PERMEABILITY TESTING METHODS

FOR

SECONDARY CONTAINMENT SYSTEMS

Prepared for

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Introduction

Background

Earthen secondary containment systems are commonly used at most oil storage facilities in the State. To function properly these systems must be impermeable to the product stored to prevent oil from reaching ground or surface water. They must also be properly constructed according to all regulations pertaining to secondary containment areas at bulk petroleum facilities.

Secondary containment is a requirement of several different federal and state regulations, specifically Part 112 of Title 40 of the Code of Federal Regulations and Parts 610, 613 and 614 of Title 6 of the New York State Code of Rules and Regulations.

Part 112 of Title 40 establishes procedures, methods and equipment to prevent the discharge of oil from non-transportation related on-shore and off-shore facilities into the waters of the United States. These facilities must have one of the following means of secondary containment or its equivalent to retain discharged oil: (1) Dikes, berms or retaining walls sufficiently impervious to contain spilled oil; (2) Curbing; (3) Culverting, gutters or other drainage systems; (4) Weirs, booms or other barriers; (5) Spill diversion ponds; (6) Retention ponds; or (7) Sorbant materials. Part 112 applies to all on-shore facilities with an underground storage capacity greater than 42,000 gallons of oil or an aboveground storage of greater than 1,320 gallons of oil.

The Petroleum Bulk Storage Regulations (6 NYCRR Part 613.3) require secondary containment for petroleum storage tanks that are: (a) in sensitive areas, such as over aquifers or near rivers; or (b) which have a capacity of 10,000 gallons or more. The secondary containment must be constructed so that spills of petroleum or chemical components of petroleum will not permeate, drain, infiltrate or otherwise escape to groundwater or surface water before clean-up occurs. Construction of diking and the storage capacity of the diked area must be in accordance with NFPA No. 30, section 2-2.3.3.

Purpose

This purpose of this paper is to discuss a few of the available testing methods that use Darcy's Law, both laboratory and in-place tests, to determining a soil's permeability. Different variables, such as soil stratigraphy and soil type, will be discussed and how they can effect the results of these tests.

Evaluating a Secondary Containment System

Proper Construction

A secondary containment area can be constructed according to two methods. The first is constructing a diked area that is sufficiently impervious to the lightest product stored within the area. The second is to divert an oil spill to a retention pond or holding tank. Although diking is most common, diversion of spills to a retention pond can be a good alternative when the expense of making the containment area sufficiently impervious to an oil spill is too costly. Federal regulations, such as 40 CFR 112, subdivision 112.7(c) and NFPA 2-2.3.2, both mention remote impounding. Because diked areas are the most common method used in secondary containment, remote impounding methods will not be discussed. More information can be obtained from a consulting engineering group experienced in this type of operation.

When evaluating a diking structure, three questions must be addressed. First, is the dike properly constructed? Second, what soil materials are present, both at the surface and beneath the surface? Finally, how long can the containment area retain the lightest product stored? Proper construction of the containment area is one of the most important aspects in evaluating if the dike is an effective impermeable barrier.

The guidelines for constructing a dike can be found in the National Fire Protection Association (NFPA) 30, Flammable and Combustible Liquids Code 1981, section 2-2.3.3. A copy of this section is in Appendix A. The NFPA Flammable and Combustible Liquids Code Handbook is also a good source for guidelines in proper construction. These guidelines explain in detail how dike walls should be formed, what the required capacity of the dike should be, material of construction to use, etc. As shown in Appendix B, illustrations from DEC's Recommended Practices for Aboveground Storage of Petroleum Products Manual, pp. 5-2 and 5-3, the construction of the dike should restrict both the horizontal and vertical flow of any petroleum product released in the area. Proper construction of the dike walls will prevent the structure from being toppled over in the event of a large release. Once careful consideration has been made that the dike is properly constructed, the next step is to determine the types of soil present at the surface of the dike and beneath the surface.

Determination of the soil type at the surface can be done by visual inspection, however, more in-depth investigation is required to determine the subsoil profile. Commonly, boring logs or test pits are employed to obtain a subsurface profile at a site. Boring logs evaluate subsurface conditions on the number of blows it takes to drive a soil sampling device a certain distance with a driver of known weight and the types of soils encountered. At the very least a boring log should contain the number of blows needed to drive the auger a certain distance, the types of soils and rocks encountered in each sample, the depth to groundwater and any changes in soil stratigraphy. Samples are usually retrieved and examined every two feet, while the number of blows are recorded every six inches.

To obtain a good subsoil profile, a series of boreholes must be used. This information will more clearly define areas of uniformity and variation in soil stratigraphy. To efficiently develop a good subsoil profile this information should be evaluated into a subsurface profile as the boreholes are made. In this manner one can decide where further subsurface evaluation will be needed.

Even though soil borings provide good soil profile information, limitations do exist on information furnished by the driller's log book. Usually the members of the field crew are drillers by trade and may not have the training to perform detailed soil classification. Important items of information about a soils profile can be overlooked because the driller's main concern is often the rate of drilling progress. For this reason, soil borings should only be used as a guideline for a soil's profile. With the soil boring information, the selection of an appropriate test can be made to determine the soil's permeability. Once an average permeability rate has been established for the entire diked area, the retention time for the lightest product stored can be calculated.

Definition of Permeability

Darcy's Law

Permeability is defined as the ability of water, or any other fluid, to flow through a soil by traveling through the void spaces. Using an engineering approach, Darcy's Law defines permeability by the equation:

$$k = \frac{q}{iA}$$

k = permeability of the soil (cm/s)
q = seepage rate (cm^3/sec)
i = hydraulic gradient (dimensionless)
A = area perpendicular to q (cm^2)

By measuring the quantities q, A & i from a laboratory or in-place test, the permeability rate can be calculated.

The calculated permeability rate is usually considered to be constant throughout the soil, however, it can vary at certain locations because of a change in the soil's make-up, such as a sand layer followed by a clay layer. In this situation, the permeability rate will be higher in the sand layer and lower in the clay layer. This is largely dependant on the properties of the fluid flowing through the soil, most importantly its viscosity.

The ease with which the fluid can travel through the soil depends upon:

(1) The viscosity of the flowing fluid;

(2) The size and continuity of the pore spaces or joints through which the fluid flows, which depends in soils upon:

(a) The size and shape of the soil's particles;
(b) The density of the soil;
(c) The detailed arrangement of the individual soil grains, called the structure;
(d) The presence of discontinuities in the soil's stratigraphy.

Because these variables have such a large effect on the permeability rate, Darcy's Law can only give a statistical average factor representing a definite cross section of the soil. Thus, to achieve a more representative view of the actual field conditions, a larger area of soil must be evaluated by a test. The properties of the soil, such as grain size, can also be used as an indication of the approximate range of the permeability to be expected. As a rule, however, permeability should only be determined by a laboratory or in-place test.

