209

HIGHWAY RESEARCH BOARD

Bulletin 209

Subsurface Drainage of Highways and Airports

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Bulletin 209

Subsurface Drainage of Highways and Airports

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Preface

Subdrainage has long been recognized as a basic element of pavement design. In 1824, John Macadam wrote:

> ". . . water with alternate freeze and thaw are the evils to be guarded against and, after having secured the soil from under water, the roadmaker should then secure it from rainwater."

Lack of drainage can result in loss of base and subgrade support and contributes to pumping, deterioration of pavement materials, surface icing, frost heave, and loss of strength during thaw. Moisture changes in clay may cause detrimental volume change.

The committee prepared a bulletin on "Subsurface Drainage" (HRB Bulletin 45) which showed the variety of practices in the United States in 1951. Common principles were apparent, with many variations due to local conditions or preferences. The trend to use of filters in trench backfill was apparent.

The current bulletin presents basic principles of location, design, and construction of subsurface drainage, and illustrates their application.

Contents

Subsurface Drainage of Highways and Airports

Report of Committee on Subsurface Drainage

E. S. BARBER, Chairman

● SUBSURFACE drainage is a method of controlling the moisture content of subgrade soils and base courses for pavements by restricting the entrance of water or providing means for its escape, or in special cases, preventing excessive loss of water.

The bulletin is particularly concerned with the control of moisture below the surface of the ground or pavement in the area that will affect pavement performance. Principles are stressed rather than details which may depend on local conditions and preference. The same principles apply to drainage behind abutments and retaining walls, but such locations are not specifically considered.

Lack of subsurface drainage may result in excessive moisture beneath or adjacent to pavements which can in turn cause poor performance or failure of the pavement system. This may be evidenced by inadequate subgrade or base support, pumping of fines through cracks in or at the edge of the pavement, excessive frost heave and loss of strength upon thawing, deterioration of pavement surfacing, or surface icing in freezing weather.

Water is also a major factor in many landslides. They can often be controlled by diversion of surface water, cut-off trenches or horizontal drainage by tunnels, or more often by drilled holes. Study of landslides is a specialty which is treated in HRB Special Report 29 entitled "Landslides and Engineering Practice."

Drainage may permit placing fills over very soft soils which cannot be removed economically by excavation or displacement. Starting the fill with a permeable layer and controlling the rate of construction is sometimes sufficient. Such a layer permits water to drain upward out of the soft soil while preventing water being forced up into the fill. The required construction time can further be reduced by placing sand in vertical holes through the soft material, particularly if it is stratified. This use of sand drains is reviewed in HRB Bulletin 115. Additional consolidation may be obtained with a temporary surcharge or, for small areas, through lowering the water table by pumping from wells or wellpoints. Given sufficient time, marshy areas can sometimes be stabilized by improving surface drainage alone.

The importance of controlling subsurface water is generally appreciated; however, such control is often inadequate due to lack of design and the difficulty of predetermining conditions that show up during or after construction. Many organizations provide for completing subdrainage designs during construction. Adequate construction and maintenance records should provide a basis for newer and improved designs. Factors to be considered in subdrainage design are climate, soil, and groundwater.

CLIMATE

Climate is an important factor in drainage. While in a small area, areal variation may not be important, climatic variation seasonally and over several years should be considered.

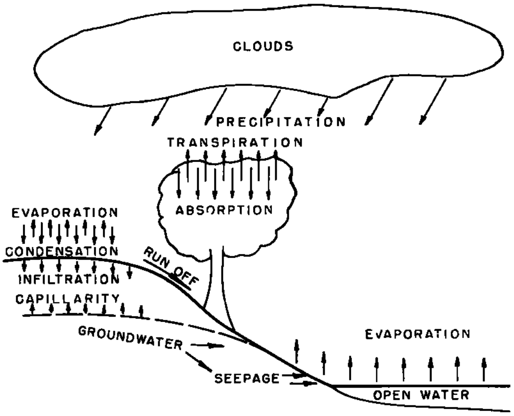


Figure 1. Hydrologic cycle.

The basic hydrologic cycle (1) is shown in Figure 1. Water from evaporation and transpiration goes into the atmosphere and returns to the surface as snow, rain, or condensation. Then it flows toward open water by runoff or thru infiltration and lateral ground water flow. At the same time, water is returning to the atmosphere by evappration from open water, from seepage areas and from the ground water through capillarity. All these factors may be involved in changing the water condition under a pavement from that built in at the time of construction.

Evaporation is increased by winds and low humidity. Pavements reduce evaporation so that soils often become wetter after paving, as evidenced by the greener growth along pavements in arid regions. Freezing generally restricts infiltration, but a snow layer thawing from below may increase the ground water supply. Frost depths depend not only on air temperature, but on exposure, insulation, and water content. Drainage is an important factor in design against frost as presented in HRB Bulletin 71, entitled "Soil Temperature and Ground Freezing."

SOIL AND GROUND WATER INVESTIGATION

Site investigation includes study of published data and aerial photographs as well as direct investigation in the field to specifically locate soil strata and ground water conditions.

Geological reports (2) provide data on ground water and on stratification which are directly concerned with infiltration and lateral seepage. Seepage generally occurs at the base of weathered rock and at the top of impervious layers overlain by relatively porous material. Detailed geologic study may indicate where drainage will be required.

Agricultural soil survey reports (3) are directly concerned with moisture conditions. Some states have correlated subsurface drainage requirements with certain groups of agricultural soils. The newer reports include a chapter on engineering properties of soils.

Aerial photographs (4) now used in making the above maps may indicate water conditions. For instance, good internal drainage is indicated by lack of surface drainage, light color tones, and orchards, while poor natural drainage is indicated by dark color, birch, and willow trees, intensive drainage pattern and agricultural drainage systems. The reduced moisture over buried tile often makes drainage system show up as if by X-ray.

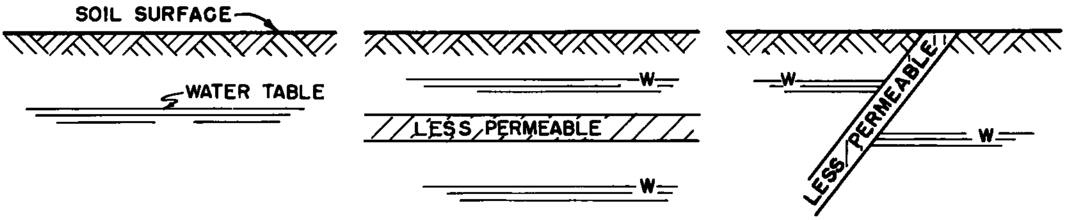
Geophysical methods of exploration are sometimes advantageous. Seismic surveys are useful in outlining rock surfaces which often control seepage. The resistivity method is more effective in locating strata of considerably different water content.

The standard soil survey as presented in AASHO Method T 86 provides a soil and water profile as a direct basis of design. It is especially important to note any seepage at the time the survey is made or wet soils and stratification which may cause seepage in wetter seasons. The ground water table should be determined plus any available information on its seasonal or long-time variation either naturally or due to construction of dams, canals or walls which may block its flow. Typical ground water conditions are shown in Figure 2. In frost zones, pockets of silt or other perched water should especially be noted.

Clays having high volume change with change in moisture content should be noted as well as appreciable amounts of soluble material since they are especially sensitive to moisture changes. Special consideration of durability of drain or pavement materials is required if the pH is not between 5 and 8 or the amount of sulfates is above 0.3 percent. Acid waters are particularly detrimental to unprotected metal while sulfates are most damaging to concrete, especially if porous.

CAPILLARITY AND PERMEABILITY

Because water normally prefers soil to air, the surface tension of water causes it to move from a region of low tension to a region of higher tension - to drier soil and to finer soil. This movement is often upward from the water table. The amount of water held at static equilibrium is shown in Figure 3. The scale to the right shows that soil will dry out in an atmosphere for which the relative humidity is not practically 100 percent. Evaporation will reduce the moisture near the surface, conversely, pavements generally cause an increase in moisture due to reduced evaporation.



