6.0

GROUNDWATER INVESTIGATIONS

6.1 GENERAL

Groundwater conditions and the potential for groundwater seepage are fundamental factors in virtually all geotechnical analyses and design studies. Accordingly, the evaluation of groundwater conditions is a basic element of almost all geotechnical investigation programs. Groundwater investigations are of two types as follows:

- Determination of groundwater levels and pressures and
- Measurement of the permeability of the subsurface materials.

Determination of groundwater levels and pressures includes measurements of the elevation of the groundwater surface or water table and its variation with the season of the year; the location of perched water tables; the location of aquifers (geological units which yield economically significant amounts of water to a well); and the presence of artesian pressures. Water levels and pressures may be measured in existing wells, in boreholes and in specially-installed observation wells. Piezometers are used where the measurement of the ground water pressures are specifically required (i.e., to determine excess hydrostatic pressures, or the progress of primary consolidation).

Determination of the permeability of soil or rock strata is needed in connection with surface water and groundwater studies involving seepage through earth dams, yield of wells, infiltration, excavations and basements, construction dewatering, contaminant migration from hazardous waste spills, landfill assessment, and other problems involving flow. Permeability is determined by means of various types of seepage, pressure, pumping, and flow tests.

6.2 DETERMINATION OF GROUNDWATER LEVELS AND PRESSURES

Observations of the groundwater level and pressure are an important part of all geotechnical explorations, and the identification of groundwater conditions should receive the same level of care given to soil descriptions and samples. Measurements of water entry during drilling and measurements of the groundwater level at least once following drilling should be considered a minimum effort to obtain water level data, unless alternate methods, such as installation of observation wells, are defined by the geotechnical engineer. Detailed information regarding groundwater observations can be obtained from ASTM D 4750, “Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well” and ASTM D 5092 “Design and Installation of Groundwater Wells in Aquifers”.

6.2.1 Information on Existing Wells

Many states require the drillers of water wells to file logs of the wells. These are good sources of information of the materials encountered and water levels recorded during well installation. The well owners, both public and private, may have records of the water levels after installation which may provide extensive information on fluctuations of the water level. This information may be available at state agencies regulating the drilling and installation of water wells, such as the Department of Transportation, the Department of Natural Resources, State Geologist, Hydrology Departments, and Division of Water Resources.

6.2.2 Open Borings

The water level in open borings should be measured after any prolonged interruption in drilling, at the completion of each boring, and at least 12 hours (preferably 24 hours) after completion of drilling. Additional water level measurements should be obtained at the completion of the field exploration and at other times designated by the engineer. The date and time of each observation should be recorded.

If the borehole has caved, the depth to the collapsed region should be recorded and reported on the boring record as this may have been caused by groundwater conditions. Perhaps, the elevations of the caved depths of certain borings may be consistent with groundwater table elevations at the site and this may become apparent once the subsurface profile is constructed (see Chapter 11).

Drilling mud obscures observations of the groundwater level owing to filter cake action and the higher specific gravity of the drilling mud compared to that of the water. If drilling fluids are used to advance the borings, the drill crew should be instructed to bail the hole prior to making groundwater observations.

6.2.3 Observation Wells

The observation well, also referred to as piezometer, is the fundamental means for measuring water head in an aquifer and for evaluating the performance of dewatering systems. In theory, a "piezometer" measures the pressure in a confined aquifer or at a specific horizon of the geologic profile, while an "observation well" measures the level in a water table aquifer (Powers, 1992). In practice, however, the two terms are at times used interchangeably to describe any device for determining water head.

The term "observation well" is applied to any well or drilled hole used for the purpose of long-term studies of groundwater levels and pressures. Existing wells and bore holes in which casing is left in place are often used to observe groundwater levels. These, however, are not considered to be as satisfactory as wells constructed specifically for the purpose. The latter may consist of a standpipe installed in a previously drilled exploratory hole or a hole drilled solely for use as an observation well.

Details of typical observation well installations are shown in Figure 6-1. The simplest type of observation well is formed by a small-diameter polyvinyl chloride (PVC) pipe set in an open hole. The bottom of the pipe is slotted and capped, and the annular space around the slotted pipe is backfilled with clean sand. The area above the sand is sealed with bentonite, and the remaining annulus is filled with grout, concrete, or soil cuttings. A surface seal, which is sloped away from the pipe, is commonly formed with concrete in order to prevent the entrance of surface water. The top of the pipe should also be capped to prevent the entrance of foreign material; a small vent hole should be placed in the top cap. In some localities, regulatory agencies may stipulate the manner for installation and closure of observation wells.