Instead, the size of the soil grains and the plasticity of the soil are used as a basis to determine the soil type. The United Soil Classification System groups soils on the basis of coarse and fine grain. The four common groupings are gravel, sand, silt and clay. A diagram further describing these different soil classifications is attached in Appendix C.

The arrangement of soil particles can influence permeability in two important ways. The first is through natural stratification. Natural soil deposits are always stratified in structure to some extent when they are formed, causing the permeability to be higher in a horizontal direction than vertically or vice-versa. Some examples of stratification include open-work gravel, water deposited soils and windblown sands and silts. The second is through detailed orientation of particles and dispersion of fines. Permeability tends to increase in soils of fine grain size, due to its higher density, and when moisture content is high at the time of compaction. For these reasons, direct calculations from a chart of drainage characteristics of soils can only provide a rough estimate of a soil's permeability.

Soil Classifications

Permeability is largely dependant on the void between soil particles. This is shown by the larger value for k for coarse grain soils, such as gravel, and the much smaller values of k in finer grain soils, such as silt or clay. The reason for this is that in finer soils the smaller pore spaces only allow low velocity flow, where the larger pore spaces in the coarser soils yield the opposite affect. In clays, the extremely small flow channels become saturated as the clay particles absorb the water which further reduces the area of flow. In ideal conditions of uniform void between soil particles, the permeability of a soil could be directly calculated from the soil's void ratio. Since these void spaces are not uniform, permeability is more practically determined through the use of a laboratory or field test. As a reference for different soil properties, a table of permeability and drainage characteristics is attached in Appendix D. This describes the different soil types and the applicability of direct and indirect methods for determining permeabilities in various soils.

The relationship between void ratio and permeability is logarithmic. Generally, a semilog plot of void ratio values and their corresponding permeability values will produce a straight line for most soils. This illustrates that even small changes in the void ratio, in the process of retrieving a soil sample or recompacting a sample in a test chamber, will greatly affect the permeability rate. Therefore, it is extremely important that a soils stratification remain undisturbed in order to accurately determine the permeability rate. In layered soils the measured flow rate in the horizontal direction can be greatly different from the flow rate in the vertical direction. Fine grained non-homogeneous soils, such as clay with alternating horizontal layers of silt, will generally have higher flow rates in a horizontal direction compared to a vertical direction.

Conditions other than void ratio and soil grain size also will affect the flow rate of a fluid through a given soil. Seams, cracks, fissures, cavities and trapped air all play a role in the soil's permeability rate. Field investigations reveal information on the presence of these conditions to allow testing methods to reliable measure the rate of flow of a fluid through a given soil.

In the best conditions, permeability tests, either field or laboratory methods, are only reliable to an order of magnitude. Since these tests usually concentrate on a specific area of the soil, more accurate results are obtained through testing over a greater area of the soil. This is because surface conditions as well as subsurface conditions will most likely change, even over short distances. Because of the wide variety of laboratory tests and field tests available, careful evaluation of the soil's make-up, as well as the applicability of the testing method in these soil conditions, must be done to choose the best test and achieve an accurate permeability rate.

Permeability Testing Methods

Laboratory Tests

Two common laboratory tests used to determine the variables needed to calculate a soil's permeability, which apply Darcy's Law, are of the "constant head" and the "falling head" types. Illustrations of these tests are shown in Appendix E. Field tests include standpipe tests, such as the method described in PACE 79-2, borehole tests, bail-down or slug tests using Hvorslev's Method and well pumping tests.

The constant head test is used mostly for permeable soils, such as filter or drain aggregates. A sample of the material is placed in a cylindrical mold, and a continuous supply of water is fed through the sample. Darcy's Law is then applied to the test results to determine the soil's permeability. The water is introduced at the top of the cylinder and passes through the sample of cross sectional area A, in time t, collected at a flow rate q into a container beneath the sample. The hydraulic gradient i, is equal to the net head h, divided by the length of the sample L. Problems arise with this test when the sample is an impervious soil. This is because impervious soils have an excessive seepage time and errors occur in the results because of evaporation. A more suitable test for impervious soils is the falling head permeability test.

The falling head test is similar to the constant head test because it measures the amount of water passing through a sample of the material. The difference is this test uses a standpipe to introduce water into the sample. The diameter of the standpipe is adjusted so that a medium flow rate is established through the sample to compensate for evaporation and increase the accuracy of the results. Applying Darcy's Law, the form of the equation used is (see appendix G):

$$k = 2.3 \frac{aL}{Adt} \log (h_1/h_2)$$

k = permeability (cm/sec)

a = area of the standpipe (cm^2)

A = cross-sectional area of the sample (cm^2)

L = sample length (cm)

h_1 = initial height in the standpipe (cm)

h_2 = final height in the standpipe (cm)

dt = the time it took the water to fall from h_1 to h_2 (seconds)

Falling head tests may be done with either downward or upward flow through the sample. Although downward flow would seem to be the most logical direction of flow, reverse flow is applied to prevent migration of fines which leads to clogging and a misleading result of a higher permeability rate. One specific test that takes advantage of reverse flow, or backflow, is the flexible wall permeameter test. This is a triaxial device specifically designed for fine grained soils. The key element to this device is the flexible rubber membrane chamber than holds the sample.

Because of the flexible chamber, this test can simulate in-place conditions by applying the proper chamber pressure and vertical load. Drain holes are located on opposite ends of the cylindrical chamber to calculate the seepage rate through the specimen. The flexible wall is tightly pressed against the sample to prevent leaks and sideflow between the wall and soil. This is the major reason for using a triaxial device. Back pressure is applied to the sample while maintaining the same effective stress on the soil's skeleton. In this manner, a fully saturated permeability rate, with a minimal amount of clogging, is achieved. The most important factor in obtaining accurate results is retrieving a sample with the least amount of disturbance to it's natural stratigraphy.

Typically, relatively undisturbed soil samples can be obtained in clay soils using thin walled tubes or a split-spoon sampler. The permeability of these samples can then be tested successfully in the laboratory. If possible, laboratory tests should be performed with the lightest petroleum product that will be stored within the diked area to increase their accuracy. Rigid walled systems are usually not recommended because recompacting of the sample in the chamber of the apparatus often produces incorrect permeability values. Results can be altered from a factor of 10 to a factor of 100.

Field Tests

Field permeability tests offer an advantage over laboratory tests at certain sites because they evaluate a volume of soil in its natural environment. Retrieving undisturbed laboratory samples in sands and silty soils is difficult, even when using a shelby tube or a split-spoon sampler. This is due to the large vibrations and shearing from the hollow tube or auger as it penetrates the soil. Natural fines and voids are disturbed, altering the natural stratigraphy and changing the soil's permeability.

An in-place test is an alternative method to a laboratory test which overcomes this problem. Field methods test soils in their natural location. This avoids the problem of disturbing the material's natural stratigraphy. The field methods described herein are of the cased boring type. Illustrations of these types of tests are shown in Appendix F. These testing methods are based on the time it takes for a volume of water to flow into, or out of, a well casing.