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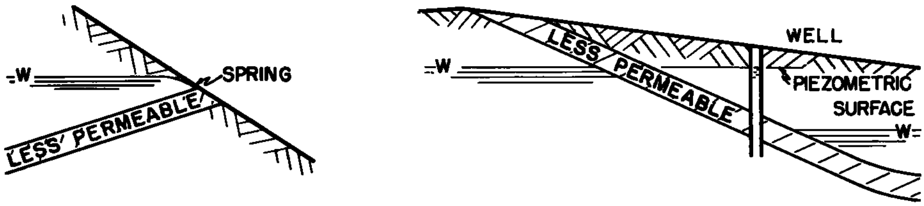

OUTCROP

ARTESIAN

Figure 2. Groundwater conditions.

In soils the rate of flow of water in quantity per unit gross area is proportional to the hydraulic gradient (difference in pressure plus elevation head divided by the flow distance between two points). The proportionality factor is called the hydraulic conductivity or permeability. The effects of type and amount of fines on permeability are shown in Figure 4 (5). These data are for materials as compacted wet but not saturat-

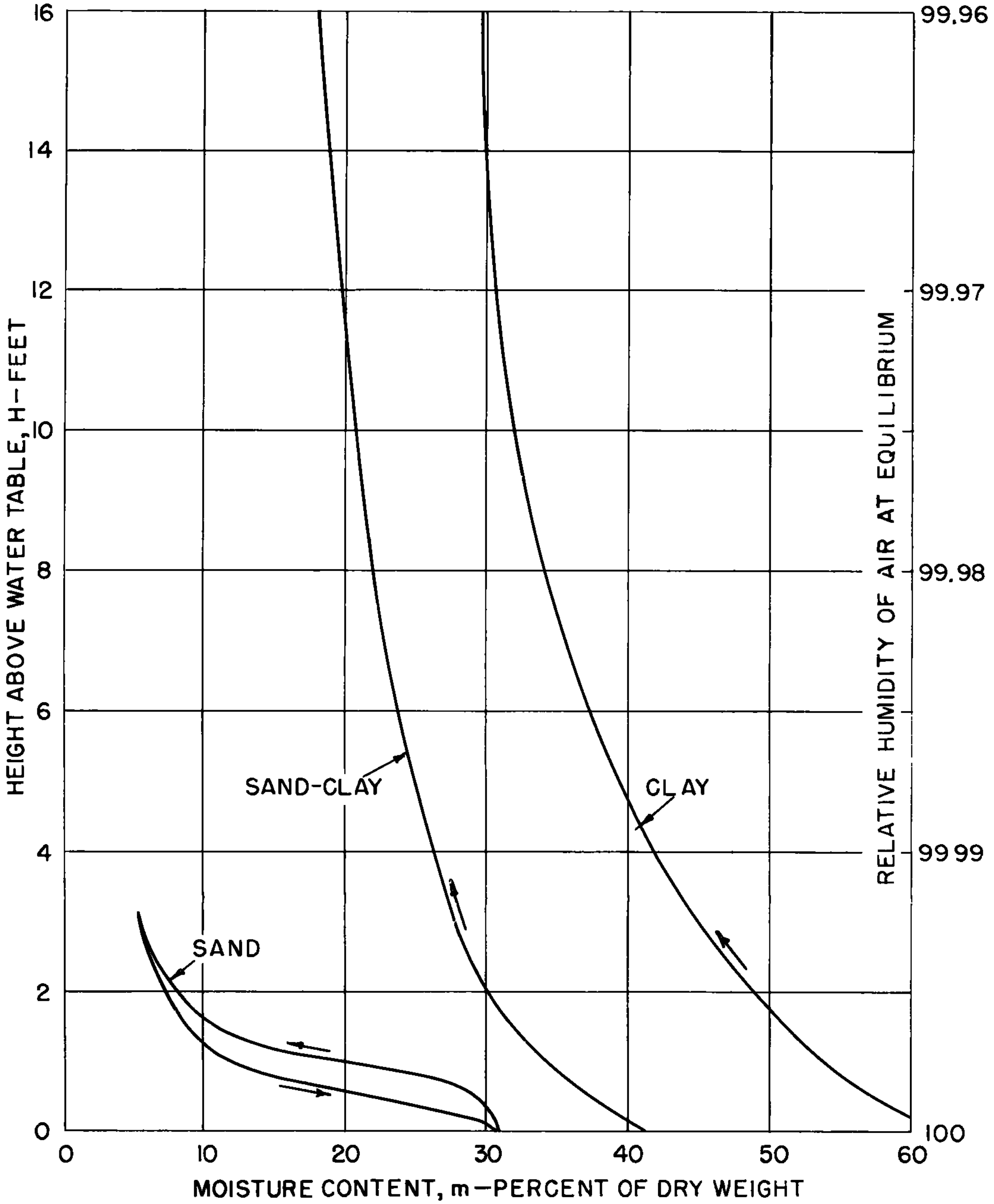

Figure 3. Moisture-height relations for various soils.

ed since they are to simulate base courses which would normally not be saturated even though water flows through them. The permeability of stratified material with these average gradations will be much higher parallel to the stratification.

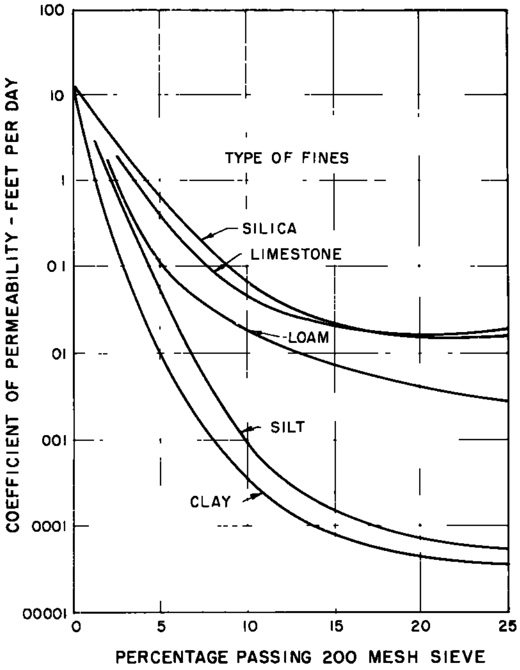

Figure 4. Effect of fines on permeability of graded aggregate.

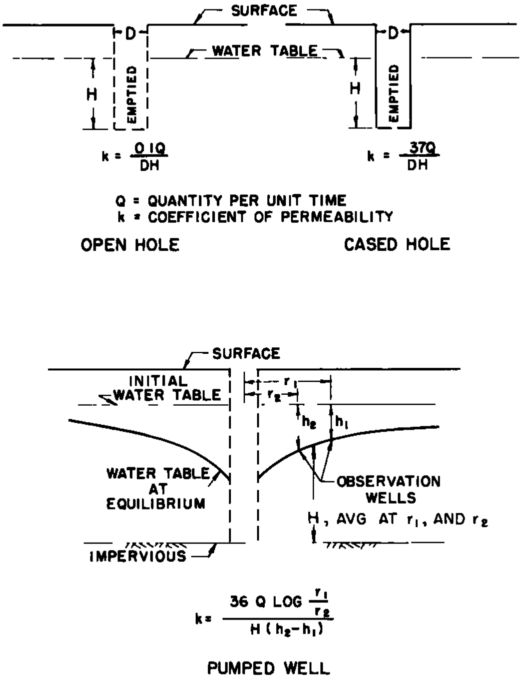

Figure 5. Determination of coefficient of permeability in field below water table.

TABLE 1

PERMEABILITY OF SIEVE FRACTIONS OF SAND

Sand fraction		Saturated capillary height	Permeability coefficient k	Average grain size D
Passing sieve No.	Retained on sieve No.	In.	Ft./day	Mm.
10	20	2.5	1,430	1.183
20	30	3.7	665	0.693
30	40	5.2	380	0.491
40	60	7.9	190	0.313
60	80	11.7	160	0.207
80	100	14.0	75	0.162
100	140	18.5	45	0.123
140	200	26.4	20	0.087
200	270	35.6	9	0.062

Capillarity and permeability may be determined by methods presented in Appendices A, B, and C. Several comparable methods are available (6). The height to which water may be raised by capillarity is inversely proportional to the diameter of the smaller soil pores while the permeability is directly proportional to the square of the pore diameter. Since the pore size is approximately proportional to the grain size, the capillary height is inversely proportional to the grain size while the permeability is proportional to the square of the grain size, as shown in Table 1 (5).

