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Hydraulic Head Measurements in Soils with High Water Tables

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MEMBER A.S.A.E.

PREVENTION of the accumulation of excess salts in the soil or the amelioration of areas affected by alkali is accomplished by leaching. The possibility of leaching depends upon the permeability of the soil and upon the hydraulic head and gradient of the ground water. Adequate leaching is impossible if the water table is high, or if the hydraulic gradient within the normal root zone is upward. To improve either of these situations, the water table must be lowered and the hydraulic gradient reversed. This is generally accomplished by the installation of artificial drainage.

The design of land drainage systems is facilitated by information relative to the magnitude of hydraulic heads and gradients below the surface and to the depth, dip, and thickness of the aquifers and other strata which comprise the upper **20** or more feet of the earth's profile. This information is basic to the solution of such problems in drainage design as tracing the troublesome water to its source or to the place at which it can be intercepted most practicably; selection of the system of drainage to be used, such as drainage by pumping, tile or open channel drains, or some combination of these with vertical drains; determination of which stratum or strata to tap in order to secure the desired water table and hydraulic gradients with the least expenditure in drainage installation, operation, and maintenance.

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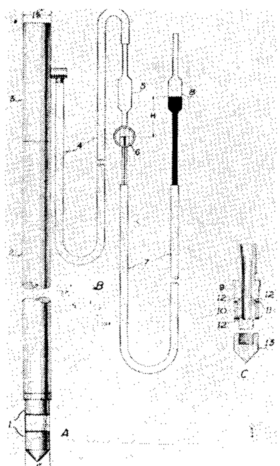


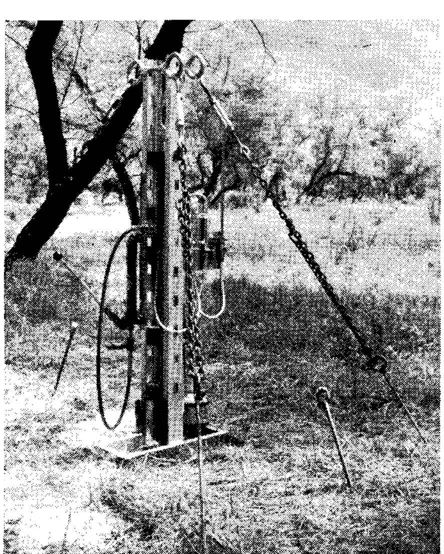
Fig. 1 The soil probe assembled, A; the manometer, B; and details of the probe point, C. The details are (1) the probe point containing a porous cell, (2) a probe tube which may be assembled to any desired length by adding additional sections, (3) a pushing cap, (4) flexible tubing connection from the probe to the manometer, (5) the fixed side of the manometer showing the capillary tubing and mercury meniscus magnified at (6), (7) flexible tubing connecting the fixed and movable bulb of the manometer, (8) manometer bulb mounted on a scale which is adjustable vertically and calibrated to read hydraulic head in feet Of water, (9) upper segment of probe point, (10) porous ceramic cell, (11) synthetic rubber gaskets, (12) holes connecting the annular space between the cell and the upper segment of the point with the inside of the probe, and (13) hardened point. The system is completely filled with water between 1 and 6. As the probe is forced into the earth, changes of water pressure at 1 are transmitted to 6. These changes are balanced by adjusting 8 vertically

With the exception of some areas for which there are many years of drainage experience, there is only fragmentary and uncoordinated data available upon which to base a drainage design, such as supplied by test wells, well logs, and shallow surface borings. This paper describes portable equipment and its application to the study of the groundwater hydrology and stratigraphy of drainage situations.

Apparatus. The apparatus consists of a soil probe, an adjustable mercury manometer calibrated to read hydraulic head in feet of water, a hydraulic jack to force the probe into the soil, and a fabricated steel tower 'anchored to the earth. The tower acts as a guide for the probe, supports the jack and manometer, and takes the reaction of the jack.

The probe (Fig. **1**) is assembled to any desired length from 5-ft sections of steel tubing of $1\frac{1}{8}$-in outer diameter and $\frac{1}{2}$-in inner diameter. The tubes are coupled by screw threads and made watertight at each joint by rubber gaskets. A point containing a porous cell closes the lower end of the probe, and a pushing cap with a pressure tubing connection to the manometer closes the upper end. The porous cell is a section of an alundum extraction thimble of medium porosity, **1** in in diameter and 11/16 in long.