Standpipe tests are of the falling or constant head method. This test is conducted by inserting a standpipe is into the soil and filling it with water. After allowing the soil to become saturated, the test is started. The pipe is filled to a certain level with a known volume of water and the level change per unit time is recorded. The drop in water level over an interval of time, usually 30 minutes, is then used to determine the soil's permeability from a graph of drop in product level verses permeability. This test is most accurately performed during the warmest and driest season of the year. Two sources of error are the test mostly accounts for vertical flow through a soil sample, and results can be effected in more permeable soils due to evaporation.

A Borehole test is a simplified version of a well pumping test. A soil's permeability is estimated through Darcy's Law from the rate at which water can be pumped out of, or into, a drill hole. When stratum is being tested above the water table, a pumping-in test is performed. When the layers are beneath the water table either pumping method can be performed.

This method provides a physical index for flow through an in-place material at a relatively low cost. A borehole test can provide useful information about a soil, however, care must be taken when applying the test since the results are not easily checked and errors are possible. The most frequent errors are:

(1) Leakage along the casing and around packers;
(2) Clogging due to sloughing of fines or sediment in the water;
(3) Air locking due to gas bubbles in the soil or water;
(4) Flow of water into cracks in soft rocks that are opened by excessive head in test holes.

A slug test, or Hvorslev's method, is based upon the theory that the time lag of water flowing to or from a hole, or well casing, is inversely proportional to the permeability of the soil. A well is first installed into the groundwater table. Next a mass or slug is dropped into the well casing causing the water level of the groundwater table to artificially rise. Once the water level in the well reaches equilibrium, the slug is removed causing the water level to drop by a known volume, the weight of the slug. Water then begins entering the casing. The amount of time, or time lag, for the water level to reach equilibrium in the well is recorded by an electronic pressure-sensing device. The soil permeability is then determined from a graph of time lag verses permeability.

The time lag theory is a practical and relatively inexpensive method for determining permeability in homogeneous and non-homogeneous soils. Errors may occur in the results due to the inaccuracy of the electronic devices and for the same reasons mentioned for the borehole test.

A well pumping test is based upon Darcy's Law and Dupuit's assumption. This theory states that the hydraulic gradient at any point is a constant from the top to the bottom of the water-bearing layer and is equal to the slope of water surface. In this test, water is pumped out of, or into, a well while water level readings are made in several nearby sounding wells. The test is continued until steady state conditions are reached.

For the case of radial flow, Darcy's Law and Dupuit's assumption are used to derive the simple well formula (see attached diagram in Appendix H):

$$k = \frac{2.3\, q \log_{10} (R/r)}{(H^2 - h^2)}$$

This formula is based upon four assumptions:

(1) The pumping well penetrates the full thickness of the water-bearing information;

(2) A steady-state flow condition exists;

(3) The water-bearing formation is homogeneous, isotropic, and extends an infinite distance in all directions;

(4) The Dupuit assumption is valid.

The reliability of this test depends on how accurately the above assumptions are met. The test is expensive but produces accurate results at moderate distances from the wells.

For all in-place tests, water has to be used as the test fluid. The final permeability rate results are then converted by means of a ratio, viscosity of petroleum to water, to reflect the permeability rate of the lightest product stored within the diked area. This value then can be used to calculate the retention time of the soil to an oil spill.

Conclusion

Summary of Findings

When determining the permeability of a soil in a secondary containment area, the object of the test must be to determine the vertical, as well as, the horizontal flow of a potential oil spill. In this manner, a good estimate of a petroleum's migration through the soil to the groundwater can be achieved. The object of the dike should be to allow for adequate clean-up time, as well as minimal soil contamination, in the event of a large release.

Proper construction should be the first step in evaluating a diked area. When this is found to be satisfactory, the next step is to determine the stratigraphy of the soil in the diked area. This is accomplished through field investigations using boring logs or test pits. Finally, after classifying the underlying soil and developing a good subsoil profile, the proper test can be applied to determine it's permeability rate.

In homogenous layers of clay where a good sample can be retrieved, a laboratory test can be used to effectively determine the soil's permeability. Laboratory tests should be of the triaxial system (i.e., flexible wall permeameter). In-place permeability test are better applied to non-homogeneous soils that are mostly comprised of silts, sands, or gravels. This is because of the difficulty in retrieving a relatively undisturbed sample. In this manner, a more accurate permeability rate for the soil will be obtained. No matter which method is used, it should be noted that the results are only accurate to an order of magnitude.

One limitation to all in-place tests and most laboratory tests is that water is used to calculate the permeability of the soil; a conversion factor (ratio of viscosity of petroleum to water) must then be applied to adjust the calculated permeability to reflect the lightest petroleum product stored at the site. Problems arise in this situation since lighter chemical elements of petroleum can flow up to fifty times faster through a given material than water. Because the viscosity of petroleum is an average of all the chemical components, a falsely higher permeability rate would be calculated. Therefore a higher permeability rate of the soil should be expected when using water as the test fluid with in-place or laboratory test.

Recommendations

The following recommendations are for upgrading secondary containment systems to comply with DEC's Major On-Shore Petroleum Facility Regulations:

1. The department will accept any permeability test results that are certified by a professional engineer. We are expecting a permeability rate that allows for adequate clean-up time with a minimal amount of soil contamination. When performing either a laboratory or field permeability test, several samples of the diked area should be tested so that a profile of the entire diked area can be obtained allowing for an average permeability rate of the entire diked area to be calculated. A professional engineer will be required to certify that the diked area is structurally sound and impervious to the product stored within the containment area.

2. All diked areas are required to be impervious to an oil spill. The department expects the diked area to provide adequate clean-up time with a minimal amount of soil contamination. We project that a clean-up time of 72 hours with no more than six (6) inches of soil contamination, will be necessary to remediate the spill and cause the least amount of environmental damage. When using a laboratory test the permeability rate must be calculated using the lightest product stored in the diked area. When using an in-place test the viscosity of the lightest product stored must be used.

3. When a diked area fails to be structurally sound or impermeable to an oil spill, two things can be done. First, the current structure can be retrofitted to meet current standards such as:

a. constructing dike walls according to NFPA 30, section 2.2.3.3;

b. performing structural tests on the dike walls to insure their strength;

c. installing natural clay or synthetic liners to increase the permeability of the dike floor.

Second, an alternate method to a diking structure can be used, such as impoundment pits or retention ponds. One possible scheme would be having a lined trench within the diked area that flowed to a sump. The trench would be designed so that any spilled oil would go directly into the trench. Oil then could be pumped to another holding tank. The capacity of this holding tank should be 110% of the largest tank in the diked area.

Retrofitting a diked area will be expensive no matter which method is used. Time and effort will be required on the part of the facility to find a means of secondary containment that is affordable yet consistent with the department's requirements. Details on cost will have to worked out within their company or with a consulting engineering group.