Similarly, densification greatly reduces the permeability. In well-graded materials an effective size is difficult to determine and segregation and stratification are apt to be more important than the average grain size. With its natural structure, a soil may be much more permeable than the same soil disturbed and compacted, particularly if wet or otherwise dispersed when compacted. To determine the permeability of soils in-place, undisturbed samples sealed in tubes are required; or, preferably, field permeability tests should be made as indicated in Figure 5 (5). The formulas in the upper part of Figure 5 are for initial flow into an empty hole.

ROAD LOCATION

While road alignment is often determined by factors other than soil conditions, they should be considered in preliminary location. If drainage is later found to be too expensive, relocation may be indicated. The following guides may be useful in evaluating potential drainage requirements for proposed road locations. Sloping strata may cause more seepage on one side of a hill than the other. Seepage is most prevalent at the foot of slopes. Exposures facing the equator are generally drier. High ground with moderate slope and granular material is generally most easily drained.

In irrigated areas proximity to canals and drainage should be considered. Provision should be made to correlate highway drainage with present and probable extensions of irrigation and land drainage.

Selection of grade line should consider requirements for interception of seepage and also base and subgrade drainage. Perfectly flat grades are undesirable. The grade must be high enough above natural water table to make subdrainage unnecessary, or high enough to provide an outlet for drainage structures. Flooding should be prevented.

In rock cuts undercutting is required to allow room for a drainable subbase. Selection of material in grading operations may eliminate need for subdrains. It is essential that over-wet material not be covered up during construction if less than 4 feet below pavement grade.

SURFACE DRAINAGE

While surface drainage is somewhat separate from subsurface drainage, increased runoff reduces infiltration and water standing on the surface increases infiltration. The pavement surface should be impermeable. Joints and cracks should be sealed. Concrete pavements are sometimes subsealed to control pumping. Many bituminous pavements have high permeabilities—unsealed bituminous concrete has a permeability greater than many soils. Since sealing the surface may cause slipperiness, a seal below the surface is sometimes considered. To prevent volume changes in clay soils due to drought or removal of water by trees, bituminous blankets have been placed below bases, or top layers of subgrade have been completely enveloped (7). A recent application used $1\frac{1}{2}$ gal per sq yd of 50-60 penetration, catalytically blown asphalt. Experimental work is being done on similar use of plastic sheets. Historically, a roadway in Louisiana was protected by a continuous roof.

The shoulder must be continuous with the pavement to prevent runoff from the pavement being diverted to the subgrade through a crack between the pavement and shoulder. Where curbs are used, it is especially important that joints be sealed. Shoulders should be sloped to provide rapid runoff, and maintained so as to prevent water from ponding in ruts and depressions adjacent to the pavement. Grassed shoulders should be below the pavement to insure runoff. Capillarity can carry water under the pavement from wet shoulders. It is particularly important to prevent entrance of water into relatively impervious soils since it is very difficult to remove water from them.

Because of greater solar heat absorption, bituminous shoulders may have the added advantage of promoting thawing to prevent melt water being trapped under the pavement.

In arid regions shoulders and backslopes are sometimes oiled in lieu of providing ditches.

Side roads should be designed to prevent surface drainage from spreading water and soil on the pavement.

Ditches required for surface drainage should be designed and maintained to prevent standing water. If deep enough they may control lateral seepage or lower the water table beneath the pavement. Figure 6 shows a typical section with ditch drainage. Nearly flat slopes are required for safety to traffic.

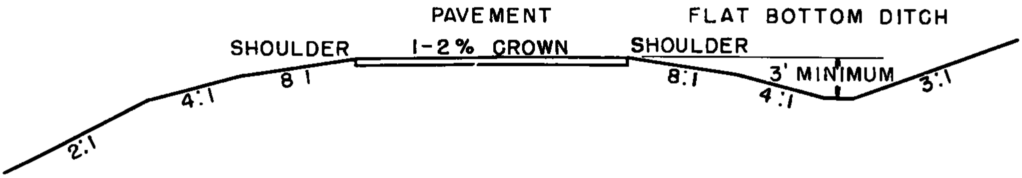

Figure 6. Typical section with ditch drainage.

SUBSURFACE DRAINS

The required depth of the water table and the capillary fringe above it depends on the amount of frost heaving permissible and on the strength of subgrade used in pavement thickness design. It would generally be adequate to keep the water table below both the bottom of the base and the maximum frost penetration by a distance of 4 feet (or by the saturated capillary height of the material below the base if the latter is less than 4 feet). Capillarity may be stopped by an impervious membrane, or its height reduced by a granular subbase. Granular material below a fine soil may reduce the velocity of capillary rise but will not reduce the moisture which the fine soil could hold at a given height above the water table.

Subsurface drainage of roadways may be effected by an underdrain - a pipe placed in a trench near the pavement, surrounded with pervious backfill and leading to an unobstructed outlet - or by a ditch at a greater distance from the pavement to which the pervious base or subbase is extended. The underdrain is more costly than the ditch and, therefore, is much less used in practice, but the underdrain is generally more effective and is less hazardous to traffic than the ditch.

The three chief functions of subsurface drainage are (a) interception of ground water flowing toward the pavement, as in a cut slope; (b) lowering of a high water table under the pavement; and (c) drainage of pervious base and subbase courses. Often a subsurface drain performs two or all three of these functions.

INTERCEPTION DRAINS

If the water table is supplied by surface or subsurface flow from a specific direction, it may be possible to intercept the flow before it reaches the road bed. If the source of infiltration to the ground water is known, it may be possible to eliminate the seepage by surface interception—for example, by draining ponds, sealing canals, and diverting streams. Otherwise, seepage may be intercepted below the surface by an underdrain between the ditch and the pavement, as shown in Figure 7. If the ditch is paved, the drain should be below the ditch to protect its paving. An interceptor should be in relatively impervious material below the water-bearing material or aquifer. In rock excavation special care is required to prevent flow from bypassing beneath the drain. If the gradeline intersects the seepage zone, as often happens at the end of cuts, a drain across the pavement area may be required to intercept the water before it reaches the base. A U-shaped plan may minimize drainage cost. For very thick aquifers, a blanket drain may be indicated, that is, an extra-thick permeable subbase.

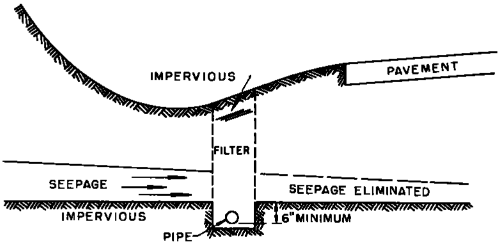

Figure 7. Intercepting lateral seepage.

WATER TABLE DRAINS

If the source of water is not apparent or is too deep to intercept, it may be possible to provide a subdrain which will lower the water table generally. This is especially true for small pockets of perched water which may be eliminated by a drain from the lowest point, possibly supplemented by a drain on each side (8).

It is occasionally possible to drain perched water by simply penetrating the impervious layer which supports it. Finally, underdrains on each side of the pavement can be used to lower the water table locally, as shown in Figure 8 (9). Provision for an outlet for the drains must be considered in the original location. In level terrain an outlet may be excessively long. If the drains reach an impervious layer, the water table between them will remain above the bottom of the drain pipe by a height, h, depending upon the spacing between the drain lines, a, the average rate of infiltration between the drains, q, and the coefficient of permeability of the soil, k. Thus, $h = \frac{a}{2}\sqrt{q/k}$. With a film of water on the surface of the soil, the rate of infiltration equals the permeability. Sometimes an underdrain on one side only may be sufficient to lower the water to an acceptable level.

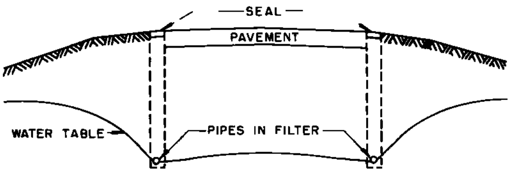

Figure 8. Underdrains to lower water table.