Driven or pushed-in well points are another common type for use in granular soil formations and very soft clay (Figure 6-1b). The well is formed by a stainless steel or brass well point threaded to a galvanized steel pipe (see Dunnicliff, 1988 for equipment variations). In granular soils, an open boring or rotary wash boring is advanced to a point several centimeters above the measurement depth and the well point are driven to the desired depth. A seal is commonly required in the boring above the well point with a surface seal at the ground surface. Note that observation wells may require development (see ASTM D 5092) to minimize the effects of installation, drilling fluids, etc. Minimum pipe diameters should allow introduction of a bailer or other pumping apparatus to remove fine-grained materials in the well to improve the response time.

Local or state jurisdictions may impose specific requirements on "permanent" observation wells, including closure and special reporting of the location and construction that must be considered in the planning and installation. Licensed drillers and special fees also may be required.

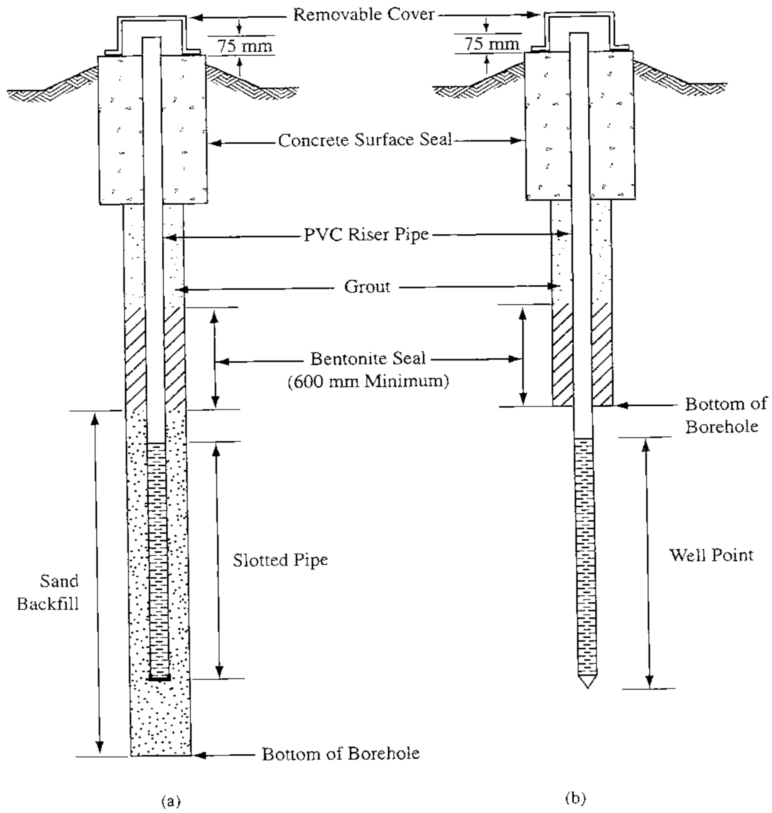

Figure 6-1. Representative Details of Observation Well Installations. (a) Drilled-in-place Stand-Pipe Piezometer, (b) Driven Well Point.

Piezometers are available in a number of designs. Commonly used piezometers are of the pneumatic and the vibrating wire type. Interested readers are directed to Course Module No. 11 (Instrumentation) or Dunnicliff (1988) for a detailed discussion of the various types of piezometers.

6.2.4 Water Level Measurements

A number of devices have been developed for sensing or measuring the water level in observation wells. Following is a brief presentation of the three common methods that are used to measure the depth to groundwater. In general, common practice is to measure the depth to the water surface using the top of the casing as a reference, with the reference point at a common orientation (often north) marked or notched on the well casing.

Chalked Tape

In this method a short section at the lower end of a metal tape is chalked. The tape with a weight attached to its end is then lowered until the chalked section has passed slightly below the water surface. The depth to the water is determined by subtracting the depth of penetration of the line into water, as measured by the water line in the chalked section, from the total depth from the top of casing. This is probably the most accurate method, and the accuracy is useful in pump tests where very small drawdowns are significant. The method is cumbersome, however, when taking a series of rapid readings, since the tape must be fully removed each time. An enameled tape is not suitable unless it is roughened with sandpaper so it will accept chalk. The weight on the end of the tape should be small in volume so it does not displace enough water to create an error.