4. Maintenance of secondary containment areas is as important as having the proper design and construction. Steps must be taken by the facility to keep up the secondary containment. Inspections on diked areas, as well as tanks, should be done on a monthly basis.

Inspection routines should consist of inspecting the area for product spills, closed storm water values and insuring that the dike floor is free of vegetation protruding through it. Since avoiding correction of these problems can lead to disastrous results, they must be corrected as soon as they are discovered. In the case of remote pumping systems, all aspects of this system must be inspected to insure that it is proper working order.

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8. Zimmie, T. F., "Geotechnical Testing Considerations in the Determination of Laboratory Permeability for Hazardous Waste Disposal Siting," Hazardous Solid Waste Testing: First Conference, ASTM STP 760, American Society for Testing and Materials (1981), pp. 299-302.

Table 2-7 Minimum Tank Spacing (Shell-to-Shell)

	Floating Roof Tanks	Fixed Roof or Horizontal Tanks	
		Class I or II Liquids	Class IIIA Liquids
All tanks not over 150 feet diameter	1/6 sum of adjacent tank diameters but not less than 3 feet	1/6 sum of adjacent tank diameters but not less than 3 feet	1/6 sum of adjacent tank diameters but not less than 3 feet
Tanks larger than 150 feet diameter			
If remote impounding is in accordance with 2-2.3.2	1/6 sum of adjacent tank diameters	1/4 sum of adjacent tank diameters	1/6 sum of adjacent tank diameters
If impounding is around tanks in accordance with 2-2.3.3	1/4 sum of adjacent tank diameters	1/3 sum of adjacent tank diameters	1/4 sum of adjacent tank diameters

SI Units: 1 ft = 0.30 m.

2-2.2.6 The minimum horizontal separation between an LP-Gas container and a Class I, Class II or Class IIIA liquid storage tank shall be 20 ft (6 m) except in the case of Class I, Class II or Class IIIA liquid tanks operating at pressures exceeding 2.5 psig (17.2 kPa) or equipped with emergency venting which will permit pressures to exceed 2.5 psig (17.2 kPa) in which case the provisions of 2-2.2.1 and 2-2.2.2 shall apply. Suitable means shall be taken to prevent the accumulation of Class I, Class II or Class IIIA liquids under adjacent LP-Gas containers such as by dikes, diversion curbs or grading. When flammable or combustible liquid storage tanks are within a diked area, the LP-Gas containers shall be outside the diked area and at least 10 ft (3 m) away from the centerline of the wall of the diked area. The foregoing provisions shall not apply when LP-Gas containers of 125 gal (475 L) or less capacity are installed adjacent to fuel oil supply tanks of 660 gal (2498 L) or less capacity. No horizontal separation is required between aboveground LP-Gas containers and underground flammable and combustible liquid tanks installed in accordance with Section 2-3.

2-2.3 Control of Spillage from Aboveground Tanks.

2-2.3.1 Facilities shall be provided so that any accidental discharge of any Class I, II or IIIA liquids will be prevented from endangering important facilities, adjoining property or reaching waterways, as provided for in 2-2.3.2 or 2-2.3.3. Tanks storing Class IIIB liquids do not require special drainage or diking provisions for fire protection purposes.

2-2.3.2 Remote Impounding. Where protection of adjoining property or waterways is by means of drainage to a remote impounding area, so that impounded liquid will not be held against tanks, such systems shall comply with the following:

(a) A slope of not less than 1 percent away from the tank shall be provided for at least 50 ft (15 m) toward the impounding area.

(b) The impounding area shall have a capacity not less than that of the largest tank that can drain into it.

(c) The route of the drainage system shall be so located that, if the liquids in the drainage system are ignited, the fire will not seriously expose tanks or adjoining property.

(d) The confines of the impounding area shall be located so that when filled to capacity the liquid level will not be closer than 50 ft (15 m) from any property line that is or can be built upon, or from any tank.

2-2.3.3 Impounding Around Tanks by Diking. When protection of adjoining property or waterways is by means of impounding by diking around the tanks, such system shall comply with the following:

(a) A slope of not less than 1 percent away from the tank shall be provided for at least 50 ft (15 m) or to the dike base, whichever is less.

(b) The volumetric capacity of the diked area shall not be less than the greatest amount of liquid that can be released from the largest tank within the diked area, assuming a full tank. To allow for volume occupied by tanks, the capacity of the diked area enclosing more than one tank shall be calculated after deducting the volume of the tanks, other than the largest tank, below the height of the dike.

(c) To permit access, the outside base of the dike at ground level shall be no closer than 10 ft (3 m) to any property line that is or can be built upon.

(d) Walls of the diked area shall be of earth, steel, concrete or solid masonry designed to be liquidtight and to withstand a full hydrostatic head. Earthen walls 3 ft (0.90 m) or more in height shall have a flat section at the top not less than 2 ft (0.60 m) wide. The slope of an earthen wall shall be consistent with the angle of repose of the material of which the wall is constructed. Diked areas for tanks containing Class I liquids located in extremely porous soils may require special treatment to prevent seepage of hazardous quantities of liquids to low-lying areas or waterways in case of spills.

(e) Except as provided in (f) below, the walls of the diked area shall be restricted to an average interior height of 6 ft (1.8 m) above interior grade.

(f) Dikes may be higher than an average of 6 ft (1.8 m) above interior grade where provisions are made for normal access and necessary emergency access to tanks, valves and other equipment, and safe egress from the diked enclosure.

1. Where the average height of the dike containing Class I liquids is over 12 ft (3.6 m) high, measured from interior grade, or where the distance between any tank and the top inside edge of the dike wall is less than the height of the dike wall, provisions shall be made for normal operation of valves and for access to tank roof(s) without entering below the top of the dike. These provisions may be met through the use of remote operated valves, elevated walkways or similar arrangements.

2. Piping passing through dike walls shall be designed to prevent excessive stresses as a result of settlement or fire exposure.

3. The minimum distance between tanks and toe of the interior dike walls shall be 5 ft (1.5 m).

(g) Each diked area containing two or more tanks shall be subdivided, preferably by drainage channels or at least by intermediate curbs in order to prevent spills from endangering adjacent tanks within the diked area as follows:

1. When storing normally stable liquids in vertical cone roof tanks constructed with weak roof-to-shell seam or floating roof tanks or when storing crude petroleum in producing areas in any type of tank, one subdivision for each tank in excess of 10,000 bbls. and one subdivision for each group of tanks (no tank exceeding 10,000 bbls. capacity) having an aggregate capacity not exceeding 15,000 bbls.

2. When storing normally stable liquids in tanks not covered in subsection (1), one subdivision for each tank in excess of 2,380 bbls. (378,500 L) and one subdivision for each group of tanks [no tank exceeding 2,380 bbls. (378,500 L) capacity] having an aggregate capacity not exceeding 3,570 bbls. (567,750 L).

3. When storing unstable liquids in any type of tank, one subdivision for each tank except that tanks installed in accordance with the drainage requirements of NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*, shall require no additional subdivision. Since unstable liquids will react more rapidly when heated than when at ambient temperatures, subdivision by drainage channels is the preferred method.