If the water comes up from an artesian aquifer, the excess head can be eliminated by a drain in the aquifer if a drain of sufficient capacity can be installed. If the artesian pressure is in a blind seam, the pressure may reduce considerably with time of drainage. Where the artesian condition is near the surface, a blanket drain over the confining layer is indicated. For a permanent artesian head, h, above the bottom of a thick cover, drains a depth, d, below the piezometric level, spaced, a, apart, will lower the piezometric surface (10) approximately $d(1 + a^2/h^2)$.

In limestone areas drains are sometimes required below fills to allow egress of intermittent flow from sinkholes.

DRAINAGE OF GRANULAR BASES

Where pavement surfaces are not consistently impermeable, granular base courses should be designed to drain water away from the bottom of the surfacing and be stable even though wet. To provide edge support, the base should extend at least 1 to 2 feet beyond the pavement surface edge with the top beyond the pavement surface edge sealed to prevent excessive infiltration. In humid regions a base without drains will become saturated unless the subgrade has a greater infiltration capacity than the surfacing or than the base. Many pavements have a permeability greater than 0.1 ft per day. However, a well-compacted, dense-graded base, if not disrupted by frost, may have low enough permeability to restrict infiltration and a low enough water capacity to be stable without drainage if the fines and plasticity are sufficiently restricted.

Unless the subgrade is quite permeable, it is good engineering practice to provide drainage for the base course. This may be done by either extending the base through the shoulders or by providing edge drains. Drainage by either method is preferably continuous rather than intermittent as sometimes specified.

Figure 9 shows the rate of drainage into a longitudinal drain of a flooded base course on an impervious soil with no inflow (5). It may become flooded by inundation, rapid infiltration or thawing from the surface. If frost penetrates a wet subgrade, it may become impervious (even though otherwise permeable) at a time when drainage is needed to remove melt water from the base. As shown in Table 2, observed values of specific field yield in graded materials are quite low (5). The specific yield is the quantity of water per unit volume not retained by capillarity during drainage.

For steady seepage the maximum rate of infiltration is $\frac{k\,H}{D}(s + H/2D)$.

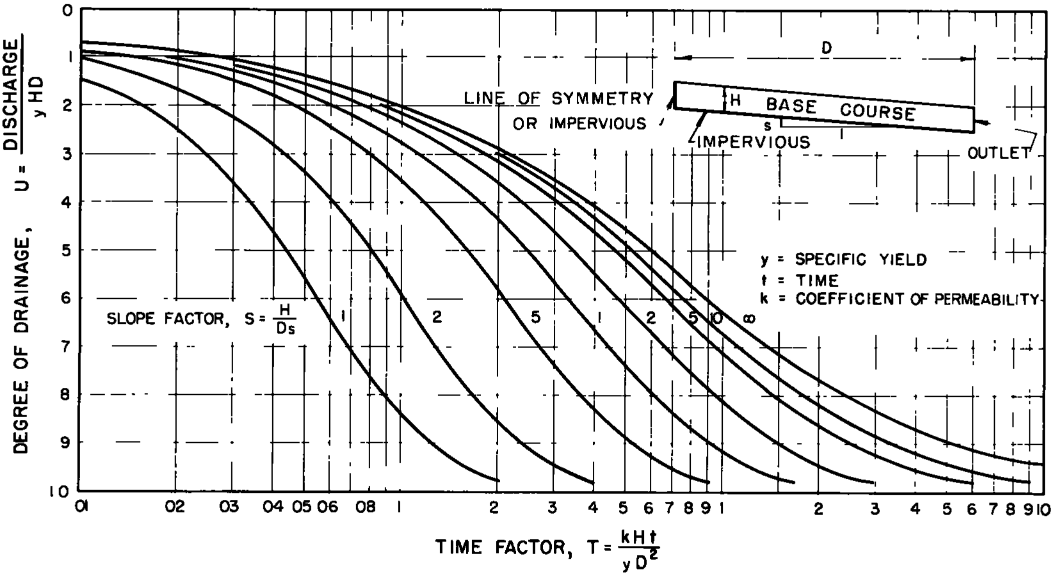

Figure 9. Rate of drainage of flooded base course.

TABLE 2

MOISTURE RETAINED AFTER DRAINAGE OF SUBMERGED COLUMNS OF SOIL

	Material passing No. 200 sieve added to sand graded from No. 10 to No. 200 sieve									
	Silica		Limestone		Marion loam		Keyport silt loam		Tuxedo clay	
	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
Dry density, lb/cu ft	123	127	123	129	123.5	127.5	125.5	131.5	126.0	131.5
Calculated moisture content, saturation, percent	13.4	11.9	13.4	11.1	13.2	11.6	12 5	10.2	12.3	10.2
Moisture before drainage, percent	9.2	9.0	10.1	9.2	10.0	9.9	9.8	8.1	9.6	9.4
Moisture at following heights after drainage, percent[a]:										
46 in.	3.9	6.1	5.1	5.6	5 6	7.7	6.2	6.4	9.5	8.7
44 in.	3.9	6.2	5.2	6.0	5.6	7.8	6.2	6.4	9 0	8.0
42 in.	4.1	6.0	5.2	5.8	5.7	7.9	6.6	6.4	8.6	9.0
40 in.	4.2	6.4	5.4	5.9	6.0	8.2	6.7	6.8	8.7	8.7
38 in.	4.4	6.4	5.6	6.7	6.1	8.0	6.9	6.7	8.7	8.6
36 in.	4.4	6.6	5.4	6.0	6.3	8.6	7.0	6.9	8.5	8.1
34 in.	4.6	6.7	5.4	6.7	6.5	9.2	7.0	7.0	8.8	8.0
32 in.	4.8	6.8	5.6	6.0	6.6	9.5	7.0	7.1	9.0	8.3
30 in.	5 3	6.7	5.5	6.0	7.0	9.9	7.1	7.7	9 1	8.6
28 in.	5.4	6.9	5.7	6.6	7.1	9.8	7.2	8.2	9.3	8.2
26 in.	5.9	7.1	5.7	6.0	7.4	9.9	7.0	9.0	8.4	9.4
24 in.	6.1	7.3	5.8	6.0	7.6	10 1	7.4	9.0	8.6	9.5
22 in.	6.5	7.6	6.0	6.1	7.7	9.7	7.7	9.0	8.2	9.8
20 in.	7.1	8.0	6.0	6.6	7.8	9.7	8.1	8.9	8.8	9.3
18 in.	7.8	7.9	6.1	6.1	8.2	10.0	8.1	8.8	8.8	10.0
16 in.	8.2	8.2	6.2	7.6	8.6	9.7	8.1	8.7	8.6	9.8
14 in.	8.3	7.7	6.3	7.1	9.1	9.3	8.5	8.4	8.5	9.9
12 in.	8.1	7.9	6.5	7.1	9.0	8.6	9.0	8.4	8.8	10.0
10 in.	8.1	7.8	7.2	7.1	6.8	8.6	8.8	8.1	8.9	10.6
8 in.	7.9	8.0	7.2	6.7	8.9	8.6	8.9	8.0	9.0	9.8
6 in.	8.2	8.2	7.8	7.0	9.2	8.5	9 2	7.4	9.0	10.0
4 in.	8.5	8.8	8.5	7.3	9.9	9.1	8.6	7.4	9.2	8.9
2 in.	9.1	9.2	9.5	8.2	10.1	9 7	8.8	8.4	9.5	9.1
½ in.	11.0	11.2	11.3	11.0	11.6	11.1	9 9	11.1	10.3	11.3
Average moisture after drainage for 10 days, percent	6.4	7.4	6.5	7.1	7.7	9.1	7.7	7.6	8.9	9.4
Specific yield										
Observed	.055	.033	.071	.043	.057	.016	.042	.006	.014	.000
From saturation to drained moisture	.138	.092	.136	.083	.109	.051	.096	.051	.069	.017

[a] Center of 2-in. increments except bottom inch.