The tower (Figs. 2 and 3), is 7 ft high and fabricated from 4-in steel channels weighing 5.25 lb per ft, placed face to face, which form the way for the jack and probe guides. It is anchored to the earth with four or more pole line anchors. The anchors used are of the two-way expansion type which are set at depths of from 3 to 4 ft in a 6-in auger hole and then expanded to $14\frac{1}{2}$ in. Each of these anchors is capable of resisting ten-



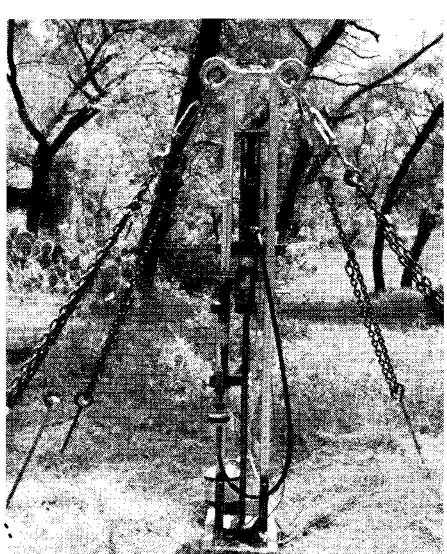


Fig. 2 (Left) Portable equipment set UP to force the probe into the earth. The manometer mounted on the back of the tower is connected to the probe by flexible tubing. The hydraulic pump is mounted on the face Of the tower and the hydraulic ram between the leads. Fig. 3 (Right) A front view of the setup shown in Fig. 2, but equipped for pulling with a pulling cap on the probe and a bridle on the ram

sion stresses varying from two to five tons. The maximum pressure required to force the probe to a depth of 45 ft in the soils we have explored is 12 tons, with an average of approximately 9 tons.

One side of the manometer is fixed in position and is connected to the probe by rubber tubing. The other side of the manometer is a leveling bulb mounted on a scale which is adjustable vertically by means of a rack and

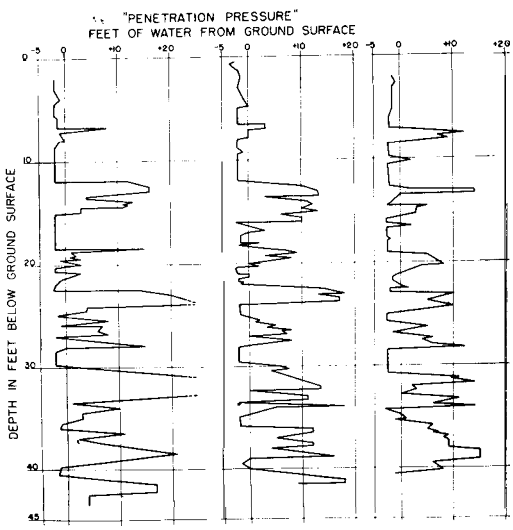


Fig. 4 Three profiles of "penetration pressure" as a function of depth, taken 30 ft apart in recent soil in overflow land near the present channel of the San Jacinto River, 3 mi east of Casa Loma

pinion. This bulb is open to the atmosphere and is connected to the fixed side of the manometer by rubber tubing. The manometer is used as a null instrument, the mercury meniscus on the fixed side being held to a horizontal line on a glass capillary tube by raising or lowering the leveling bulb. The hydraulic head is read on the scale in feet of water above or below the ground surface.

Operation. The probe and its connections are completely filled with water from the porous cell to the manometer. The manometer scale is set to read zero-head when the water table is at ground level. The probe is then forced into the soil at an approximately constant rate of 4 in per min and hydraulic head readings are plotted as a function of the depth of the cell below the ground surface. A party of three men can complete one exploration of 45 ft of soil profile in one working day.

Soil and water are displaced by the probe as it penetrates the soil, temporarily increasing the pressure in the soil water surrounding the cell. We have called these induced pressures "penetration pressures" to distinguish them from the equilibrium pressures reported as hydraulic head. The magnitude of a "penetration pressure" is related to the nature of the stratum penetrated and the rate of penetration and will vary from zero in coarse sand to hydraulic heads of 20 ft and greater in clay.