4. Whenever two or more tanks storing Class I liquids, any one of which is over 150 ft (45 m) in diameter, are located in a common diked area, intermediate dikes shall be provided between adjacent tanks to hold at least 10 percent of the capacity of the tank so enclosed, not including the volume displaced by the tank.

5. The drainage channels or intermediate curbs shall be located between tanks so as to take full advantage of the available space with due regard for the individual tank capacities. Intermediate curbs, where used, shall be not less than 18 in. (45 cm) in height.

(h) Where provision is made for draining water from diked areas, such drains shall be controlled in a manner so as to prevent flammable or combustible liquids from entering natural water courses, public sewers, or public drains, if their presence would constitute a hazard. Control of drainage shall be accessible under fire conditions from outside the dike.

(i) Storage of combustible materials, empty or full drums, or barrels, shall not be permitted within the diked area.

2-2.4 Normal Venting for Aboveground Tanks.

2-2.4.1 Atmospheric storage tanks shall be adequately vented to prevent the development of vacuum or pressure sufficient to distort the roof of a cone roof tank or exceeding the design pressure in the case of other atmospheric tanks, as a result of filling or emptying, and atmospheric temperature changes.

2-2.4.2 Normal vents shall be either sized in accordance with: (1) the American Petroleum Institute Standard No. 2000, *Venting Atmospheric and Low-Pressure Storage Tanks, 1982*, or (2) other accepted standard; or shall be at least as large as the filling or withdrawal connection, whichever is larger, but in no case less than 1¼ in. (3 cm) nominal inside diameter.

2-2.4.3 Low-pressure tanks and pressure vessels shall be adequately vented to prevent development of pressure or vacuum, as a result of filling or emptying and atmospheric temperature changes, from exceeding the design pressure of the tank or vessel. Protection shall also be provided to prevent overpressure from any pump discharging into the tank or vessel when the pump discharge pressure can exceed the design pressure of the tank or vessel.

2-2.4.4 If any tank or pressure vessel has more than one fill or withdrawal connection and simultaneous filling or withdrawal can be made, the vent size shall be based on the maximum anticipated simultaneous flow.

2-2.4.5 The outlet of all vents and vent drains on tanks equipped with venting to permit pressures exceeding 2.5 psig (17.2 kPa) shall be arranged to discharge in such a way as to prevent localized overheating of, or flame impingement on, any part of the tank, in the event vapors from such vents are ignited.

2-2.4.6 Tanks and pressure vessels storing Class IA liquids shall be equipped with venting devices which shall be normally closed except when venting to pressure or vacuum conditions. Tanks and pressure vessels storing Class IB and IC liquids shall be equipped with venting devices which shall be normally closed except when venting under pressure or vacuum conditions, or with listed flame arresters. Tanks of 3,000 bbls. (476,910 L) capacity or less containing crude petroleum in crude-producing areas, and outside aboveground atmospheric tanks under 23.8 bbls. (3,785 L) capacity containing other than Class IA liquids may have open vents. (*See 2-2.6.2.*)

2-2.4.7 Flame arresters or venting devices required in 2-2.4.6 may be omitted for IB and IC liquids where conditions are such that their use may, in case of obstruction, result in tank damage. Liquid properties justifying the omission of such devices include, but are not limited to, condensation, corrosiveness, crystallization, polymerization, freezing or plugging. When any of these conditions exist, consideration may be given to heating, use of devices employing special materials of construction, the use of liquid seals, or inerting (*see* NFPA 69, *Standard on Explosion Prevention Systems*).

2-2.5 Emergency Relief Venting for Fire Exposure for Aboveground Tanks.

2-2.5.1 Except as provided in 2-2.5.2, every aboveground storage tank shall have some form of construction or device that will relieve excessive internal pressure caused by exposure fires.