TABLE 3

TIME REQUIRED FOR LATERAL DRAINAGE OF 50 PERCENT OF DRAINABLE WATER FOR SATURATED BASE COURSE ON IMPERVIOUS SUBGRADE

Base course geometry	Time required for drainage with following material added to sand graded from No. 10 to No. 200 sieves									
	Silica dust		Limestone dust		Manor loam		Keyport silt loam		Tuxedo loam	
	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
1 % slope, 6-in. thickness, and width of										
5 ft	4	16	5	24	3	16	16	69	8	6
10 ft	12	54	16	81	11	54	54	230	25	20
15 ft	25	112	35	130	23	108	108	460	49	41
20 ft	42	185	56	215	38	178	180	760	80	67
25 ft	60	270	82	300	55	255	255	1,090	117	97
30 ft	82	370	114	415	76	345	345	1,475	160	130
1 % slope, 12-in. thickness, and width of										
5 ft	2	9	3	10	2	8	8	36	4	3
10 ft	8	37	11	40	8	32	32	140	15	12
15 ft	16	78	24	84	16	67	68	290	32	26
20 ft	26	126	39	135	26	108	109	460	53	41
25 ft	39	190	57	200	37	160	160	675	80	60
30 ft	53	260	80	275	52	215	220	920	110	82
2 % slope, 6-in. thickness, and width of										
5 ft	3	13	4	15	3	14	13	58	6	5
10 ft	10	45	14	52	9	45	44	190	20	17
15 ft	20	94	28	103	20	86	86	370	40	33
20 ft	32	150	45	165	30	135	135	575	63	51
25 ft	45	205	63	225	42	185	185	785	88	70
30 ft	61	270	84	300	55	240	240	1,015	115	90
2 % slope, 12-in. thickness, and width of										
5 ft	2	9	3	10	2	8	8	36	4	3
10 ft	6	31	10	34	6	27	27	115	14	10
15 ft	13	65	20	68	13	54	56	230	27	20
20 ft	22	107	33	114	22	89	93	380	46	34
25 ft	32	155	49	165	31	130	135	545	66	48
30 ft	44	210	70	230	42	175	185	740	90	65

TABLE 4

PERMEABILITY OF OPEN BASES

Percent passing	Material No.								
	1	2	3	4	5	6	7	8	9
1½-in. sieve									100
1-in. sieve									0
3/4-in. sieve	100	100	100	100	100	100			
1/2-in. sieve	85	84	83	82	80	75		100	
3/8-in. sieve	78	76	74	72	70	63		0	
No. 4 sieve	56	56	52	49	44	32	100		
No. 10 sieve	39	35	30	25	17	0	2		
No. 20 sieve	26	22	16	10	0				
No. 40 sieve	18	13	6	0			0		
No. 60 sieve	13	8	0						
No. 140 sieve	5	0							
No. 200 sieve	0								
Dry density, lb/cu ft	121	117	115	111	104	101	102	101	104
Coefficient of permeability, ft per day	10	110	320	1,000	2,600	3,000	7,800	82,000	106,000

When H is small compared to D, the permeability of the base must be many times greater than that of the surface in order to provide adequate drainage capacity. To keep the surface drained where long longitudinal slopes are much steeper than the cross-slope, underdrains across the pavement under the base may be required. They are often placed at each pavement joint or with a maximum spacing of 80 ft. Such drains are generally required in sags.

Table 3 calculated from Figure 9 shows the effect of permeability, slope, thickness, and width on the time required for 50 percent of the drainable water to escape laterally from a saturated base course (5). Comparison with the 10 days' maximum time sometimes specified shows that for ordinary dimensions of base courses less than 5 percent passing a 200-mesh sieve may be required in the base course material to satisfy this particular criterion of drainage. Some materials with such a limited amount of fines are difficult to densify by rolling and are hard to keep in place. Crushed stone has been used successfully. The use of a base course with enough fines to prevent most of the pore water from draining may be justified if drainage is sufficient to prevent positive water pressure. There is evidence of loss of base course strength due to water pressures caused by rising temperatures where drainage is inadequate.

For appreciable drainage of water in a base course over an impervious subgrade, very open bases are required. Typical permeabilities are presented in Table 4. To prevent infiltration of fine soils into open bases, a filter layer must be placed between them.

To reduce the required width of base course and to insure an outlet, underdrains along the edge of the pavement may be specified. In frost areas it is often difficult to maintain drainage through shoulders even if all snow is removed in thawing periods. For base drainage alone, underdrains should be at least 12 in. below the base. Underdrains for lowering the water table may also serve as base underdrains.

OTHER METHODS

Control of water is involved in various methods of restricting the void space in materials by selection of gradation, compaction, binders or grouting. The achievement of increased density by means of improved gradation is common to all paving materials. The practice of compaction by rolling, tamping and vibration is presented in HRB Bulletin 58-R, (in preparation, 1959), entitled "Compaction of Embankments, Subgrades and Bases."

Special methods of controlling void space include compaction by piles, silt injection and vacuum in sealed wells or under surface covers. Voids may be partially or completely closed by grouting methods; materials such as cement slurry, liquid bitumens, chemical solutions, and sometimes clay slurry may be injected into porous soils and fissured clay or rock. Water may also be controlled by freezing; this method is generally temporary but may be permanent in permafrost areas.

The tendency for water to flow with a direct electric current, electro-osmosis, has been used to control water in excavations but has not yet been found practical for roadway drainage.

The variation of capillary retention with temperature is enough to retard drainage after a cold rain and promote drainage during warm, fair weather. While heat from electric cables or hot water pipes is sometimes used to prevent surface icing, it is too expensive for general use in drainage. In the subarctic, steam jetting is used to clean drainage inlets and culverts of icing.

Ventilation through porous bases or drain pipes, particularly if open at both ends, may aid drying; however, it may also increase front penetration.

ECONOMICS

Economic choice of drainage methods depends upon current prices and local conditions. Typical choices are whether to provide base course drainage or whether a deep base is preferable to raising the grade. Where subdrainage is needed, quite considerable construction costs are warranted to protect investment in pavement and to reduce maintenance costs. Secondary roads may not always warrant as adequate drainage as primary roads; however, consideration should be given to possible future increases in traffic when planning the drainage for secondary roads.

UNDERDRAIN CONSTRUCTION

Figure 10 shows details of an underdrain. Minimum distance from pavement edge depends on method of excavation and ability of sides of ditch to stand. A distance between the pavement and the edge of the ditch of one-third the depth is sometimes specified; a trenching machine may permit closer construction.

If the trench bottom is extra soft, gravel or stone or concrete sand may be tamped into fine soils. Local materials, such as crushed oyster shell may also be used. In extreme cases wooden runners may be used to keep pipe aligned. For rock or noncohesive materials 4 in. of filter material should be placed below the pipe. Some recommend filter material under drains in all soil or rock types while others prefer a bedding of the adjacent soil if it is firm.

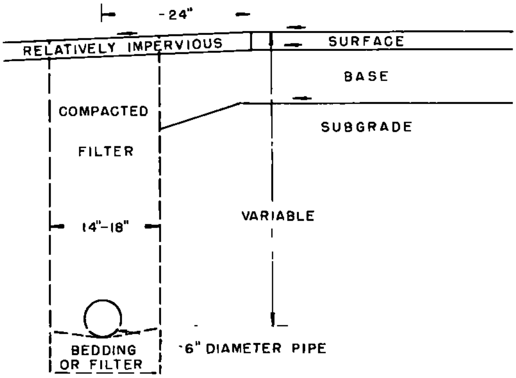

Figure 10. Typical underdrain detail.

The filter material should have greater permeability than the soil to be protected but must be fine enough to prevent the soil washing into or through it. The following specifications (11) provide this:

$$\frac{\text{15 percent size of filter material}}{\text{15 percent size of protected soil}} \geqq 5 \text{ for permeability}$$

$$\frac{\text{15 percent size of filter material}}{\text{85 percent size of protected soil}} \leqq 5 \text{ to prevent intrusion}$$

$$\frac{\text{50 percent size of filter material}}{\text{50 percent size of protected soil}} \leqq 25 \text{ to provide similar gradations}$$

$$\frac{\text{85 percent size of filter material}}{\text{diameter of hole in pipe}} \geqq 1.0$$

$$\frac{\text{85 percent size of filter material}}{\text{width of slot between pipes}} \geqq 1.2$$

In stratified material "the protected soil" is the finer-grained water-bearing material. Within the frost zone, filters should be investigated with respect to frost susceptibility.