Soil profiles were explored in recent outwash soils along the San Jacinto River in California. Penetration pressure and hydraulic heads for these profiles are plotted as functions of depth in Figs. 4 and 6. The soils in this region are highly stratified with alternating strata and lenses in a wide variety of textures. The penetration pressures reveal this stratified condition, attaining various positive values through strata of intermediate to low permeability and dropping precipitately when sand strata are encountered.

Equilibrium readings of hydraulic head are taken in the strata of high permeability at elevations immediately below that in which a precipitate drop in penetration pressure occurs. Jacking is stopped for these readings and equilibrium is attained within a few minutes, whereas it may require from one to 24 hr for the head to become steady in strata with high penetration pressures.

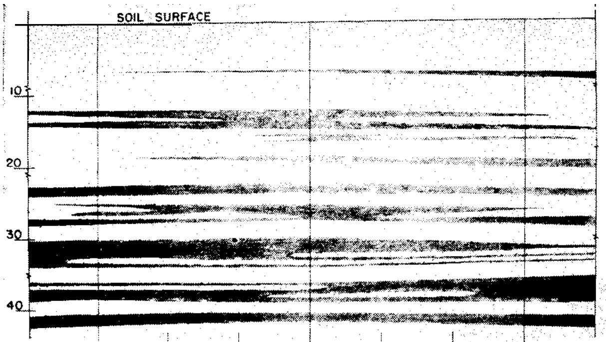
Three holes 30 ft apart were put down to test the reliability of penetration pressures as criteria of stratification. If abrupt changes in penetration pressures are taken as indicating changes in soil character, the penetration pressure profiles of Fig. 4 may be interpreted to indicate the stratification diagramed in Fig. 5. The results indicate that this probe is a tool of high sensitivity for determining the stratigraphy of unconsolidated sediments below the water table.

Application of Probe to Engineering Problems. Many applications of hydraulic head and stratigraphic information to such investigations as land and highway drainage, foundations and borrow pit sites, and small domestic or irrigation water supplies are apparent. We have planned investigations which we believe will result in an extension of its use. These include hydraulic head measurements and core sampling for the purpose of correlating penetration pressure with soil permeability, and subsurface sampling for quality of water.

SUMMARY

Portable apparatus consisting of a soil probe, a mechanism to force the probe into the earth, and a device to measure the hydraulic head at the probe point is described.

Information on the hydrology and stratigraphy of unconsolidated soil sediments below the water table may be derived with this apparatus, and application of this information to engineering investigations are discussed.



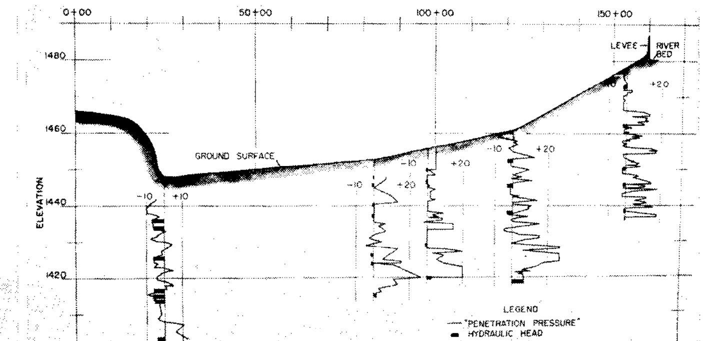


Fig. 5 (Left) Stratification as interpreted from the "penetration pressure" profiles of Fig. 4. Sand and gravel strata are stipled and less permeable strata are shaded. Fig. 6 (Right) Ground surface profile, penetration pressures, and hydraulic heads in the San Jacinto Valley, starting at the bench on the highway south of Casa Loma and extending east for approximately 3 mi to the San Jacinto River. At five points along this line penetration pressures and hydraulic heads in feet of water from the ground surface are plotted as functions of elevation in feet above sea level. Negative pressures (below the ground surface) are plotted to the left of the center line and positive to the right. Penetration pressures at 30 to 40 ft below the ground surface indicate a stratum of low permeability, 6 to 8 ft in thickness, and dipping westward between 82+50 and 122+00. Hydraulic heads immediately below this stratum are from 2 to 6.5 ft above the ground surface, indicating this stratum is continuous and of low permeability