APPENDIX B

FIGURE 5-1
DIKE SYSTEM COMPONENTS

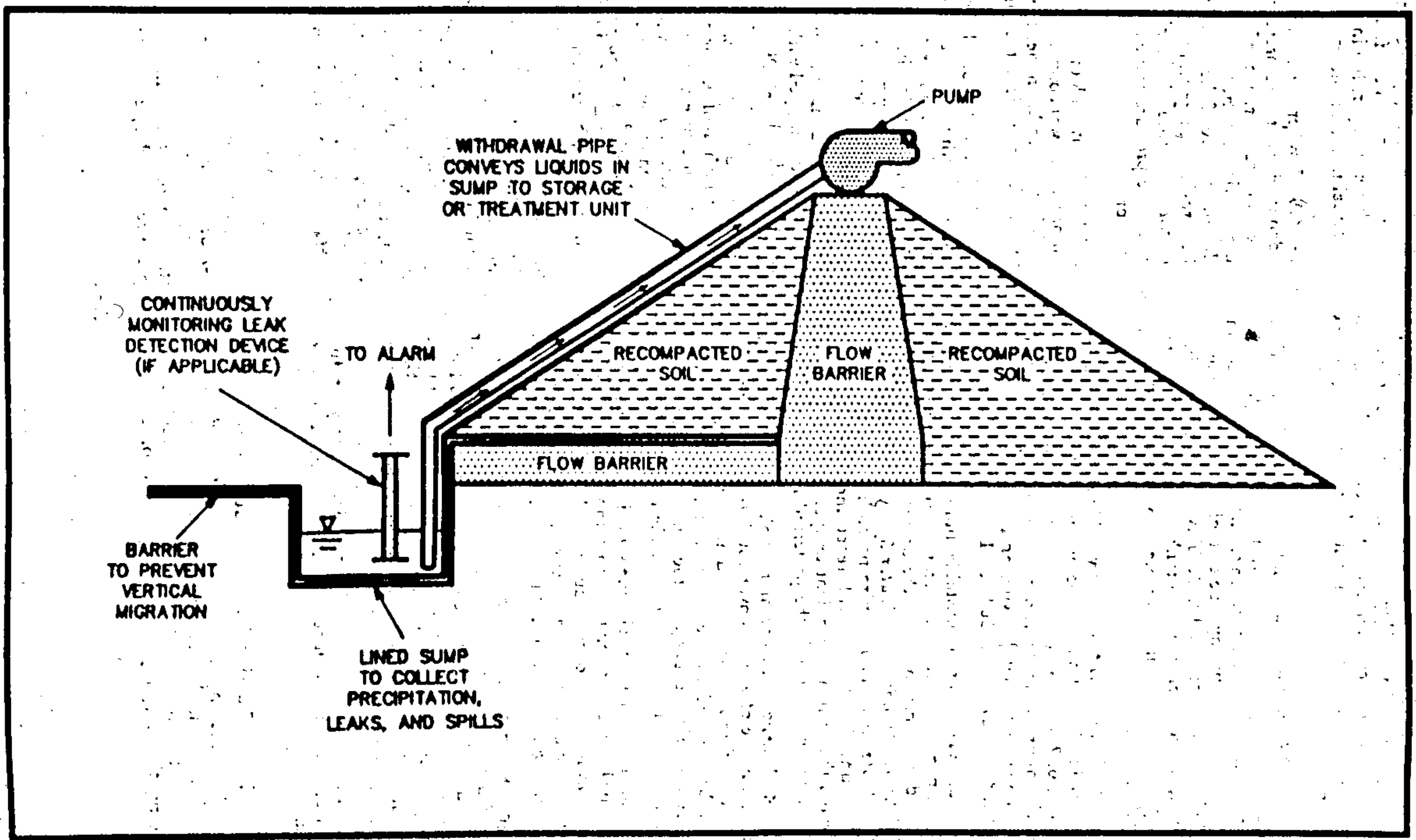
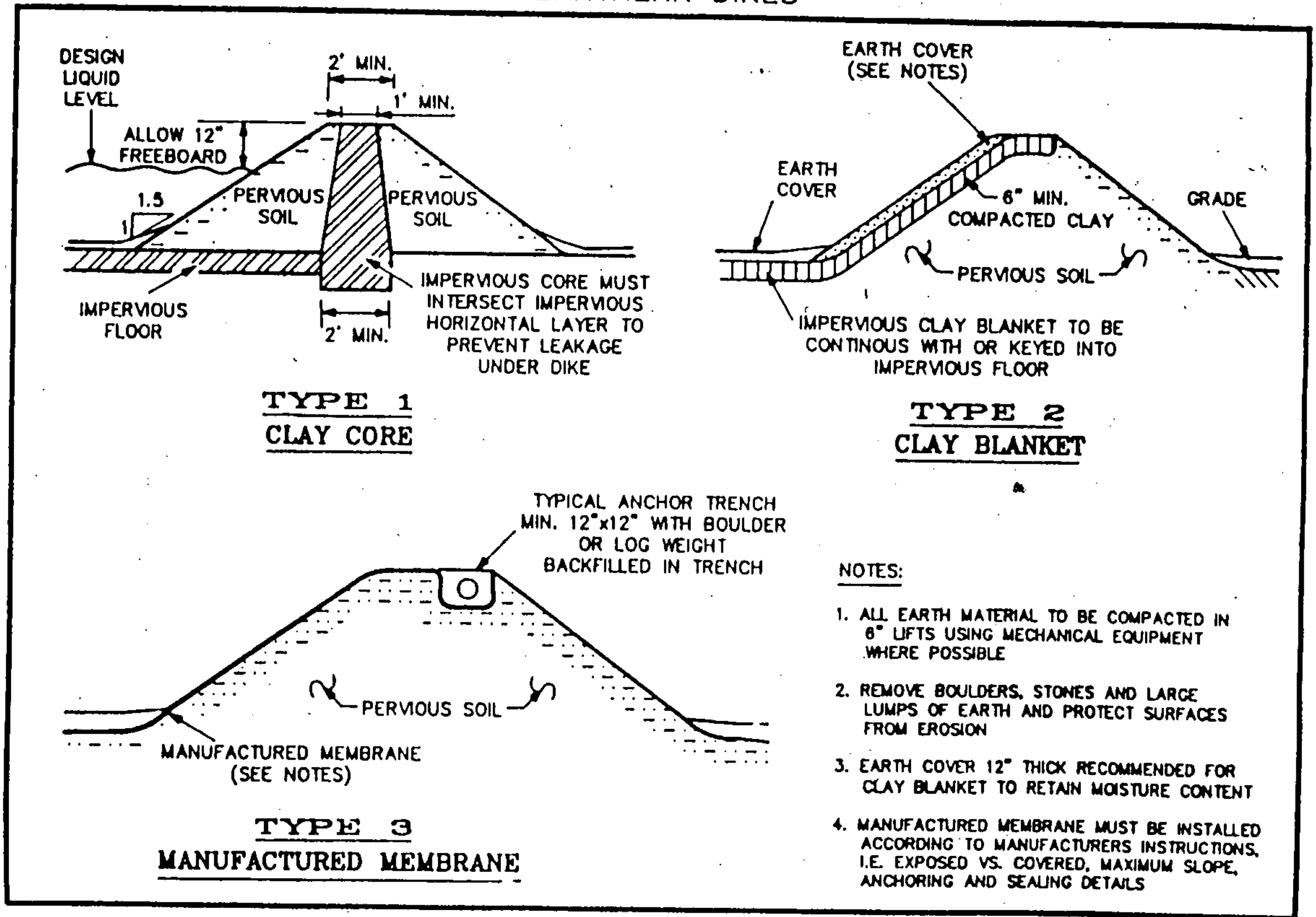


FIGURE 5-2

EARTHERN DIKES



NOTES:

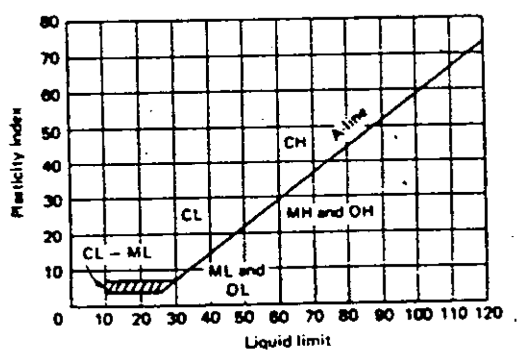
1. ALL EARTH MATERIAL TO BE COMPACTED IN 6" LIFTS USING MECHANICAL EQUIPMENT WHERE POSSIBLE
2. REMOVE BOULDERS, STONES AND LARGE LUMPS OF EARTH AND PROTECT SURFACES FROM EROSION
3. EARTH COVER 12" THICK RECOMMENDED FOR CLAY BLANKET TO RETAIN MOISTURE CONTENT
4. MANUFACTURED MEMBRANE MUST BE INSTALLED ACCORDING TO MANUFACTURERS INSTRUCTIONS, I.E. EXPOSED VS. COVERED, MAXIMUM SLOPE, ANCHORING AND SEALING DETAILS

SOURCE: PACE REPORT No. 80-3(3)

Unified Soil Classification System
(ASTM Designation D-2487)

Major division			Group Symbols	Typical Names	Classification on basis of percentage of fines	Classification Criteria
Coarse grained soils More than 50% retained on No. 200 sieve	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Less than 5% Pass No. 200 sieve: GW, GP, SW, SP	$C_u = D_{60}/D_{10}$ Greater than 4; $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW
		Gravels with fines	GM	Silty gravels, gravel-sand silt mixtures	More than 12% Pass No. 200 sieve: GM, GC, SM, SC	Atterberg limits plot below "A" line or plasticity index less than 4
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits plot above "A" line and plasticity index greater than 7
	Sands More than 50% of coarse fraction passes No. 4 sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines	5% to 12% Pass No. 200 sieve: Borderline classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 6; $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			SP	Poorly graded sands and gravelly sands, little or no fines		Not meeting both criteria for SW
		Sands with fines	SM	Silty sands, sand-silt mixtures		Atterberg limits plot below "A" line or plasticity index less than 4
			SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above "A" line and plasticity index greater than 7
Fine grained soils 50% or more passes No. 200 sieve	Silts and Clays Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands		Check plasticity chart
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			OL	Organic silts and organic silty clays of low plasticity		
	Silts and Clays Liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts		
			CH	Inorganic clays of high plasticity, fat clays		
			OH	Organic clays of medium to high plasticity		
Highly organic soils			Pt	Peat, muck and other highly organic soils		Fibrous organic matter, will char, burn, or glow

(a)



Plasticity chart for the classification of fine-grained soils.
Tests made on fraction finer than No. 40 sieve.