To limit segregation the filter material should not be skip-graded; it should have a uniformity coefficient less than 20 and should be placed damp. The backfill should be compacted while being careful not to damage the pipe. Sand for concrete aggregate will provide filter protection for practically all fine-grained soils.

The pipe is preferably placed without open joints and perforated with $\frac{1}{4}$-in. diameter holes on each side 30 deg below the horizontal. If the pipe will be used to carry water discharged from construction operations and there is danger of soil in such water being deposited at the perforations, it is prudent to place the holes up. A thin cover of fine gravel or crushed stone is then desirable over the holes to prevent sand backfill from entering them (12).

Pipe with open joints may require an extra layer of coarse filter material around the joints or a filter composed of a mixture of sand and stone. A continuous envelope of gravel may be placed with slip forms. Burlap or tar paper do not provide permanent protection for open pipe joints.

The minimum size pipe is generally 6 in. in diameter with a slope preferably not less than 0.5 percent. From Manning's formula, this will carry a flow of 0.2 cu ft per sec. Using $q = 2kh$ from Figure 11, a 6-in. pipe is adequate for 500 ft of drain if h is 6 ft and k is as high as 3 ft per day. Larger pipe is seldom required.

The pipe should be impermeable where not collecting water and near the outlet. The outlet should be clear with a small headwall or 2-ft projection and screened to prevent entrance of animals.

In exceptional cases drains may be used to collect surface water and subsurface water combined; any openings in the pipe to admit water should be near the top of the pipe. A subdrain discharging into a storm drain should enter at the top of the storm drain to prevent backwater from flooding the subdrain; and the storm drain should have generous capacity, provision for cleaning, and a hinged screen.

Drains should generally be installed before placing subbases or bases. To keep pipe and backfill clean, backfill should be placed over pipes and covered as soon as practicable. Surface water should be kept out of subdrains.

Drainage outlets should be marked for ready location in the field by maintenance forces. "As constructed" plans of subdrainage should be provided.

UNDERDRAIN FAILURES

Failures of drainage have resulted from pipe being broken or misaligned during construction and from silting of backfill which was too coarse. too often subdrains are too shallow. Outlets have been blocked

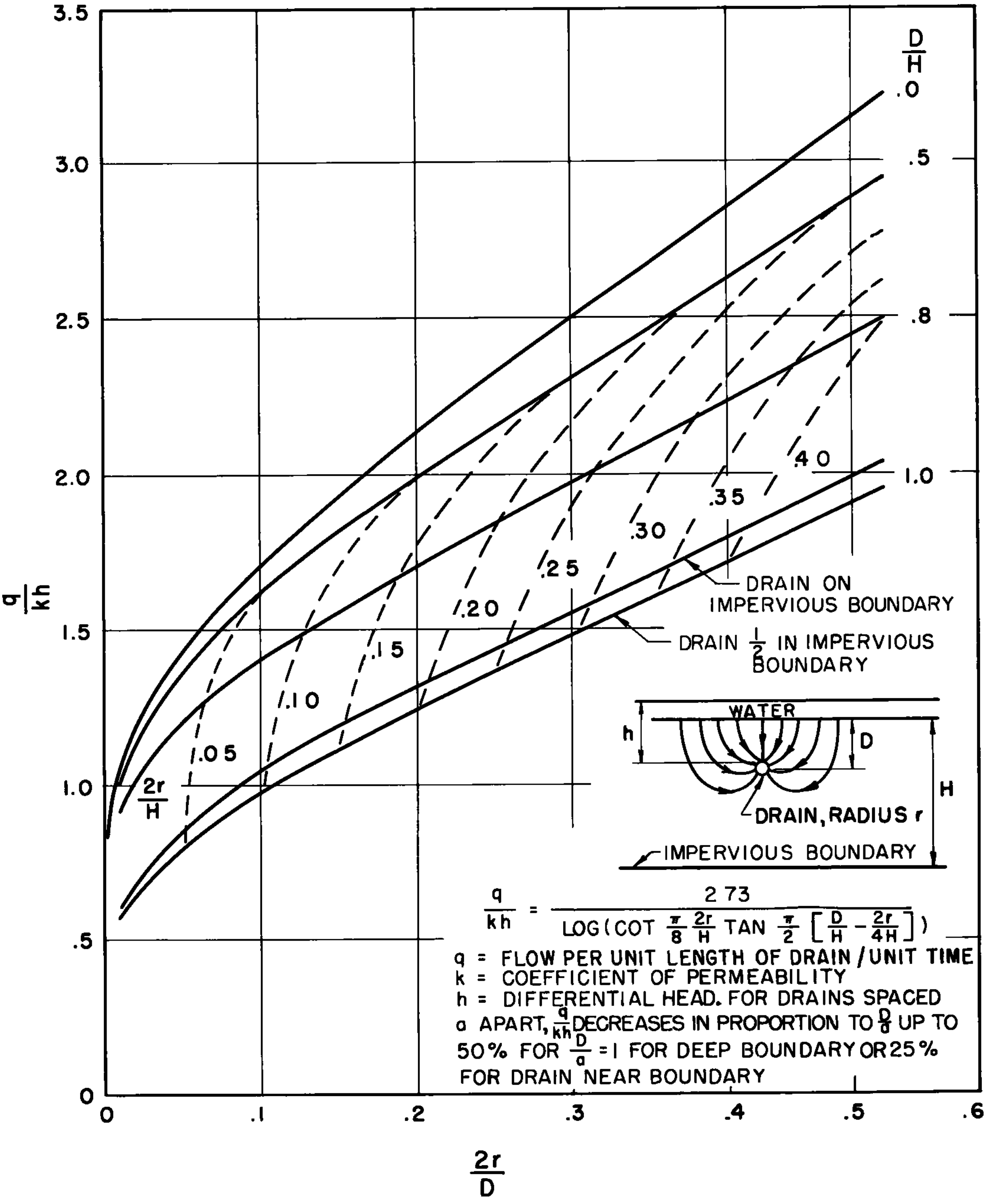

Figure 11. Flow into buried horizontal drain from flooded surface.

by weeds and surface wash or broken by maintenance equipment. Occasionally tree roots have blocked drains. Underdrain pipes and backfill have been clogged during construction by heavy rainfall washing down soil from cut slopes (12).

The aim should be to construct an underdrain rather than simply bury a pipe.

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APPENDIX A

Method of Test for Determining Saturated Capillary Height of Soil

SCOPE

1. This method covers the determination of saturated capillary height of soil.

APPARATUS

2. The apparatus shall consist of the following:

(a) Glass filter tube - a glass filter tube similar to that shown in Figure 1.

(b) Perforated support - a perforated support fitted to the shoulders of the filter tube.

(c) Glass tubes - 2 glass tubes the same diameter as the lower part of the glass filter tube and at least 41 in. long.

(d) Flask - the two glass tubes are joined above a stopcock which leads into a flask supplied with a pressure bulb.

(e) Sieves - a series of sieve disks to fit the filter tube. The sieve openings to be never much smaller than necessary to retain the particles to be tested.

PROCEDURE

3. (a) The apparatus is assembled as shown in Figure 12. Powdered soil is poured without tamping into the filter tube to a height of 4 cm

(1.57 in.). Next, water is admitted to both tubes until the apparatus is filled to a level skightly above the top of the soil.

(b) After 5 minutes' inundation, the level of the water in the right tube is lowered level with the bottom of the cork disk. The excess water is allowed to drain from the soil. Then the elevation of the water in the right tube is lowered by 2-in. increments with a 5-min pause for additional drainage of the sample between each increment.

(c) The distance in inches between the top of the water in the right tube and the bottom of the soil when the water column in the filter tube breaks is reported as the capillary rise.

Note: Measurable heights may be increased by applying air pressure above the soil. To determine retained moisture, heights greater than the saturated height can be applied by using unglazed porcelain sealed in place of the sieve disk.