Tape with a Float

In this method, a tape with a flat-bottomed float attached to its end is lowered until the float hits the water surface and the tape goes slack. The tape is then lifted until the float is felt to touch the water surface and it is just taut; the depth is then measured. With practice this method can give rough measurements, but its accuracy is poor. A refinement is to mount a heavy whistle, open at the bottom, on a tape. When it sinks in the water, the whistle will give an audible beep as the air within it is displaced.

Electric Water-Level Indicator

This battery-operated indicator consists of a weighted electric probe attached to the lower end of a length of electrical cable that is marked at intervals to indicate the depth. When the probe reaches the water, a circuit is completed and this is registered by a meter mounted on the cable reel. Various manufacturers produce the instrument, utilizing as the signaling device a neon lamp, a horn, or an ammeter. The electric indicator has the advantage that it may be used in extremely small holes.

The instrument should be ruggedly built, since some degree of rough handling can be expected. The distance markings must be securely fastened to the cable. Some models are available in which the cable itself is manufactured as a measuring tape. The sensing probe should be shielded to prevent shorting out against metal risers. When the water is highly conductive, erratic readings can develop in the moist air above the actual water level. Sometimes careful attention to the intensity of the neon lamp or the pitch of the horn will enable the reader to distinguish the true level. A sensitivity adjustment on the instrument can be useful. If oil or iron sludge has accumulated in the observation well, the electric probe will give unreliable readings.

Data Loggers

When timed and frequent water level measurements are required, as for a pump test or slug test, data loggers are useful. Data loggers are in the form of an electric transducer near the bottom of the well which senses changes in water level as changes in pressure. A data acquisition system is used to acquire and store the readings. A data logger can eliminate the need for onsite technicians on night shifts during an extended field permeability test. A further significant saving is in the technician's time back in the office. The preferred models of the data logger not only record the water level readings but permit the data to be downloaded into a personal computer and, with appropriate software, to be quickly reduced and plotted. These devices are also extremely useful for cases where measurement of artesian pressures is required or where data for tidal corrections during field permeability tests is necessary.

6.3 FIELD MEASUREMENT OF PERMEABILITY

The permeability (k) is a measure of how easily water and other fluids are transmitted through the geomaterial and thus represents a flow property. In addition to groundwater related issues, it is of particular concern in geo-environmental problems. The parameter k is closely related to the coefficient of consolidation (c_v) since time rate of settlement is controlled by the permeability. In geotechnical engineering, we designate small k = coefficient of permeability or hydraulic conductivity (units of cm/sec), which follows Darcy's law:

$$q = k \cdot i \cdot A \qquad (6\text{-}1)$$

where q = flow (cm^3/sec), i = dh/dx = hydraulic gradient, and A = cross-sectional area of flow.

Laboratory permeability tests may be conducted on undisturbed samples of natural soils or rocks, or on reconstituted specimens of soil that will be used as controlled fill in embankments and earthen dams. Field permeability tests may be conducted on natural soils (and rocks) by a number of methods, including simple falling head, packer (pressurized tests), pumping (drawdown), slug tests (dynamic impulse), and dissipation tests. A brief listing of the field permeability methods is given in Table 6-1.

The hydraulic conductivity (k) is related to the specific (or absolute) permeability, K (cm^2) by:

$$K = k \mu / \gamma_w \qquad (6\text{-}2)$$

where μ = fluid viscosity and γ_w = unit weight of the fluid (i.e., water). For fresh water at T = 20°C, μ = 1.005·E-06 kN-sec/m^2 and γ_w = 9.80 kN/m^3. Note that K may be given in units of darcies (1 darcy = 9.87·E-09 cm^2). Also, please note that groundwater hydrologists have confusingly interchanged $k \neq K$ in their nomenclature and this conflict resides within the various ASTM standards. The rate at which water is transmitted through a unit width of an aquifer under a hydraulic gradient i = 1 is defined as the transmissivity (T) of the formation, given by:

$$T = k \cdot b \qquad (6\text{-}3)$$

where b = aquifer thickness.

The coefficient of consolidation (c_v for vertical direction) is related to the coefficient of permeability by the expression:

$$c_v = k \cdot D' / \gamma_w \qquad (6\text{-}4)$$

where D' = (1/m_v) = constrained modulus obtained from one-dimensional oedometer tests (i.e., in lieu of the well-known e-log σ_v' curve, the constrained modulus is simply $D = \Delta\sigma_v'/\Delta\varepsilon_v$). In conventional one-