(b)

Figure 4-16. **Unified Soil Classification System (ASTM Designation D-2487).**

Coefficient of Permeability k in cm per sec (log scale)

10^2 10^1 1.0 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}

Drainage	Good	Poor	Practically Impervious	
Soil types	Clean gravel	Clean sands, clean sand and gravel mixtures	Very fine sands, organic and inorganic silts, mixtures of sand silt and clay, glacial till, stratified clay deposits, etc.	"Impervious" soils, e.g., homogeneous clays below zone of weathering
			"Impervious" soils modified by effects of vegetation and weathering	
Direct determination of k	Direct testing of soil in its original position—pumping tests. Reliable if properly conducted. Considerable experience required			
	Constant-head permeameter. Little experience required			
Indirect determination of k	Falling-head permeameter. Reliable. Little experience required	Falling-head permeameter. Unreliable. Much experience required	Falling-head permeameter. Fairly reliable. Considerable experience necessary	
	Computation from grain-size distribution. Applicable only to clean cohesionless sands and gravels		Computation based on results of consolidation tests. Reliable. Considerable experience required	

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*, by K. Terzaghi and R. B. Peck, John Wiley and Sons, New York, 1948.)

a tubular chamber of suitable diameter, usually a few inches, and connected with a suitable over-flow arrangement and collection container. A small-diameter standpipe tube is connected to the top of the larger tube. The diameter of the standpipe tube is adjusted to the permeability of the material being tested. If the standpipe is too large, the rate of fall of the water level will be excessively slow; and if the standpipe is too small, the rate will be too fast for accurate measurement.

In making a test with a falling head type of apparatus, the standpipe is filled to a level somewhat above point P in Fig. 2.12c. When

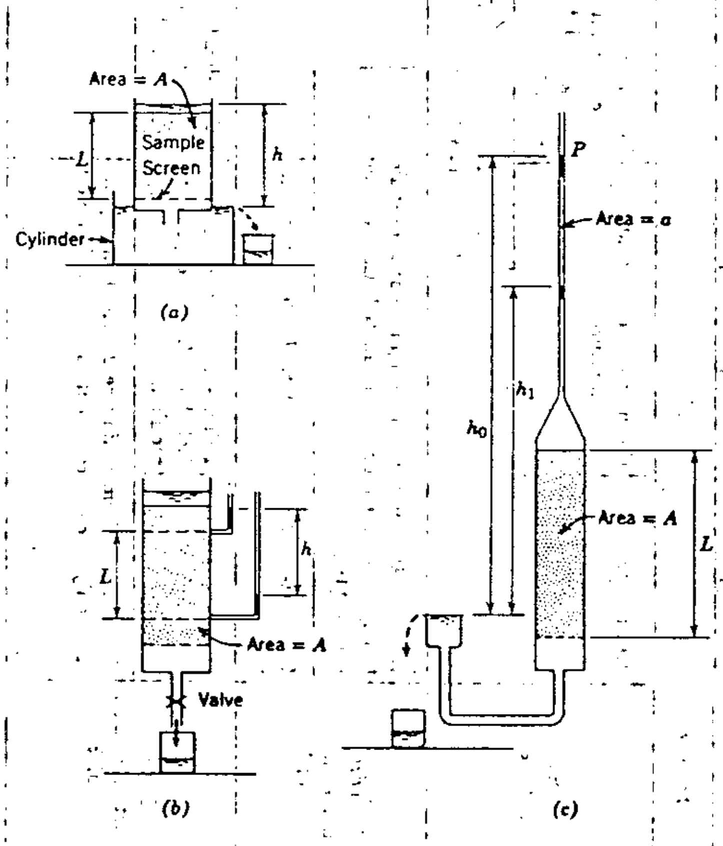


FIG. 2.12 Laboratory permeameters. (*a*) Constant head permeameter. (*b*) Constant head permeameter. The arrangement here eliminates errors due to filter skin at top or bottom of specimen. (*c*) Falling head permeameter. (Some of the above arrangements are from *Soil Mechanics in Engineering Practice*, by Terzaghi and Peck, John Wiley and Sons, New York, 1948, Fig. 14, p. 46.)

APPENDIX F

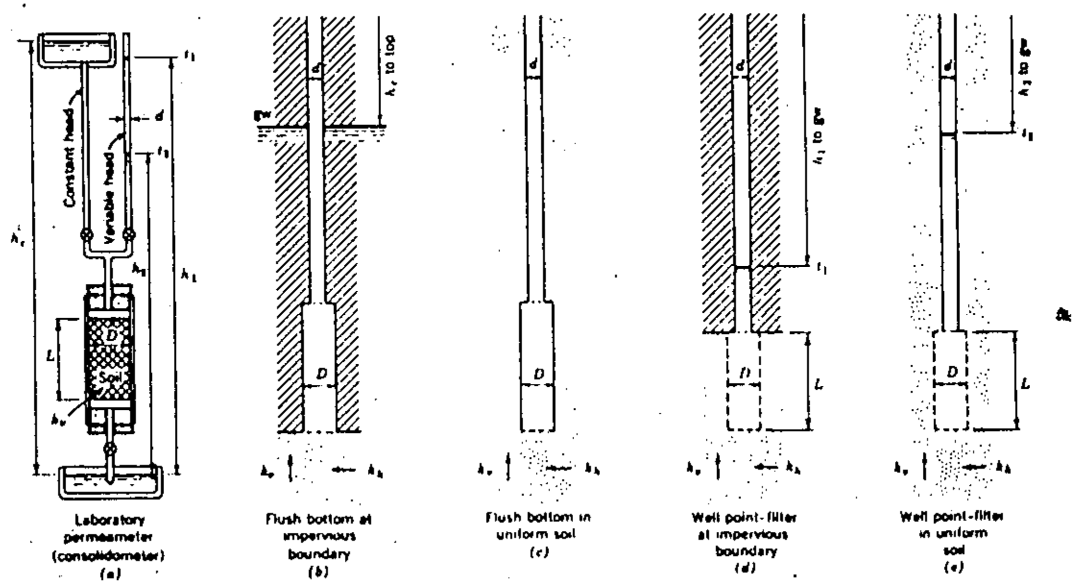
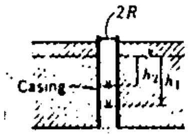
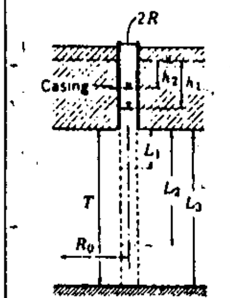
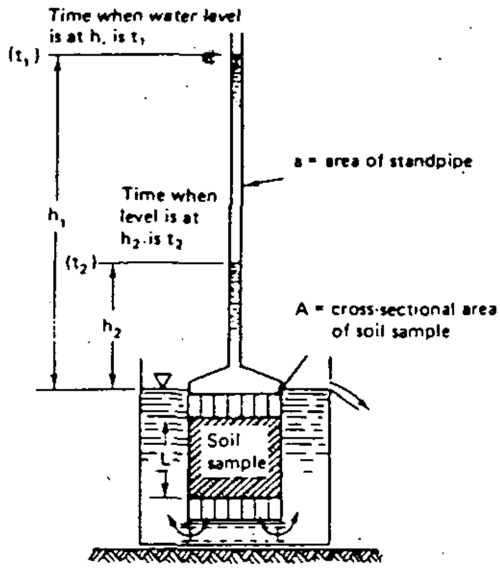