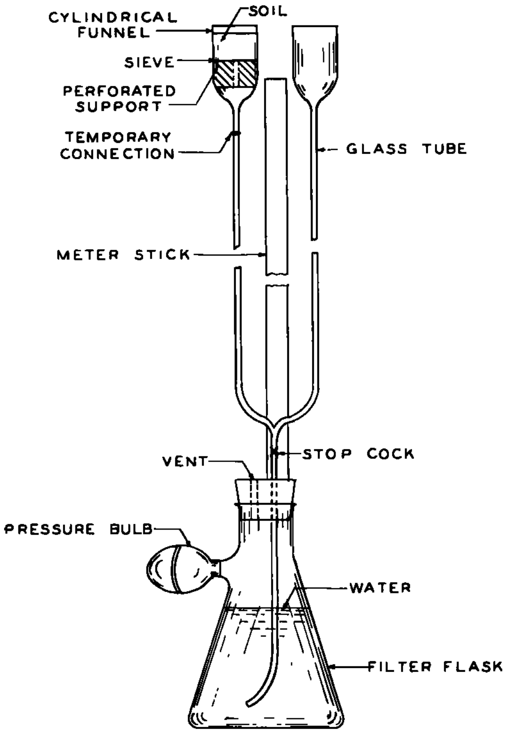

Figure 12. Apparatus for capillarity test.

APPENDIX B

Suggested Method of Test for the Coefficient of Permeability of Soils with Values Less than One Foot per Day

SCOPE

1. This method of test determines the coefficient of permeability of soils having values less than one foot per day by means of a falling head permeameter.

APPARATUS

2. The apparatus consists of:

(a) Permeameter Ring. - A cylindrical metal ring fitted with a perforated piston, piston guide, and tube outlets from the channeled base. The piston and the base are fitted tightly with medium porous stone disks (see Figs. 13 and 14).

(b) Water Supply Apparatus. - A flask for water supply at room temperature is fitted with pressure bulb, two-hole rubber stopper, stopcock, and connections to one tube of the permeameter ring as shown in Figures 13 and 14.

(c) Transparent Standpipes. - A standpipe is connected to one tube of the permeameter ring as shown in Figures 13 and 14. Standpipes of various diameters are available so that during the test the rate of

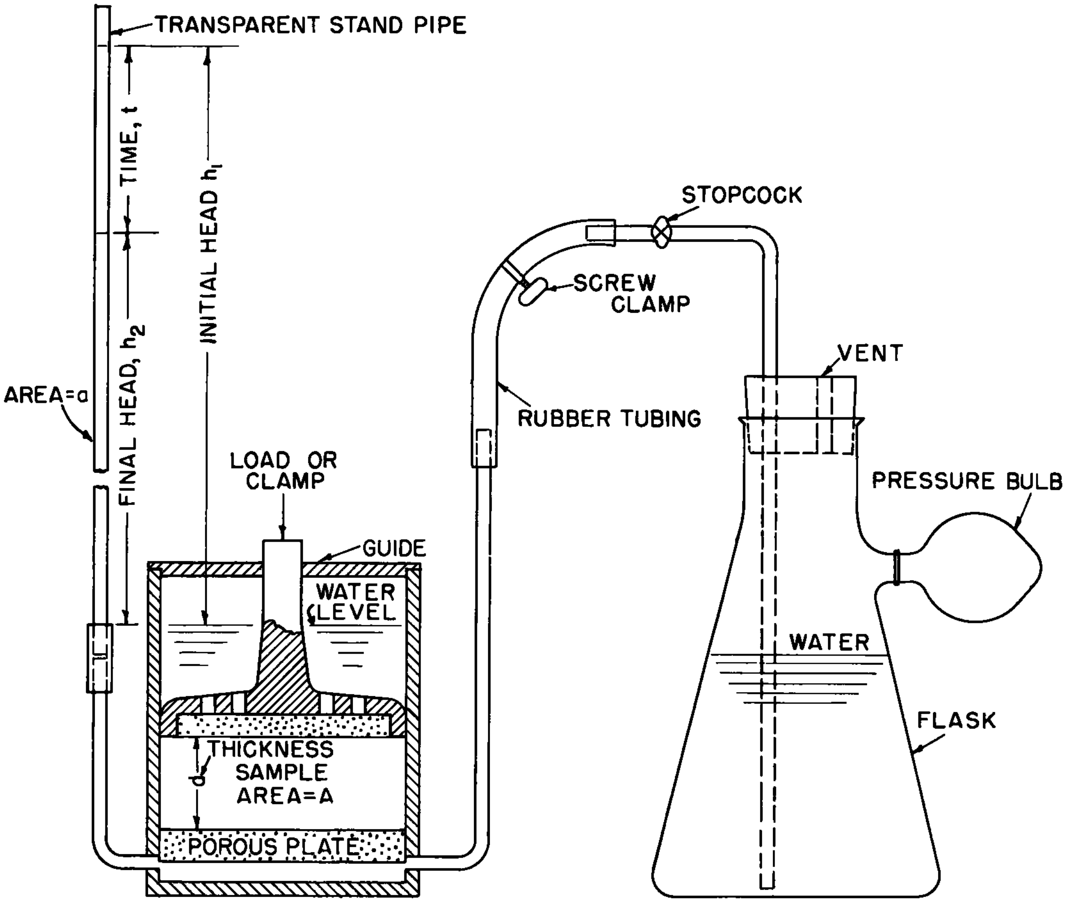

Figure 13. Apparatus for measuring permeability by means of a falling head.

fall of the water level is not more than one centimeter per second.

(d) Thickness Control Devices. - A loading device, clamp, and support for controlling thickness or density of the sample (see Fig. 14).

(e) Dial Gage. - A dial gage reading to 0.001 of an inch, and a dial support.

(f) Blank. - A metal blank having a height equal to that of the sample.

(g) Balance. - A balance sensitive to 0.1 percent of the weight of samples.

(h) Oven. - A thermostatically controlled drying oven capable of maintaining a temperature of 110 C (230 F).

(i) Miscellaneous Apparatus. - A metric scale, thermometer, and stop watch (Fig. 14).

PREPARATION

3. Calibrate the dial gage by taking readings on the metal blank in place of the soil sample. Prepare a sample by Method of Preparing Soil Samples for Structural Tests and place it in the ring. Assemble the de-

vice, load as desired and clamp the beam to maintain a constant thickness.

PROCEDURE

4. After flushing the base by pumping water from the flask, maintain a head in the standpipe until water appears around the perforated piston. Add water at room temperature until the ring is full. Raise the head of water in the standpipe to h_1, close the stopcock, and record the time required for the water to drop to h_2 (see Fig. 13).

CALCULATIONS

5. (a) Calculate the coefficient of permeability, k, in ft per day as

$$k = \frac{276\ ad}{At} \log \frac{h_1}{h_2}$$

where

a = area of standpipe
d = thickness of sample in inches
A = area of sample, in same units as "a"
t = time necessary for the head of water to drop from h_1 to h_2 in min.

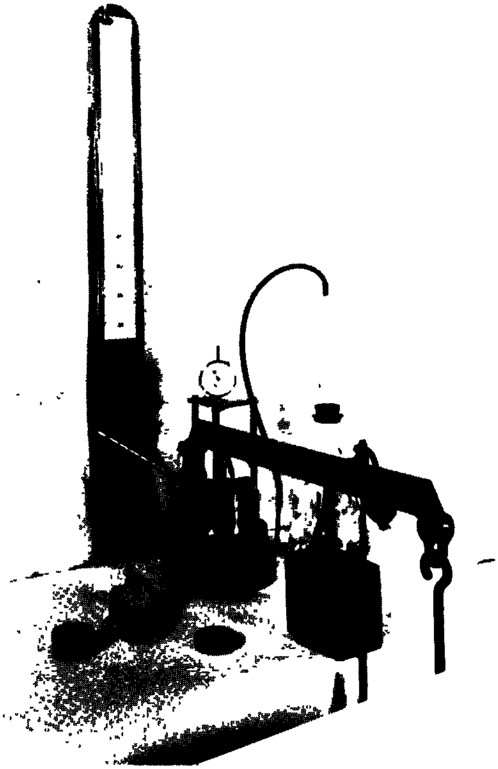

Figure 14. Permeability apparatus, falling head method.