FIG. 2.19 Formulas for determination of permeability. (After Hvorslev, U.S. Corps of Engineers, W.E.S.)

TABLE 2.6 Shape Factors for Computation of Permeability from Variable Head Tests (*Continued*)

	Condition	Diagram	Shape factor, F	Permeability, k by variable head test	Applicability
Observation well or piezometer in aquifer with impervious upper layer	(*e*) Cased hole, opening flush with upper boundary of aquifer of infinite depth		$F = 4R$	$k = \frac{\pi R}{4(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right)$	Used for permeability determination when surface impervious layer is relatively thin; may yield unreliable results in falling head test with silting of bottom of hole
	(*f*) Cased hole, uncased or perforated extension into aquifer of finite thickness: (1) $\frac{L_1}{T} \leq 0.20$ (2) $0.2 < \frac{L_1}{T} < 0.85$ (3) $\frac{L_1}{T} = 1.00$ *Note.* R_e equals effective radius to source at constant head		(1) $F = C_s R$	$k = \frac{\pi R}{C_s(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right)$	Used for permeability determinations at depths greater than about 5 ft, for values of C_s see Fig. 2.16
			(2) $F = \frac{2\pi L_2}{\ln(L_2/R)}$	$k = \frac{R^2 \ln(L_2/R)}{2L_2(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right)$ for $\frac{L_2}{R} > 8$	Used for permeability determinations at greater depths and for fine grained soils using porous intake point of piezometer
			(3) $F = \frac{2\pi L_3}{\ln(R_e/R)}$	$k = \frac{R^2 \ln(R_e/R)}{2L_3(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right)$	Assume value of $\frac{R_e}{R} = 200$ for estimates unless observations wells are made to determine actual value of R_e

(From U.S. Navy Bureau of Yards and Docks.)



Falling head test: $k = \frac{L}{(t_2 - t_1)} \cdot \frac{a}{A} \cdot \ln \frac{h_1}{h_2}$

or $k = \frac{(2.303)L}{(t_2 - t_1)} \cdot \frac{a}{A} \log_{10} \frac{h_1}{h_2}$

Figure 5-8. Falling-head permeameter.

Darcy's coefficient of permeability is the factor for a condition of steady flow through a soil. In performing laboratory permeability tests it is essential that volumes be measured only after steady flow has been occurring for some period. It is important to assure that no air or other gases are trapped within the soil to interfere with flow. A vacuum may be required to remove trapped air. In general, the constant-head test is easier to perform, and requires less skill and experience than the falling-head test. Care is required during testing of fine granular soils (such as in the fine sand range) to prevent the particles from being carried along with the discharging water. Details for performing permeability tests are presented in the *ASTM Procedures for Testing Soils*.

• • • • •

Illustration 5-1: A constant-head permeability test is performed on a sample of granular soil. The test setup is as indicated in Fig. 5-7. The length of soil sample is 15 cm and the cross-sectional area is 10 cm². If a 24 cm³ volume of water passes through the soil sample in a 3-minute period, when Δh is 30 cm, compute the coefficient of permeability.

$$k = \left(\frac{Q}{t}\right)\left(\frac{L}{A\ \Delta h}\right)$$

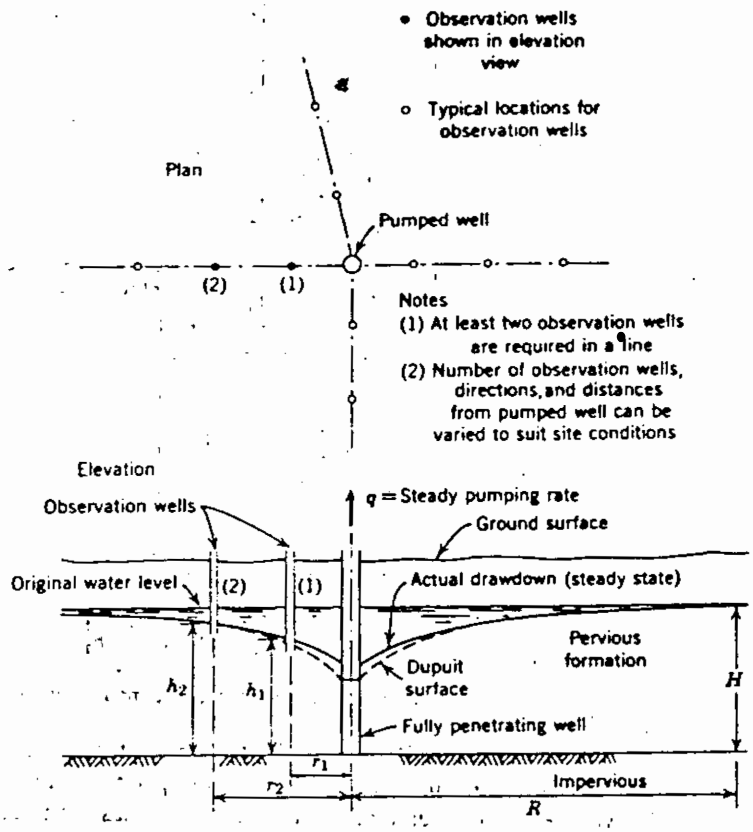


FIG. 2.13 Typical arrangements for determining soil permeability by well pumping test.

At a distance r from the well, the area A through which the water is flowing is $2\pi rh$. Applying Dupuit's assumption that $i = dh/dr$

$$q = 2k\pi rh \frac{dh}{dr}$$

80

$$\frac{q\,dr}{r} = 2k\pi h\,dh$$

and

$$q \log_e r = \frac{2\pi kh^2}{2} + 0 = \pi kh^2 + c$$