REPORT

6. Report initial conditions and preparation method, loading, temperature, and coefficient of permeability.

APPENDIX C

Suggested Method of Test for the Coefficient of Permeability of Soils with Values Greater than One Foot per Day

SCOPE

1. This method of test determines the coefficient of permeability of compacted soils having values greater than one foot per day by means of variable head permeameter.

APPARATUS

2. The apparatus consists of:

(a) Permeameter Mold. - A cylindrical mold, in which the sample is supported on wire screens, rests in a tank equipped with an outlet valve and a hook gage (see Fig. 15).

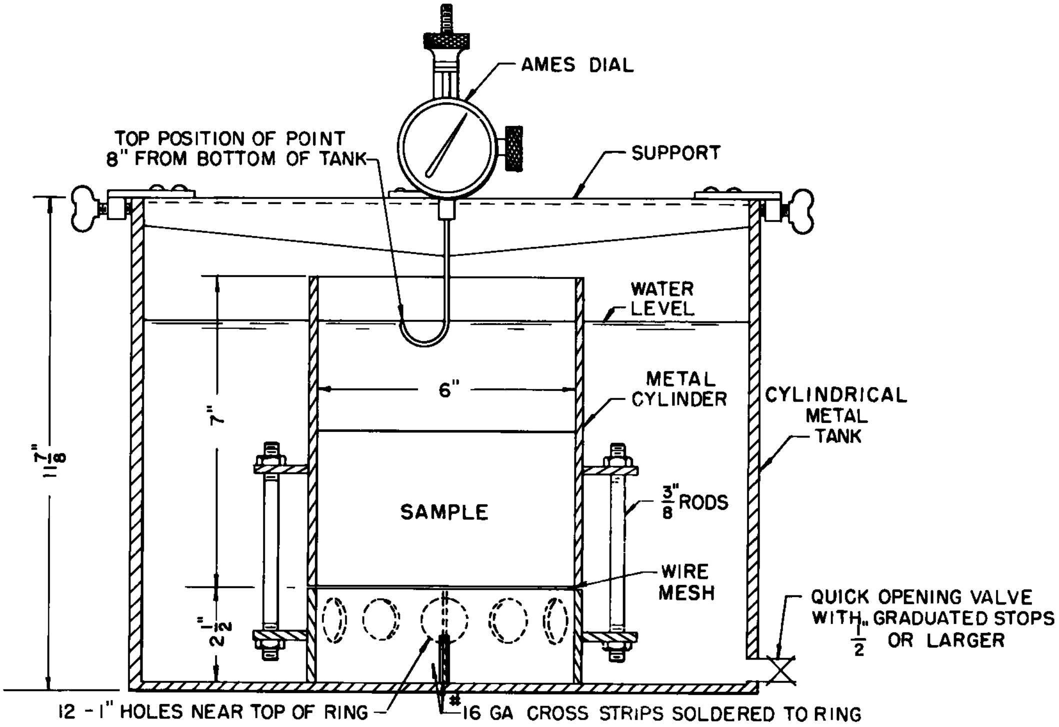

Figure 15. Drainage lag permeameter.

(b) Stopwatch.
(c) Gallon Can.
(d) Scales. - 5-kg capacity reading to 1 gm.
(e) Thermometer. - Range - 32 to 122 F (0 - 50 C).
(f) Miscellaneous. - Compaction equipment, drying oven.

PREPARATION OF SAMPLE

3. Compact the sample at the desired moisture content in the mold to a height of 3 in. (±0.01) by a specified method. With the mold containing the sample in the tank, fill the tank (Fig. 15) slowly with clean water without exceeding a hydraulic gradient of 0.5. With at least an inch of water above the sample, take readings with the hook gage until the water level is constant.

Note: For poorly graded material the inside of the mold may be coated with waterpump grease to prevent piping. Where saturated flow is desired, a gasketed lid is placed on the tank and a high vacuum applied.

PROCEDURE

4. With the hook gage lowered a measured amount, open the valve and start the stop watch simultaneously. The water is caught in a gallon can. When the water level reaches the hook gage, close the valve and stop the watch simultaneously. Measure the temperature at the top of the sample. The lowering of the hook gage and the valve opening are selected to pro-

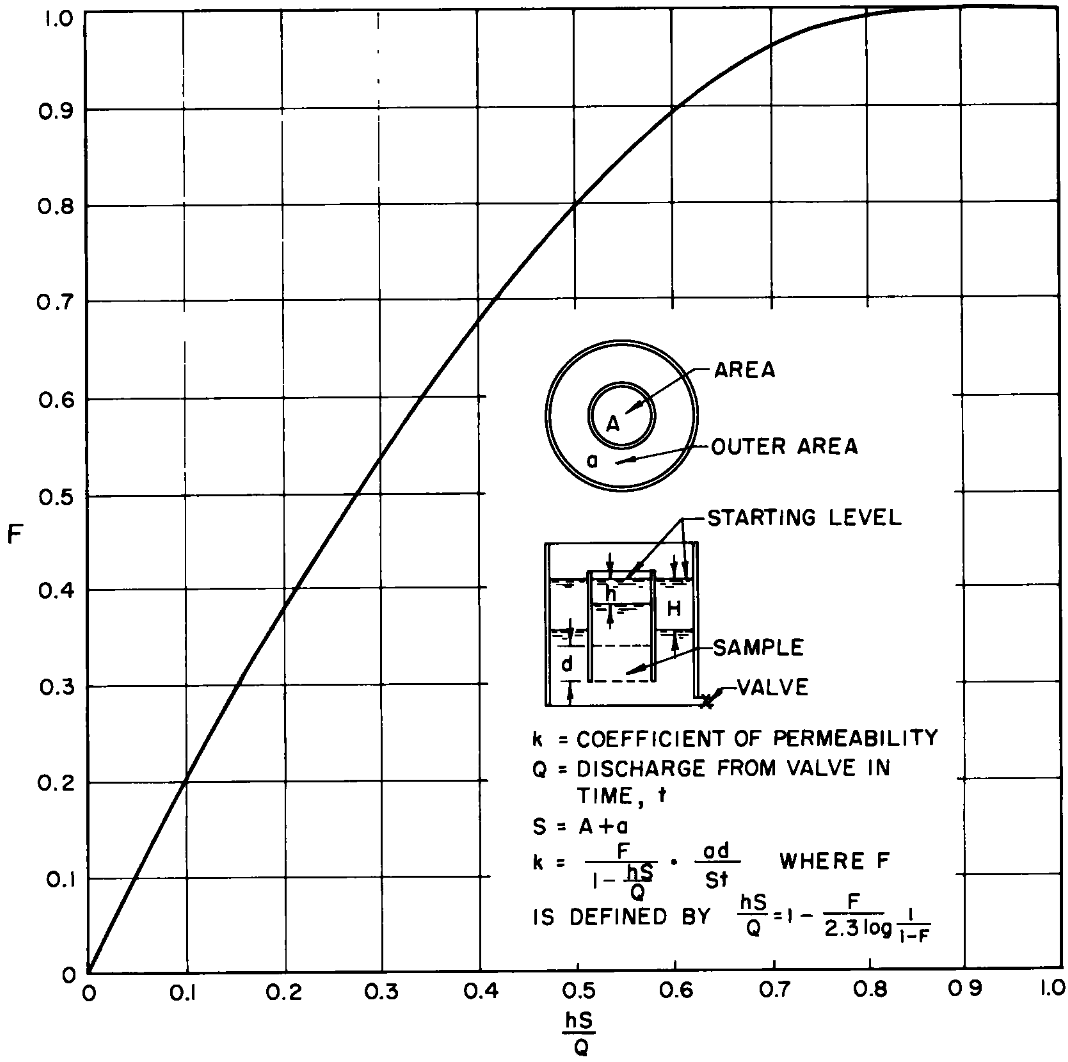

Figure 16. Permeability from drainage lag device.

duce a time of test not less than 20 seconds and a lowering of water in the metal tank less than 20 percent of the depth.

Note: For low permeability H may be maintained large and constant, and the device operated as an ordinary falling head permeameter.

CALCULATIONS

5. Calculate the coefficient of permeability by the graph and formula shown in Figure 16, which assumes a constant rate of discharge.

REPORT

6. Report the initial moisture, initial density, appearance, method of compaction, temperature, and coefficient of permeability.

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